Le pubblicazioni scientifiche del Luiss Sport Lab

LUISS

A cura di
Luiss Sport Lab


LNP
2
BNL
BNP PARIBAS
LNP
2

"Misurate ciò che è misurabile
e rendete misurabile ciò che non lo è."

Galielo Galilei

AS
LUISS
1999

LUISS

Comitato tecnico scientifico del Luiss Sport Lab

Paolo Del Bene
Direttore Scientifico

Stefano D'Ottavio
Responsabile Scientifico

Carlo Castagna
Responsabile ricerca

Bruno Ruscello
Responsabile analisi dati, statistiche e reportistica

Raffaella Spada
Medico nutrizionista CONI

Loredana Torrisi
Dietista CONI

Paolo Roberto Gabrielli
Referente area coordinamento scientifico

Gianmarco Mecangeli
Project Manager

SOMMARIO

Short Abstract degli articoli scientifici

1. Bilateral Deficit and Bilateral Performance: Relationship with Sprinting and Change of Direction in Elite Youth Soccer Players

ENG: The purpose of the study was to examine the differences in bilateral deficit (BLD) at different loadings during the half-squat jump (SJ) and horizontal counter movement jump (HCMJ) to determine if there is a relationship with linear sprint or change of direction (COD). The second goal was to check if fast players were more powerful in SJ and HCMJ than slow players in bilateral performance (BP). Twenty-seven male youth soccer players participated in the study.

ITA: Lo scopo dello studio è stato quello di esaminare le differenze nel deficit bilaterale (BLD) a carichi differenti durante il mezzo-squat jump (SJ) e il counter movement jump orizzontale (HCMJ) per determinare se esiste una relazione con lo sprint lineare o il cambio di direzione (COD). Il secondo obiettivo era verificare se i giocatori veloci fossero più potenti in SJ e HCMJ rispetto ai giocatori lenti nella prestazione bilaterale (BP). Allo studio hanno partecipato 27 giocatori di calcio giovanili maschi.

2. Gender differences in instep soccer kicking biomechanics, investigated through a 3D human motion tracker system

ENG: This study aims at describing and comparing each other male and female soccer players kicking instep a stationary ball. The different measures we collected by the 3d motion capture system Movit G1 and the high-Speed camera (240 fps) were considered as dependent variables, whereas the gender was considered as the independent one.

ITA: Questo studio si propone di descrivere e confrontare tra loro giocatori di calcio maschi e femmine che calciano di collo del piede un pallone fermo. Le diverse misure raccolte dal sistema di motion capture 3D Movit G1 e dalla telecamera ad alta velocità (240 fps) sono state considerate come variabili dipendenti, mentre il genere è stato considerato come variabile indipendente.

3. Fitness profiles of elite male Italian teams handball players

ENG: The aim of this study was to examine the fitness profile of the Italian national male Team-Handball players of different competitive level.

ITA: Lo scopo di questo studio è stato quello di esaminare il profilo di forma fisica dei giocatori della nazionale italiana maschile di pallamano a squadre di diverso livello agonistico.

4. Talent development environments in elite taekwondo population: a study within an Italian context:

ENG: The aim of this study was to analyze the quality perception of the main talent development environments within the elite taekwondo population, through the Talent development environment Questionnaire (TdeQ-5).

ITA: Lo scopo di questo studio è stato quello di analizzare la percezione della qualità dei principali ambienti di sviluppo del talento all'interno della popolazione di taekwondo d'élite, attraverso il Talent development environment Questionnaire (TdeQ-5).

5. Exploring the age of taekwondo athletes in the Olympic Games: an analysis from Sydney 2000 to Rio 2016

ENG: The aim of this study was to quantify the age at which taekwondo athletes competed in the Olympic Games and to provide initial insights into weight category changes over time.

ITA: L'obiettivo di questo studio è stato quello di quantificare l'età in cui gli atleti di taekwondo hanno gareggiato ai Giochi Olimpici e di fornire le prime informazioni sulle variazioni della categoria di peso nel tempo.

6. Hypertrophic adaptations to a 6-week in-season barbell vs. flywheel squat added to regular soccer training

ENG: The aim of this study was to compare the hypertrophic adaptations to barbell or flywheel squat exercise added to regular in-season soccer training.

ITA: Lo scopo di questo studio è stato quello di confrontare gli adattamenti ipertrofici all'esercizio di squat con bilanciere o con volano aggiunto all'allenamento regolare di calcio durante la stagione.

7. Exploring the age of taekwondo athletes in the Olympic Games: an analysis from Sydney 2000 to Rio 2016

ENG: The aim of this study was to quantify the age at which taekwondo athletes competed in the olympic Games and to provide initial insights into weight category changes over time.

ITA: Lo scopo di questo studio è stato quello di quantificare l'età in cui gli atleti di taekwondo hanno gareggiato ai Giochi olimpici e di fornire una prima visione dei cambiamenti della categoria di peso nel tempo.

8. Relative age effects and the youth-to-senior transition in Italian soccer: the underdog hypothesis versus knock-on effects of relative age

ENG: This study aimed to : (a) provide further test of RAEs by exploring the birth quarter (BQ) distribution of 2,030 Italian players born from 1975 to 2001 who have played in any of the Youth National Italian Soccer Teams ; and (b) investigate how RAEs influence future career outcomes, by exploring the BQ distribution of players who completed the transition from youth squads to the Senior National Team (n = 182).

ITA: Questo studio si proponeva di: (a) fornire un'ulteriore verifica dei RAE esplorando la distribuzione del trimestre di nascita (BQ) di 2.030 giocatori italiani nati dal 1975 al 2001 che hanno giocato in una qualsiasi delle Squadre Nazionali Giovanili italiane di calcio; e (b) indagare come i RAE influenzino i risultati futuri della carriera, esplorando la distribuzione del BQ dei giocatori che hanno completato la transizione dalle squadre giovanili alla Nazionale maggiore (n = 182).

9. Relative age effect in Italian soccer: a cultural issue in talent management?

ENG: Relative age effect (RAE) is a well-known phenomenon among those involved in youth sports, especially when the sport being investigated is widespread and involves early selection for participation in national and international competitions.

ITA: L'effetto dell'età relativa (RAE) è un fenomeno ben noto a chi si occupa di sport giovanile, soprattutto quando lo sport oggetto di studio è molto diffuso e comporta una selezione precoce per la partecipazione a competizioni nazionali e internazionali.

10. Hypertrophic adaptations to a 6-week in-season barbell vs. flywheel squat added to regular soccer training:

ENG: The aim of this study was to compare the hypertrophic adaptations to barbell or flywheel squat exercise added to regular in-session soccer training.

ITA: Lo scopo di questo studio è stato quello di confrontare gli adattamenti ipertrofici all'esercizio di squat con bilanciere o con volano aggiunto all'allenamento regolare di calcio durante la sessione.

11. Temporal patterns of fatigue in repeated sprint ability testing in soccer players and acute effects of different IHRs: a comparison between genders

ENG: The aim of this study was to investigate the acute effects of two different Initial Heart Rate (IHR) on fatigue when testing RSA in males and females' soccer players and to compare the respective patterns of fatigue.

ITA: Lo scopo di questo studio è stato quello di indagare gli effetti acuti di due diverse frequenze cardiache iniziali (IHR) sulla fatica durante il test RSA in giocatori di calcio maschi e femmine e di confrontare i rispettivi modelli di fatica.

12. (Beyond) the field of play: contrasting deterministic and probabilistic approaches to talent identification and development system

ENG: In this framework, the main aim of sport systems is to enhance predictability and reduce uncertainty, by investigating the causal relationship between entering a talent pathway and becoming an expert performer.

ITA: In questo contesto, l'obiettivo principale dei sistemi sportivi è quello di migliorare la prevedibilità e ridurre l'incertezza, studiando la relazione causale tra l'ingresso in un percorso di talento e il diventare un performer esperto.

13. All roads lead to Rome? Exploring birthplace effects and the 'southern question' in Italian soccer

ENG: This study aimed to investigate the presence of the "southern question" in Italian soccer.

ITA: Questo studio si proponeva di indagare la presenza della "questione meridionale" nel calcio italiano.

sports

MDPI

Article

Bilateral Deficit and Bilateral Performance: Relationship with Sprinting and Change of Direction in Elite Youth Soccer Players

Giampiero Ascenzi [1,2,*], Bruno Ruscello [3,4,5,6], Cristoforo Filetti [3], Daniele Bonanno [2], Valter Di Salvo [2], F. Javier Nuñez [7], Alberto Mendez-Villanueva [8] and Luis Suarez-Arrones [7,9]

1. Faculty of Sport, University of Pablo de Olavide (UPO), 41013 Sevilla, Spain
2. Department Football Performance & Science, Aspire Academy, Doha 22287, Qatar; daniele.bonanno@aspire.qa (D.B.); valter.disalvo@aspire.qa (V.D.S.)
3. Italy School of Sport Sciences and Exercise, Faculty of Medicine and Surgery, "Tor Vergata" University, 00133 Rome, Italy; bruno.ruscello@alice.it (B.R.); cris.86@hotmail.it (C.F.)
4. School of Sports and Exercise Sciences, "San Raffaele" University, 00166 Rome, Italy
5. Department of Industrial Engineering, Faculty of Engineering, "Tor Vergata" University, 00133 Rome, Italy
6. LUISS Sport Lab, LUISS University, 00197 Rome, Italy
7. Physical Performance and Sport Research, Pablo de Olavide University, 41013 Sevilla, Spain; fjnunsan@upo.es (F.J.N.); ljsuamor@upo.es (L.S.-A.)
8. Qatar Football Association, Doha 22287, Qatar; amendezvillanueva@yahoo.com
9. Performance Department, FC Basel 1893, 4052 Basel, Switzerland

* Correspondence: giampiero.ascenzi@hotmail.it; Tel.: +974-33617242

Received: 28 April 2020; Accepted: 27 May 2020; Published: 3 June 2020

Abstract: The purpose of the study was to examine the differences in bilateral deficit (BLD) at different loadings during the half-squat jump (SJ) and horizontal countermovement jump (HCMJ) to determine if there is a relationship with linear sprint or change of direction (COD). The second goal was to check if fast players were more powerful in SJ and HCMJ than slow players in bilateral performance (BP). Twenty-seven male youth soccer players participated in the study. Players were divided in two groups, faster and slower, according to their sprint performance (10 and 40 m). BLD average power with body weight (BW) and 25%BW were significantly higher than 50%BW ($p < 0.01$). BLD during HCMJ was significantly higher than BLD during SJ with BW, 25%BW and 50%BW ($p < 0.01$). There were no statistical relationships between BLD and sprint or COD performance ($p > 0.05$). Fast players showed significantly higher SJ power with all the different loads and HCMJ than slow players ($p < 0.01$), and fast players lost more time executing COD-90° than slow players ($p < 0.01$). There were no statistical differences between fast and slow players in BLD. BLD seems to be dependent on motor task, contraction type and load and could not be a proper measure to estimate sprint and COD performance. Faster players are confirmed to be more powerful players than slow players, and decrements in COD could be a key benchmark to identify deficit between linear and COD performance.

Keywords: performance analysis; BLD; bilateral testing; unilateral testing; power

1. Introduction

Strength motor task assessments can be performed with bilateral (BL) or unilateral (UL) exercises. When the sum of the force or power produced by each limb acting in the UL condition is larger than the force or power generated in the BL condition, it is defined as the bilateral deficit (BLD) phenomenon. [1–3]. The occurrence of the BLD has been showed in different contraction types: isokinetic [4,5], isometric [6] and specific sport-related motor tasks [7]. Nevertheless, the elements that influence the BLD are not well defined in the literature. Several researchers have focused on the potential mechanisms explaining this phenomenon, such as neural aspects [8], changes in motor unit recruitment [9], force–velocity relationship [10], limb dominance [8], training preference [8] and the postural behaviors in the UL jump [11]. Consequently, it seems plausible to consider the BLD as a multifactorial phenomenon rather than due to a single factor.

Due to the diversity of the contractile elements and mechanisms that seem to be involved, the BLD emerges significantly in all human movements, particularly when multiple joints are engaged [1]. On the other hand, when the action is accomplished by a single joint, the relevance of the BLD is less evident [12]. Conversely, when the sum of the force or power produced by each limb acting in the UL condition is smaller than the force or power generated in the BL condition, it is defined as the bilateral facilitation (BLF) [8,13].

Considering all of the above, the selection of assessment procedures suitable to describe the player strength profile plays a crucial role in defining the BLD. A previous study by Bishop et al. [14] reported that a larger BLD in countermovement jump (CMJ) was associated with a faster change-of-direction speed (CODS) during the 505 (r = −0.48 and r = −0.53, for left and right legs respectively) but not with linear speed. Furthermore, Bračič et al. [15] showed a significant correlation between a smaller BLD, high peak force production and a higher total impulse (r = −0.63; $p < 0.01$), suggesting that the 60 and 10 m sprint performances were associated with a lower BLD. Consequently, we can assume that lower values of BLD are associated more with the performance of tasks where BL actions are the primary requirement (e.g., volleyball, rowing, weightlifting, etc.); conversely, a higher value of BLD can have more potential benefits during the performance of tasks that require UL actions [1] (e.g., soccer, football, basketball and hockey, among others). Nevertheless, numerous researchers are trying to explain BLD in different sports [10,14,15], but to date there is a lack of studies regarding BLD applied in soccer players.

Soccer is a physically demanding sport where endurance, strength, explosive power and repeated sprint abilities have been shown to be important factors in determining success [16–23]. During soccer training and matches, lower-limb strength and power are crucial for executing different specific actions such as accelerating, decelerating, changing direction or sprinting. Straight sprinting is the most frequent action in goal situations in soccer [24]. Increasing the concentric explosive strength and reactive strength improves the stride length and ground contact during the first meters in a sprint [25]. Horizontal and vertical power are important factors to explain sprint performance in soccer players. Previous studies have been demonstrating strong correlations between squat, sprinting and jumping performances in elite soccer players [26,27]. In addition, horizontal hop distance is a predictor of lower body strength and power in soccer athletes [28]. Squat and vertical jump movements have been systematically employed to explain sprint performance, showing substantial associations with performance in short sprints [26]. In contrast, previous investigations have not found significant relationships between strength, jump and sprint times [29,30]. Straight sprinting is considered one of the key potentials for the effectiveness of COD performance [31], and a recent study showed statistical correlations between linear straight sprinting, COD 90° and 180° performance tests [32]. COD can be considered multifactorial, defined as the ability to decelerate, reverse or change movement direction and accelerate again [33,34]. The vast majority of actions or movements in soccer require 3-dimensional deceleration and acceleration, calling for rapid and agile CODs [35,36]. COD ability has been considered one of the most useful soccer-specific tools in training sessions [37]. Previous studies have shown improvements in COD due to eccentric overload training using flywheel and vibration exercises [35], back squat strength training [38] and UL and BL squat training with flywheel resistance exercises [39].

The relationship between UL strength training and COD in soccer has been largely investigated [40–43]. Recently, Núnez et al. [39] demonstrated that UL strength training seems to be more effective in improving COD abilities performance than the BL modalities. In addition, Gonzalo-Skok et al. [43] showed that one training session per week for eleven weeks of UL eccentric overload, in addition to vibration training, improved the linear speed, jump performance and COD ability more than the conventional strength training in youth soccer players. Furthermore, Gonzalo-Skok et al. [44] showed that with two training sessions per week, BLD increased more than in BL strength training in elite youth basketball players. Despite the existence of a large number of studies showing relationships between all these variables, straight linear sprinting, jumping performance, CODs and half-squat power are, for the most part, separate motor qualities; therefore, it is suggested that all of them should be tested and trained individually [32]. Despite the relevance of the connections among the BLD, COD abilities and soccer, there is a lack of investigations that have recently studied the phenomenon of BLD applied to young soccer players. Consequently, the aim of this study was to examine the differences between BLD at different loadings during half squat jumps (body weight (BW), 25%BW and 50%BW) and horizontal CMJ (HCMJ) and to determine if there was a relationship with linear sprint (10, 20, 30 and 40 m) and COD. The second goal was to examine if fast players were more powerful in squats (at different loadings) and horizontal jumps than slow players in bilateral performance (BP).

2. Materials and Methods

2.1. Experimental Design

An observational study was designed to verify the given hypotheses. The measures obtained by testing were considered to be dependent variables, whereas different factors, such as fast and slow players and different loadings, were set as independent ones.

2.2. Participants

Twenty-seven young male soccer players from Aspire Academy Club's U-17's and 18's Qatar National Team (Doha, Qatar) participated in this study (n = 27; age: 18.5 ± 0.6 years; height: 175.4 ± 15 cm; body weight 67.5 ± 14.8 kg). Within the sample there were 23 players that participated in the previous FIFA U-20 World Cup (Poland 2019). All subjects in the study had a minimum of 3 years' experience in a professional football academy. Over the previous year, the players usually trained 5 to 7 times per week (six to eight training sessions, two strength-training sessions, one or two conditioning sessions, and two international club games every three weeks). Twenty-four players competed at the international level and may be considered elite level for their age group. Before undergoing assessment, all players with previous knee injuries or chronic lower limb injures did not fulfil the eligibility criteria and were not considered. The methodology used was approved by the Ethics Committee (Qatar Antidoping Lab, E2013000004) and conformed to the policy statement with respect to the Declaration of Helsinki. All participants and their parents were informed of the risk and benefits of the procedure and signed an informed consent for participation in the study.

2.3. Procedures

Data were collected during the preparation period for the FIFA-U20 World Cup. The experimental stage consisted of two different phases. On day 1, the participants underwent the strength assessments (squat jump at different loadings and horizontal jump). On day 2, the participants underwent all speed assessments: COD and linear sprinting. A recovery time of 72 h was granted between day 1 and day 2 in order to reduce the effect of fatigue. To avoid any circadian influences on testing, all the assessments were carried out at the same time each day. To ensure familiarization with the procedures, participants conducted trial tests over 10 sessions, spanning three weeks prior to testing. Strength testing was performed in an indoor gym (Aspire Academy, Doha, Qatar) where the environmental conditions were considered optimal in terms of stability and reproducibility (10.30 a.m., 21 ± 0.5 °C average temperature and 50% ± 2% relative humidity). COD and sprinting testing were performed on an artificial turf homologated for international competitions. Players wore soccer shoes usually adopted during competitions. Participants refrained from any heavy training in the two days prior to testing.

On testing day 1, BW was measured in order to compute BW25% and BW50%. During day 1, all players performed a general warm up comprising 5 min cycling, 3 min ballistic stretching, 1 × 8 repetitions of back squats (Smith Machine) in bilateral and UL execution and 1 × 3 repetitions HCMJ at 50%, 70% and 90%, approximate capacity in BL and UL execution. During day 2, all players completed a general warm up comprising 5 min bicycle, 3 min ballistic stretching, run for 30–40 m at gradually increasing speeds and acceleration over 10–20 m, including taking off at maximum effort and sharp COD at 90°.

2.4. Squat Jump Test (SJ)

All the strength assessments during squatting were performed in three different approaches: (a) BL execution, (b) UL execution pushing with left leg (UL_L) and (c) UL execution pushing with right leg (UL_R). All assessments were recorded using a linear encoder (SmartCoach™, EuropeAB, Stockholm, Sweden). After the general warm up, each player performed three repetitions of BL, UL_L and UL_R SJ with the Smith Machine (Multipower, Technogym tm, Gambettola, Italy) as the specific warm up. For testing, players performed three repetitions of BL followed by three UL_L and UL_R SJ. During the BL, participants were positioned at 90° knee angle [45] using a professional goniometer (Baseline® Measurement, White Plains, NY, USA) and then performed the SJ a maximal ballistic push off (positive phase, upward extension). During the UL_L and UL_R, participants performed one-leg squats at 90° knee angle [46,47], and each player carried out a maximal ballistic push off [48]. Thirty seconds of recovery was set between BL, UL_L and UL_R repetitions, and two minutes of recovery was set between the three different loadings. The testing sequence involved lifting the bar (7.3 kg) of the Smith Machine without weights for the BW trial, and additional loading for the BW25% and the BW50% trials. The best mean power (avg. power) and the best peak power trials with each load were considered for the consequent statistical analysis [49,50].

2.5. Horizontal Countermovement Jump (HCMJ)

Participants stood on the starting point as per standing long jump. Hands were fixed on the hips, and it was requested to hop and land, remaining stationary when landing (no additional hops were allowed) until the test leader recorded the result [51]. If the players failed the landing phase the test was considered invalid and was repeated. Subjects performed three jumps. Recovery time between jumps was 1 min. The best performance in terms of horizontal distance (cm) was used for the subsequent analysis.

2.6. Horizontal Countermovement Jump Single Leg ($HCMJ_L$ and $HCMJ_R$)

Participants began standing, balancing on a single leg (the one to be tested) and then requested to hop as far as possible landing on the same leg. Hands were fixed on the hips, and opposite leg swing was permitted. As per HCMJ, subjects were requested to hop and land, remaining stationary when landing (no additional hops were allowed) until the result was noted [51,52]. If subjects failed the landing phase the test was considered invalid and was repeated. Subjects performed a total of three jumps with each leg. Recovery time between jumps was 1 min. The best performance with each leg in terms of horizontal distance (cm) was used for the subsequent analysis.

2.7. Bilateral Deficit (BLD)

The BLD was computed according to the following formula (Howards et al. [8]):

$$\text{BLD } (\%) = [100 \times (\frac{\text{bilateral}}{\text{Right unilateral } + \text{ Left unilateral}})] - 100, \quad (1)$$

This determines the ratio between the BL execution and the sum of the UL ones during ballistic strength tasks (e.g., SJ and HCMJ).

2.8. Sprint Assessment (10, 20, 30 and 40 m)

Participants performed a maximal 40 m sprinting test. Two trials were considered. Split 10, 20 and 30 m times were also recorded (Smart-Fusion Sport™, Brisbane, Australia). Players started each trial from a standing still position with their front foot 0.5 m behind the first timing gate. They self-administered their starting. They were encouraged to perform the sprint as fast as possible until the last gate [52]. Each trial was separated by two minutes of passive recovery, and the best performance was used for the subsequent analysis.

2.9. Change of Direction Assessment (COD-90°)

Participants performed a maximal 10 + 10 m "L" sprinting test (with a 90° change of direction) with left and right turns. Players started each trial from a stationary standing position with their front foot 0.5 m behind the first timing gate (Smart-Fusion Sport™, Brisbane, Australia). They self-administered their starting. They were encouraged to perform the sprint as fast as possible until the last gate [53]. Two trials for each side were considered. Each trial was separated by two minutes of passive recovery, and the best performance was used for the subsequent analysis [54]. The best result for the right and for the left COD-90° test was compared to the fastest 20 m straight-line sprint time. The loss of speed caused by executing COD-90° (DEC-COD) was calculated as a percentage using a formula as in previous studies [32]:

$$[(\text{T COD-90}^\circ \times 100)/\text{T 20 m}] - 100 \quad (2)$$

T COD-90° = Time in COD-90° test
T 20 m = Time in maximal 20 m sprinting test

2.10. Data Analysis

Data are presented as the mean and standard deviation (M ± SD) and the range. The assumption of normality was assessed using the Kolmogorov–Smirnov test. The intraclass correlation coefficients (ICCs) for measures were provided as indices of relative reliability of the measurements. A correlation matrix (r) describing the association of several variables was provided. To find significant differences among the collected measures performing different testing (dependent variables), the different loadings (BW, 25%BW, 50%BW) and HCMJ were set as independent variables, and analysis of variance (ANOVA) was then performed. Subsequent post hoc tests performed with Bonferroni's correction of significance level were provided. The value of statistical significance was accepted as $p \leq 0.05$. IBM SPSS 25.0 for Windows was used to analyze and process the collected data. The corresponding p values were provided for each analysis ($p \leq 0.05$). To assess how each sprinting performance parameter (10 and 40 m) could behave in relation to the strength measures, the sample was divided in two groups: "fast" and "slow" [31–54]. The two groups were created by computing the mean of the overall sample, for each sprinting distance, and then allocating the players to the respective groups (below and above the mean). To investigate the possible differences between the two groups "fast" and slow" in the sprinting performance, a t-test for independent samples was performed showing significant differences between groups ($p \leq 0.05$). The effect size (ES) was determined, and the threshold values for Cohen's ES statistics were classified as trivial (0.0–0.19), small (0.2–0.59), moderate (0.6–1.1), large (1.2–1.9) and very large (>2.0) [55].

3. Results

The ICCs as relative reliability of the measurements collected during testing were bilateral deficit avg power (0.76 (0.52–0.89), $p < 0.01$), bilateral deficit peak power (0.14 (−0.33–0.53)), sprint time (0.99 (0.98–0.99), $p < 0.01$) and change of direction time (0.88 (0.73–0.95), $p < 0.01$).

Descriptive values of parameters measured and computed are shown in Tables 1 and 2. BL power and BL HCMJ were significantly higher than UL power and UL HCMJ (right or left leg interchangeably, $p < 0.01$).

The BLDs during SJ with different loadings (BW, 25%BW and 50%BW) and during HCMJ are illustrated in Figure 1. $BLD_{AvgPower}$ with BW and 25%BW were significantly higher than 50%BW ($p < 0.01$). $BLD_{PeakPower}$ with BW and 25%BW were significantly higher than 50%BW ($p < 0.01$). BLD during HCMJ was significantly higher than BLD avg and peak power during SJ with BW, 25%BW and 50%BW ($p < 0.01$). There are no statistical relationships between BLD in SJ and sprint or COD performance ($p > 0.05$), except a moderate correlation between SJ BLD $25\%BW_{Avg}$ and COD-DEC on the right side (r = −0.448). There are no statistical relationships between BLD in HCMJ and sprint or COD performance ($p > 0.05$).

Table 1. Squat jump bilateral (B) and unilateral (L/R) tests performed with body weight (BW), 25% body weight (25%BW) and 50% body weight (50%BW).

Variables	Mean ± SD	Range	
		Max	Min
BL Average Power (W)			
BW	937.9 ± 114.2 **	1157.7	728.9
25%BW	992.6 ± 159.7 **	1529.6	798.1
50%BW	1064.4 ± 170.7 **	1593.1	838
UL Average power (W)			
BW	749.7 ± 92.3	978.1	587.1
25%BW	772.5 ± 107.3	1107.7	617.1
50%BW	755.9 ± 99.3	955.6	578.7
UR Average power (W)			
BW	715.4 ± 86.7	917.2	547.3
25%BW	765.1 ± 94.8	971.8	647.7
50%BW	768.5 ± 105.2	987.7	585.1
BL Peak power (W)			
BW	2921.9 ± 366.2 **	4382	1265
25%BW	2962.6 ± 533.6 **	4814	2310
50%BW	3042.1 ± 534.4 **	4686	2333
UL Peak power (W)			
BW	1845.9 ± 329.9	2551.4	1348.2
25%BW	1834.1 ± 352.1	2731	1399.7
50%BW	1730.1 ± 356.9	2384	1024.4
UR Peak power (W)			
BW	1712.5 ± 295.9	2370.4	1209
25%BW	1766.8 ± 289.3	2524.3	1163.9
50%BW	1761.9 ± 362.8	2652.2	883.7

BL = bilateral; UL = unilateral left; UR = unilateral right; W (watts); ** Significantly different vs. unilateral power. $p < 0.01$.

Table 2. Sprinting, change of direction (COD) and horizontal countermovement jump test (HCMJ).

Variables	Mean ± SD	Range	
		Max	Min
Sprinting (s)			
10 m	1.67 ± 0.06	1.84	1.53
20 m	2.91 ± 0.01	3.14	2.69
30 m	4.05 ± 0.12	4.37	3.77
40 m	5.19 ± 0.16	5.61	4.89
COD-90° (s)			
COD-Left	4.10 ± 0.11	4.30	3.89
COD-Right	4.14 ± 0.17	4.46	3.82
COD-DEC (%)			
Left	41.5 ± 3.8	49.1	54.3
Right	42.9 ± 5.4	33.4	35.5
HCMJ (cm)			
HCMJ-Bilateral	235.1 ± 12.9 **	271	208
HCMJ-Left	212.6 ± 7.8	232	190
HCMJ-Right	212.6 ± 11.2	239	189

COD-90° (s): change of direction time; COD-DEC (%): decrement (percentage) during change of direction; ** significantly different vs. unilateral countermovement jump ($p < 0.01$).

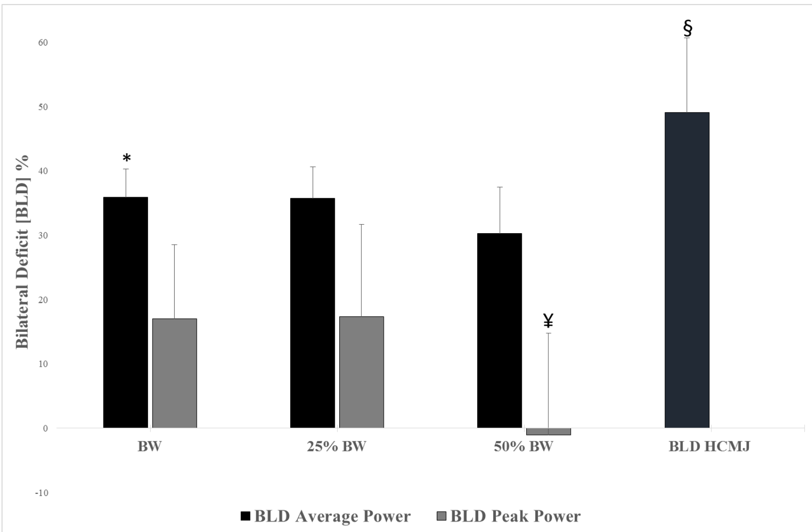


Figure 1. Bilateral deficit (BLD) behaviors at three different loadings during squat jump and horizontal countermovement jump. *: Significantly different vs. 50% body weight (BW) ($p < 0.05$); ¥: significantly different vs. BW and 25%BW ($p < 0.01$); §: significantly different vs. all the others ($p < 0.01$).

The differences between fast and slow players are shown in Table 3. Fast players showed significantly higher $BP_{AvgPower}$ with all different loads compared to slow players (except with 25%BW in the fast players in 10 m) ($p < 0.01$, ES from 0.87 to 1.39). Fast players exhibited statistically higher HCMJ than slow players ($p < 0.01$, ES = −0.83; and ES = −0.73 for fast players in 10 and 40 m respectively). Fast players lost more time executing COD-90° than slow players ($p < 0.01$, ES = −1.30 and −1.16 for left and right leg, respectively, in fast players in 10 m; and $p < 0.01$, ES = −0.91 for left leg in fast players in 40 m). There were no significant differences between fast and slow players in COD-90° ($p > 0.05$). There are no statistical relationships between 10 m time and COD-90° (r = 0.46 (−0.01; 0.63), R^2 = 0.22 (average time for left and right)), while a small association is detected between 40 m time and COD-90° (r = 0.58 (0.26; 0.77), R^2 = 0.33 (average time for left and right)). There were no statistical differences between fast and slow players in BLD.

Table 3. Differences between fast and slow players in bilateral power, horizontal contra movement jump (HCMJ) and DEC-COD (%) (loss of speed caused by executing COD-90°).

Variables	Sprinting 10 m (s)			Sprinting 40 m (s)		
	Fast (n = 18)	**Slow (n = 9)**	**ES**	**Fast (n = 17)**	**Slow (n = 10)**	**ES**
$BP_{Avg\ Power}$ (W)						
BW	966.1 ± 101.4	863.4 ± 102.8 *	−0.87 ± 0.69↓↓	980.9 ± 89.7	846.8 ± 95.3 **	−1.39 ± 0.70↓↓
25%BW	1010.8 ± 182.6	957.2 ± 99.8	−0.35 ± 0.62	1039.3 ± 176.3	909.4 ± 83.5 *	−0.90 ± 0.61↓↓
50%BW	1101.5 ± 179.5	958.4 ± 59.1 **	−1.03 ± 0.58↓↓	1116.2 ± 171.9	946.7 ± 74.2 **	−1.23 ± 0.60↓↓
$BP_{Peak\ Power}$ (W)						
BW	2904.1 ± 598.2	2705.2 ± 284.8	−0.41 ± 0.61	2936.8 ± 607.1	2065.5 ± 260.4	−0.55 ± 0.60↓
25%BW	3052.5 ± 619.9	2846.3 ± 377.8	−0.39 ± 0.64	3159.1 ± 598.4	2667.8 ± 277.9 **	−1.01 ± 0.61↓↓
50%BW	3088.3 ± 750.8	2675.3 ± 220.3 *	−0.71 ± 0.57↓↓	3108.6 ± 764.1	2682.8 ± 238.4 *	−0.72 ± 0.58↓↓
Jump (cm)						
HCMJ	237.8 ± 12.9	227.5 ± 11.0**	−0.83 ± 0.70↓↓	238.1 ± 12.8	228.6 ± 12.5 **	−0.73 ± 0.71↓
COD 90°						
Left	4.08 ± 0.13	4.14 ± 0.09	0.50 ± 0.70	4.07 ± 0.12	4.17 ± 0.09	0.86 ± 0.73↓
Right	4.12 ± 0.18	4.17 ± 0.17	0.29 ± 0.72	4.10 ± 0.18	4.23 ± 0.12	0.77 ± 0.71↓
COD-DEC (%)						
Left	42.7 ± 3.4	38.2 ± 3.1 **	−1.30 ± 0.80↓↓	42.6 ± 3.5	39.1 ± 3.5 **	−0.91 ± 0.78↓↓
Right	44.3 ± 5.6	39.2 ± 2.5 **	−1.16 ± 0.66↓↓	43.7 ± 5.6	41.6 ± 4.9	−0.46 ± 0.75

BP: bilateral performance; AVG: average; (W): watts; BLD (%): percentage of bilateral deficit; BW: body weight; COD-DEC (%): decrement (percentage) during change of direction. ** Significantly lower vs. fast players. $p < 0.01$. * Significantly lower vs. fast players ($p < 0.05$). ↓↓ Significantly different. ↓ Substantial difference.

4. Discussion

The purpose of the study was to examine the differences in BLD at different loadings during half squat jump and horizontal CMJ to determine if there was a relationship with linear sprint (10, 20, 30 and 40 m) or COD, and to check if fast players were more powerful in squat jumps and horizontal jumps than slow players in BP. To our knowledge this is the first study that analyzed elite young soccer players' BP and BLD in SJ and HCMJ in relation to the linear sprinting and COD ability. The main findings of this study are the following: (i) BLD with low loads (i.e., BW, 25%BW) was significantly higher than BLD with high loads (i.e., 50% BW); (ii) BLD during HCMJ was significantly higher than BLD during SJ at different loads; (iii) no relationships were found between BLD and SJ, HCMJ, sprint and COD performance; (iv) fast players showed significantly higher $BP_{AvgPower}$ and HCMJ than slow players and (v) fast players lost more time executing COD-90° than slow players.

Psycharakis et al. [56] studied BLD in SJ as well as CMJ with BW and 10%BW in recreationally active participants. They showed that BLD was present in SJ and CMJ at both loaded and unloaded conditions, but the additional load did not have a significant influence on the magnitude of BLD in both tests. In our case, present findings show a significantly higher percentage of BLD in SJ with BW and 25%BW than 50%BW (−16%). Based on these results, we speculate that, as we increase the load, BLD is reduced due to the lack of UL force in order to produce optimal levels of power. Moving this concept to a practical application, it seems that SJ with 50%BW could be considered a high demanding load in this ballistic strength task for this specific population of elite youth soccer players. Along this line, BLD computed in HCMJ was an order of magnitude greater (from 28% to 40%) than the ones developed in the selected vertical task with different loads. This finding suggests how BLD could be considered a sensible phenomenon across the different jump tasks [14]. Furthermore, in line with previous studies [1,4–7], our results demonstrate how BLD seems to be dependent on the motor task, contraction type and load.

The relationship between BLD jump and sprint performance has been previously examined in scientific literature. Bracic et al. [15] highlighted that the sprinters with higher CMJ BLD produced a lower total impulse of force on the block and lower block velocity, which were related with 60 and 100 m sprint performances. Showing the relationship between these two variables, the study suggested that elite sprinters with high BLD in CMJ should have a lower performance during sprinting. In contrast, the present findings shows no associations between the sprinting performance with SJ BLD at different loadings and HCMJ BLD in elite young soccer players. Along the same line, Bishop et al. [14] did not identify any relationships between BLD and sprint performance over both 10 and 30 m. Therefore, the findings in the scientific literature cannot conclude that changes in the BLD of athletes may have an influence on sprint performance.

In this study, no relationships between both BLD (SJ and HCMJ) and CODs variables have been observed, except a moderate correlation between SJ BLD $25\%BW_{AvgPower}$ and COD-DEC in the right leg ($r = -0.448$). Our findings are different from those previously reported by Bishop et al. [14], which reported a moderate relationship between BLD in CMJ height and COD (expressed as deficit). A possible explanation for this discrepancy could be that the strength assessments used in our study differed from the ones by Bishop et al. [14] in the contraction type (concentric (SJ) vs. eccentric–concentric (CMJ)), and in the type of movement (horizontal (HCMJ) vs. vertical (CMJ)). Likewise, the COD tests used in the two studies were different (L-test 90° vs. 505), which required different cutting COD angles (90° vs. 180°) and starting type (standing vs. flying). Consequently, the differences found in the BLD between the present study and one by Bishop et al. [14] might be attributed to factors related to task, physiology and neuro physiology [12], which could provide different responses, whereas different testing and measurement procedures are applied.

Linking the previous findings to the COD performance, present results show no significant differences between the "faster" and "slower" players in COD-90° ($p > 0.05$). This result suggests that "faster" players over 10 and 40 m are not necessarily fast in COD-90°. Although both abilities have been considered as fundamental for football performance [24], our results with elite young soccer players do not demonstrate a clear relationship between linear sprint and COD performance (r from 0.46 to 0.58; R^2 from 0.22 to 0.33). Therefore, based on the results of the present study, linear sprinting and COD are separate motor qualities and should be specifically assessed and trained. In addition to this, our results demonstrate how the "slower" players over 10 m showed a significantly lower COD-DEC in left- and right-side executions (ES = 1.30 and ES = 1.16) than "faster" players. Similarly, the "slower" players over 40 m showed a significantly lower DEC-COD in left side execution than the "faster" players ($p < 0.04$, ES = 0.91). Present results are in line with the recent study of Suarez-Arrones et al. [32] in which the fastest players lost more time performing the COD than their slower counterparts. As a practical application, in cases where athletes present a high DEC-COD, coaches should prescribe specific COD training in order to reduce the percentage of decrement.

Horizontal and vertical power are important factors to explain sprint performance in soccer players [26,27]. While previous research showed statistical associations between squat strength/power, horizontal and vertical jump with sprint performance [26], other studies presented contradictory findings with no relationships between these parameters and sprint times [29,30]. To date, no study has investigated in elite young soccer players if fast players are more powerful in SJ and HCMJ than slow players. Our results show how "faster" players exhibited significantly higher $BP_{AvgPower}$ and HCMJ than their "slower" counterparts, supporting the concept that improvements in lower body strength/power would benefit sprint performance in elite young soccer players. By contrast, there were no statistical differences between fast and slow players in BLD. Due to dissociations between BLD (SJ, HCMJ) and sprint performance and the absence of differences between fast and slow players in BLD, we can state that BLD is not a useful parameter to understand or estimate sprinting and COD performance in elite young soccer players.

Limitations

This study has been carried out with the aim to analyze BLD and BP during different strength tasks and to analyze the relationships between sprinting and COD performance. For this reason, UL performance was not distinctly considered. Therefore, further research must take into consideration UL performance during strength tasks, and eventually the inter-limb asymmetries, in order to clarify the relationship between those parameters. Due to the importance that BLD could have in the identification of the neuromuscular profile in elite young soccer players, additional tests and kinetic parameters to those used in the present study should be examined.

5. Conclusions

Based on the present results, BLD seems to be dependent on the motor task, contraction type and load, and could not be a proper measure to predict or estimate sprint and COD performance in elite young soccer players. Faster players have confirmed to be more powerful players than slow players, and DEC-COD has proven to be a key benchmark for the purpose to identify deficits between linear and COD performance.

Author Contributions: Conceptualization, A.M.-V.; Data Curation, G.A., B.R., C.F., A.M.-V. and L.S.-A.; Formal Analysis, G.A. and C.F., Investigation, G.A., A.M.-V., B.R. and C.F., Methodology G.A., A.M.-V., B.R., C.F. and L.S.-A., Project Administrator, G.A. and B.R., Supervision, G.A., A.M.-V., F.J.N. and L.S.-A., Visualization, D.B. and V.D.S., Writing—Original Draft Preparation, G.A., B.R. and C.F., Writing—Review & Editing, G.A. and L.S.-A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Jakobi, J.M.; Chilibeck, P.D. Bilateral and unilateral contractions: Possible differences in maximal voluntary force. *Can. J. Appl. Physiol.* **2001**, *26*, 12–33. [CrossRef]
2. Bogdanis, G.C.; Tsoukos, A.; Kaloheri, O.; Terzis, G.; Veligekas, P.; Brown, L.E. Comparison Between Unilateral and Bilateral Plyometric Training on Single- and Double-Leg Jumping Performance and Strength. *J. Strength Cond. Res.* **2019**, *33*, 633–640. [CrossRef] [PubMed]
3. Botton, C.E.; Radaelli, R.; Wilhelm, E.N.; Silva, B.G.C.; Brown, L.E.; Pinto, R.S. Bilateral deficit between concentric and isometric muscle actions. *Isokinet. Exerc. Sci.* **2013**, *21*, 161–165. [CrossRef]
4. Brown, L.; Whitehurst, M.; Gilbert, R.; Findley, B.; Buchalter, D. Effect of velocity on the bilateral deficit during dynamic knee extension and flexion exercise in females. *Isokinet. Exerc. Sci.* **1994**, *4*, 153–159. [CrossRef]
5. Dickin, D.C.; Too, D. Effects of movement velocity and maximal concentric and eccentric actions on the bilateral deficit. *Res. Q. Exerc. Sport* **2006**, *77*, 296–303. [CrossRef] [PubMed]
6. Botton, C.E.; Wilhelm, E.N.; Brown, L.E.; Pinto, R.S. Neuromuscular Adaptations to Unilateral vs. Bilateral Strength Training in Women. *J. Strength Cond. Res.* **2016**, *30*, 1924–1932. [CrossRef] [PubMed]
7. Challis, J.H. An investigation of bilateral deficit on human jumping. *Hum. Mov. Sci.* **1998**, *17*, 307–325. [CrossRef]
8. Howard, J.D.; Enoka, R.M. Maximum bilateral contractions are modified by neurally mediated interlimb effects. *J. Appl. Physiol.* **1991**, *70*, 306–316. [CrossRef]
9. Dickin, D.C.; Sandow, R.; Dolny, D.G. Bilateral deficit in power production during multi joint leg extension. *Eur. J. Sport Sci.* **2011**, *11*, 437–445. [CrossRef]
10. Bobbert, M.F.; de Graaf, W.W.; Jonk, J.N.; Casius, L.J. Explanation of the bilateral deficit in human vertical squat jumping. *J. Appl. Physiol.* **2006**, *100*, 493–499. [CrossRef]
11. Sado, N.; Yoshioka, S.; Fukashiro, S. Free-leg side elevation of pelvis in single-leg jump is a substantial advantage over double-leg jump for jumping height generation. *J. Biomech.* **2020**, *104*, 109751. [CrossRef]
12. Skarabot, J.; Cronin, N.; Strojnik, V.; Avela, J. Bilateral deficit in maximal force production. *Eur. J. Appl. Physiol.* **2016**, *116*, 2057–2084. [CrossRef] [PubMed]
13. Ebben, W.P.; Flanagan, E.; Jensen, R.L. Bilateral facilitation and laterality during the countermovement jump. *Percept. Mot. Ski.* **2009**, *108*, 251–258. [CrossRef] [PubMed]
14. Bishop, C.; Berney, J.; Lake, J.; Loturco, I.; Blagrove, R.; Turner, A.; Read, P. Bilateral Deficit During Jumping Tasks: Relationship With Speed and Change of Direction Speed Performance. *J. Strength Cond. Res.* **2019**. [CrossRef] [PubMed]
15. Bracic, M.; Supej, M.; Peharec, S.; Bacic, P.; Coh, M. An investigation of the influence of bilateral deficit on the counter movement jump performance in elite sprinters. *Kinesiology* **2010**, *1*, 71–81.
16. Hoff, J.; Helgerud, J. Endurance and strength training for soccer players: Physiological considerations. *Sports Med.* **2004**, *34*, 165–180. [CrossRef]
17. Helgerud, J.; Rodas, G.; Kemi, O.J.; Hoff, J. Strength and endurance in elite football players. *Int. J. Sports Med.* **2011**, *32*, 677–682. [CrossRef]
18. Silva, J.R.; Nassis, G.P.; Rebelo, A. Strength training in soccer with a specific focus on highly trained players. *Sports Med. Open* **2015**, *1*, 17. [CrossRef]
19. Chaouachi, A.; Manzi, V.; Chaalali, A.; Wong del, P.; Chamari, K.; Castagna, C. Determinants analysis of change-of-direction ability in elite soccer players. *J. Strength Cond. Res.* **2012**, *26*, 2667–2676. [CrossRef]
20. Bangsbo, J.; Mohr, M.; Krustrup, P. Physical and metabolic demands of training and match-play in the elite football player. *J. Sports Sci.* **2006**, *24*, 665–674. [CrossRef]
21. Ruscello, B.; Esposito, M.; Partipilo, F.; Di Cicco, D.; Filetti, C.; Pantanella, L.; D'Ottavio, S. Exercise-to-rest ratios in repeated sprint ability training in women's soccer. *J. Sports Med. Phys. Fit.* **2018**, *58*, 1790–1799. [CrossRef] [PubMed]
22. Ruscello, B.; Partipilo, F.; Pantanella, L.; Esposito, M.; D'Ottavio, S. The optimal exercise to rest ratios in repeated sprint ability training in youth soccer players. *J. Sports Med. Phys. Fit.* **2016**, *56*, 1465–1475.
23. Ruscello, B.; Esposito, M.; Fusco, C.; Ceccarelli, C.; Pomponi, S.; Filetti, C.; Pantanella, L.; Gabrielli, P.; D'Ottavio, S. Acute effects of two different initial heart rates on testing the repeated sprint ability in elite women's soccer players. *J. Sports Med. Phys. Fit.* **2020**. [CrossRef] [PubMed]

24. Faude, O.; Koch, T.; Meyer, T. Straight sprinting is the most frequent action in goal situations in professional football. *J. Sports Sci.* **2012**, *30*, 625–631. [CrossRef] [PubMed]
25. Barr, M.J.; Sheppard, J.M.; Agar-Newman, D.J.; Newton, R.U. Transfer effect of strength and power training to the sprinting kinematics of international rugby players. *J. Strength Cond. Res.* **2014**, *28*, 2585–2596. [CrossRef]
26. López-Segovia, M.; Marques, M.C.; van den Tillaar, R.; González-Badillo, J.J. Relationships between vertical jump and full squat power outputs with sprint times in u21 soccer players. *J. Hum. Kinet.* **2011**, *30*, 135–144. [CrossRef]
27. Wisløff, U.; Castagna, C.; Helgerud, J.; Jones, R.; Hoff, J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br. J. Sports Med.* **2004**, *38*, 285–288. [CrossRef]
28. Hamilton, R.T.; Shultz, S.J.; Schmitz, R.J.; Perrin, D.H. Triple-hop distance as a valid predictor of lower limb strength and power. *J. Athl. Train.* **2008**, *43*, 144–151. [CrossRef]
29. Barker, D.; Nance, S. The Relation between Strength and Power in Professional Rugby League Players. *J. Strength Cond. Res.* **1999**, *13*, 224–229.
30. Cronin, J.B.; Hansen, K.T. Strength and power predictors of sports speed. *J. Strength Cond. Res.* **2005**, *19*, 349–357. [CrossRef]
31. Hewit, J.K.; Cronin, J.B.; Hume, P.A. Kinematic factors affecting fast and slow straight and change-of-direction acceleration times. *J. Strength Cond. Res.* **2013**, *27*, 69–75. [CrossRef]
32. Suarez-Arrones, L.; Gonzalo-Skok, O.; Carrasquilla, I.; Asian-Clemente, J.; Santalla, A.; Lara-Lopez, P.; Nunez, F.J. Relationships between Change of Direction, Sprint, Jump, and Squat Power Performance. *Sports* **2020**, *8*, 38. [CrossRef] [PubMed]
33. Ben Abdelkrim, N.; Chaouachi, A.; Chamari, K.; Chtara, M.; Castagna, C. Positional role and competitive-level differences in elite-level men's basketball players. *J. Strength Cond. Res.* **2010**, *24*, 1346–1355. [CrossRef] [PubMed]
34. Jones, P.A.; Thomas, C.; Dos'Santos, T.; McMahon, J.J.; Graham-Smith, P. The Role of Eccentric Strength in 180 degrees Turns in Female Soccer Players. *Sports* **2017**, *5*, 42. [CrossRef] [PubMed]
35. Tous-Fajardo, J.; Gonzalo-Skok, O.; Arjol-Serrano, J.L.; Tesch, P. Enhancing Change-of-Direction Speed in Soccer Players by Functional Inertial Eccentric Overload and Vibration Training. *Int. J. Sports Physiol. Perform.* **2016**, *11*, 66–73. [CrossRef] [PubMed]
36. Dos'Santos, T.; Thomas, C.; Jones, P.A.; Comfort, P. Assessing Asymmetries in Change of Direction Speed Performance: Application of Change of Direction Deficit. *J. Strength Cond. Res.* **2019**, *33*, 2953–2961. [CrossRef] [PubMed]
37. Brughelli, M.; Cronin, J.; Levin, G.; Chaouachi, A. Understanding change of direction ability in sport: A review of resistance training studies. *Sports Med.* **2008**, *38*, 1045–1063. [CrossRef]
38. Spiteri, T.; Nimphius, S.; Hart, N.H.; Specos, C.; Sheppard, J.M.; Newton, R.U. Contribution of strength characteristics to change of direction and agility performance in female basketball athletes. *J. Strength Cond. Res.* **2014**, *28*, 2415–2423. [CrossRef]
39. Nunez, F.J.; Santalla, A.; Carrasquila, I.; Asian, J.A.; Reina, J.I.; Suarez-Arrones, L.J. The effects of unilateral and bilateral eccentric overload training on hypertrophy, muscle power and COD performance, and its determinants, in team sport players. *PLoS ONE* **2018**, *13*, e0193841. [CrossRef]
40. Lockie, R.G.; Callaghan, S.J.; Berry, S.P.; Cooke, K.R.A. Relationship between unilateral jumping ability and asymmetry on multidirectional speed in team sport athletes. *J. Strength Cond. Res.* **2014**, *28*, 3557–3566. [CrossRef]
41. Ramirez-Campillo, R.; Burgos, C.H.; Henriquez-Olguin, C.; Andrade, D.C.; Martinez, C.; Alvarez, C.; Castro-Sepulveda, M.; Marques, M.C.; Izquierdo, M. Effect of unilateral, bilateral, and combined plyometric training on explosive and endurance performance of young soccer players. *J. Strength Cond. Res.* **2015**, *29*, 1317–1328. [CrossRef] [PubMed]
42. Ramirez-Campillo, R.; Sanchez-Sanchez, J.; Gonzalo-Skok, O.; Rodriguez-Fernandez, A.; Carretero, M.; Nakamura, F.Y. Specific Changes in Young Soccer Player's Fitness After Traditional Bilateral vs. Unilateral Combined Strength and Plyometric Training. *Front. Physiol.* **2018**, *9*, 265. [CrossRef] [PubMed]

43. Gonzalo-Skok, O.; Tous-Fajardo, J.; Valero-Campo, C.; Berzosa, C.; Bataller, A.V.; Arjol-Serrano, J.L.; Moras, G.; Mendez-Villanueva, A. Eccentric-Overload Training in Team-Sport Functional Performance: Constant Bilateral Vertical Versus Variable Unilateral Multidirectional Movements. *Int. J. Sports Physiol. Perform.* **2017**, *12*, 951–958. [CrossRef] [PubMed]
44. Gonzalo-Skok, O.; Tous-Fajardo, J.; Suarez-Arrones, L.; Arjol-Serrano, J.L.; Casajús, J.A.; Mendez-Villanueva, A. Single-Leg Power Output and Between-Limbs Imbalances in Team-Sport Players: Unilateral Versus Bilateral Combined Resistance Training. *Int. J. Sports Physiol. Perform.* **2017**, *12*, 106–114. [CrossRef] [PubMed]
45. Padulo, J.; Tiloca, A.; Powell, D.; Granatelli, G.; Bianco, A.; Paoli, A. EMG amplitude of the biceps femoris during jumping compared to landing movements. *SpringerPlus* **2013**, *2*, 520. [CrossRef]
46. McCurdy, K.W.; Langford, G.A.; Doscher, M.W.; Wiley, L.P.; Mallard, K.G. The effects of short-term unilateral and bilateral lower-body resistance training on measures of strength and power. *J. Strength Cond. Res.* **2005**, *19*, 9–15. [CrossRef]
47. McCurdy, K.; O'Kelley, E.; Kutz, M.; Langford, G.; Ernest, J.; Torres, M. Comparison of Lower Extremity EMG Between the 2-Leg Squat and Modified Single-Leg Squat in Female Athletes. *J. Sport Rehabil.* **2010**, *19*, 57–70. [CrossRef]
48. Tagesson, S.K.; Kvist, J. Intra- and interrater reliability of the establishment of one repetition maximum on squat and seated knee extension. *J. Strength Cond. Res.* **2007**, *21*, 801–807. [CrossRef]
49. Jidovtseff, B.; Harris, N.K.; Crielaard, J.-M.; Cronin, J.B. Using the load-velocity relationship for 1RM prediction. *J. Strength Cond. Res.* **2011**, *25*, 267–270. [CrossRef]
50. Pareja-Blanco, F.; Rodríguez-Rosell, D.; Sánchez-Medina, L.; Sanchis-Moysi, J.; Dorado, C.; Mora-Custodio, R.; Yáñez-García, J.M.; Morales-Alamo, D.; Pérez-Suárez, I.; Calbet, J.A.L.; et al. Effects of velocity loss during resistance training on athletic performance, strength gains and muscle adaptations. *Scand. J. Med. Sci. Sports* **2017**, *27*, 724–735. [CrossRef]
51. Maulder, P.; Cronin, J. Horizontal and vertical jump assessment: Reliability, symmetry, discriminative and predictive ability. *Phys. Ther. Sport* **2005**, *6*, 74–82. [CrossRef]
52. Meylan, C.; McMaster, T.; Cronin, J.; Mohammad, N.I.; Rogers, C.; Deklerk, M. Single-leg lateral, horizontal, and vertical jump assessment: Reliability, interrelationships, and ability to predict sprint and change-of-direction performance. *J. Strength Cond. Res.* **2009**, *23*, 1140–1147. [CrossRef] [PubMed]
53. Buchheit, M.; Simpson, B.M.; Peltola, E.; Mendez-Villanueva, A. Assessing maximal sprinting speed in highly trained young soccer players. *Int. J. Sports Physiol. Perform.* **2012**, *7*, 76–78. [CrossRef] [PubMed]
54. Brown, T.D.; Vescovi, J.D.; VanHeest, J.L. Assessment of linear sprinting performance: A theoretical paradigm. *J. Sports Sci. Med.* **2004**, *3*, 203.
55. Hopkins, W.G.; Marshall, S.W.; Batterham, A.M.; Hanin, J. Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Med. Sci. Sports Exerc.* **2009**, *41*, 3–12. [CrossRef]
56. Psycharakis, S.G.; Eagle, S.R.; Moir, G.L.; Rawcliffe, A.; McKenzie, C.; Graham, S.M.; Lamont, H.S.; Connaboy, C. Effects of Additional Load on the Occurrence of Bilateral Deficit in Counter-Movement and Squat Jumps. *Res. Q. Exerc. Sport* **2019**, *90*, 461–469. [CrossRef]

© 2020 EDIZIONI MINERVA MEDICA
Online version at http://www.minervamedica.it

The Journal of Sports Medicine and Physical Fitness 2020 August;60(8):1072-80
DOI: 10.23736/S0022-4707.20.10676-5

ORIGINAL ARTICLE

EXERCISE PHYSIOLOGY AND BIOMECHANICS

Gender differences in instep soccer kicking biomechanics, investigated through a 3D human motion tracker system

Bruno RUSCELLO [1, 2, 3, 4] *, Mario ESPOSITO [1], Gianmarco SILIGATO [1], Laura LUNETTA [1, 3], Lorenzo MARCELLI [1], Laura PANTANELLA [1], Paolo R. GABRIELLI [1, 4], Stefano D'OTTAVIO [1, 4, 5]

[1]School of Sport Sciences and Exercise, Faculty of Medicine and Surgery, Tor Vergata University, Rome, Italy; [2]School of Sports and Exercise Sciences, San Raffaele University, Rome, Italy; [3]Department of Industrial Engineering, Faculty of Engineering, Tor Vergata University, Rome, Italy; [4]LUISS SportLab, LUISS University, Rome, Italy; [5]Department of Clinical Science and Translational Medicine, Faculty of Medicine and Surgery, Tor Vergata University, Rome, Italy

*Corresponding author: Bruno Ruscello, School of Sport Sciences and Exercise, Faculty of Medicine and Surgery, Tor Vergata University, via Montpellier 1, 00133 Rome, Italy. E-mail: bruno.ruscello@uniroma2.it

ABSTRACT

BACKGROUND: This study aims at describing and comparing each other male and female soccer players kicking instep a stationary ball. The different measures we collected by the 3D motion capture system Movit G1 and the High-Speed Camera (240 fps) were considered as dependent variables, whereas the gender was considered as the independent one.

METHODS: Twenty soccer well trained non-professional players: 10 men (age: 25.3±6.5 yrs; height 1.80±0.07 m; body mass 76.9±13.2 kg) and 10 women (age: 19±3.34 yrs; height 1.64±0.07 m; body mass 58.2±7.2 kg) volunteered to participate in the study.

RESULTS: Gender differences were found, with a statistical significance ($P<0.05$) or interesting magnitude (Cohen $d>0.5$). The most relevant ones were the differences in hip extension of the kicking leg when the foot of the supporting one touches the ground, just before the impact on the ball (independent sample t-Test; $P=0.03$; Cohen $d=1.64$) and the speed of the ball, reached immediately after kicking ($P<0.001$;$d=1.23$).

CONCLUSIONS: These results, together with the greater pelvic acceleration shown by men compared to women, highlight the need to develop a gender-differentiated training model, in order to customize the kicking technique in women and to reduce the likelihood, currently higher than for men, of kicking related injuries.

(*Cite this article as:* Ruscello B, Esposito M, Siligato G, Lunetta L, Marcelli L, Pantanella L, *et al.* Gender differences in instep soccer kicking biomechanics, investigated through a 3D human motion tracker system. J Sports Med Phys Fitness 2020;60:1072-80. DOI: 10.23736/S0022-4707.20.10676-5)

KEY WORDS: Soccer; Imaging, three-dimensional; Exercise.

Kicking is a soccer fundamental, which depends on many different and complex factors (technique, foot-ball interaction, ball flight, etc.).[1] Kicking is the characterizing technique of soccer and the ability to perform it skillfully is a vital requisite to play efficaciously at any level.[2-5] Indeed, soccer would not be possible without mastering the fundamental abilities to control, dribble and kick the ball, for both passing or shooting at goal.[6] Several researches have aimed at investigating the basics of kicking instep biomechanics, in order to provide insights of this technique and to report the relevant information useful to train it properly, with the purpose of technique optimization and talent development.[7-12]

A good knowledge of the kicking instep biomechanics, and its gender peculiarities, is definitively important to correctly manage the technical training in every level of players' qualification, for both men and women.

Given the extremely dynamic and situational nature of soccer, it is impossible to describe all the variables that may influence the technical execution of ball kicking in open play situations.

For this reason, most of the studies regarding kicking have been directed to investigate the ability to kick a stationary ball, as it may occur during penalties or free kicks.

Particularly relevant under a methodological standpoint is to describe possible differences between men and women's soccer, in the biomechanical domain, to take into the opportune account while planning the specific training interventions.[8, 13]

Women's soccer is one of the most popular team sports in the world, as evidenced by the enormous interest aroused by the recent world championships, held in France in 2019.

The study of the complexity of women's soccer performance requires an *ad-hoc* approach, which does not consider women's soccer as a minor sport, mediated by male soccer. In other terms, what is true for men's soccer does not always apply to women's soccer, and *vice versa*.[8, 14-16]

Ball kicking is a complex movement from both a technical and biomechanical point of view, because it involves not only the foot, the ankle and the knee, but also the coxo-femoral joint, which has great mobility on different planes and requires proper stabilization of the pelvis and trunk.[12] It is an open kinetic chain skill, performed at high angular speed with the knee as its fulcrum and this is not only the most typical action of soccer but also the one that distinguishes soccer from most other sports. The biomechanics of kicking instep a stationary ball, currently available in the literature, mainly refers to adult male players. However, millions of players play soccer all over the world, belonging to both the male and female gender, and all age groups are involved.

For this reason, using the "adult male soccer player" model for training purposes is not always the best solution, since several errors may arise due to the different characteristics of the players, mainly attributable to the anthropometrics, anatomical, structural and physiological differences between genders and age groups.[8]

The need to investigate deeper the biomechanics of kicking instep a stationary ball, performed from both men and women soccer players, and compare them, emerges clearly. The purpose to allow an informed coaching while referring to the specific technical training of this fundamental soccer skill. As previously reported, what is true for men's soccer does not always apply to women's soccer, and vice versa.[17, 18] For this reason, we decided to investigate deeper soccer kicking instep biomechanics, availing of a novel 3D human motion tracker system, able to provide accurate information about the kinematics of this complex multiplanar movement.

The aim of this study was to identify the possible differences, under a biomechanical standpoint, between men and women soccer players when engaged to kick instep a stationary ball, with precision and power.

The novelty of our approach is represented the most by the instruments we used, which combined a portable 3D motion capture system and a high speed camera, sampling at 240 fps, allowing an accuracy of measurement to be reached hardly in a usual in-field situation.

Materials and methods

Experimental approach to the problem

Using a descriptive study design, participants performed, in different days, one set of 10 repetitions each of kicking instep a stationary ball, with power and precision. Relevant physical variables were measured in order to verify our principal hypothesis: there are gender differences in kicking instep a stationary ball under a biomechanical standpoint. The different measures we collected by the 3D motion capture system and high-speed camera were considered as dependent variables, whereas the gender was considered as the independent one.

Before performing the experimental procedures, face validity was established using expert judgment procedures.

Subjects

Twenty soccer well trained non-professional players (10 men, 10 women) volunteered to participate in the study. Men players (age: 25.3±6.5 yrs; height 1.80±0.07 m; body mass 76.9±13.2 kg) and women players (age: 19 ±3.3 yrs; height 1.64±0.07 m; body mass 58.2±7.2 kg) belong to two different soccer clubs, based in Rome, Italy, playing at the regional (men) and national (women) level. The players had at least 4.4 years (range: 1-11 years) of experience at this competitive level. A significant difference (P=0,01) in years of experience has been found between genders, probably due to the differences in ages. All participants perform three-four training sessions per week and play 4-5 matches per month, during the competitive season. Kicking instep a stationary ball requiring power and precision has been routinely included in the training sessions in the four weeks prior to the testing procedures.

Inclusion criteria to participate in the study were: 1) to have regularly competed during the competitive season; and 2) possession of a valid medical certificate, which would exclude current pathologies that contraindicated high intensity physical activities, such as hard kicking instep a stationary ball.

All subjects were healthy and clear of any drug consumption. Each subject completed all trials in the same time of test days to eliminate any influence of circadian variation. The Institutional Research Board (University of Rome "Tor Vergata", Faculty of Medicine Ethical Committee) provided clearance for the procedures before the commencement of this study. Written informed consent was obtained from all the participants after familiarization and explanation of the benefit and risks involved in the procedures of this study. All participants were informed that they were free to withdraw from the study at any time without penalty. All procedures were carried out in accordance with the Declaration of Helsinki of the World Medical Association as regards the conduct of clinical research.

Experimental procedures

The kicking tests were performed in October 2019, in two separate days, at the same hours of the day (*i.e.*, 6-8 pm) and the same day of the week (Tuesday) in a sport center (Rome, Italy), on a synthetic surface soccer pitch, approved by the Italian Football Association for national level competitions. The average weather conditions during the two testing days were fine, with an average temperature and wind speed of 17° and 6.1 m·s-1 on first day, 18° and 4.7 m·s-1 on last day respectively.

Three significant stages in kicking instep were analyzed under a kinematic point of view, considering these variables:

1. The loading (or stage 1), in which the kicking leg is in the loading phase by swinging back and the support one is still in the flight phase (Figure 1);
2. the support (or stage 2), *i.e.* the instant when the planter foot of the supporting leg touches the ground, next to the stationary ball (Figure 2);
3. the impact (or stage 3), *i.e.* the propelling action of the foot on the ball by kicking (Figure 3).

These are the variables we considered in this study, referring to the three stages reported above:

a) stage 1:
- hip extension of the kicking leg;
- knee bending of the kicking leg;
- extension of the supporting leg
- pelvis acceleration.

b) Stage 2:
- hip extension of the kicking leg;
- bending of the kicking leg;
- supporting leg extension
- pelvis acceleration.

c) Stage 3:
- kicking leg peak acceleration (distal third of the tibia);
- pelvis acceleration.

To investigate the ball speed immediately after the impact with the kicking foot a high-speed video footage (240 fps) has been used.

Figure 1.—Captiks motion studio analyzer – phase 1.

Figure 2.—Captiks motion studio analyzer – phase 2.

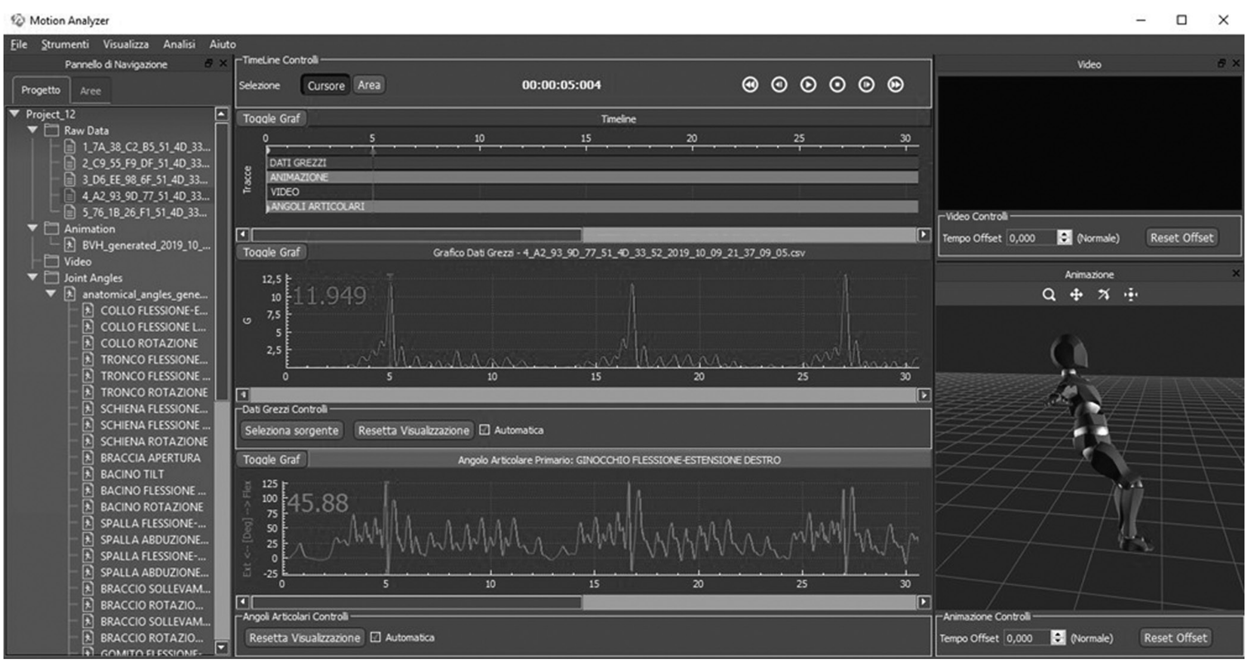


Figure 3.—Captiks motion studio analyzer – phase 3.

After calibrating the acquisition space, the space covered by the ball, derived from the video, has been divided by the measured time, thus obtaining the initial speed, expressed in meters per second (m·s-1).

Instrumentation

To investigate the biomechanics of soccer kicking we made use of a 3D human motion tracker system (Movit System G1 by Captiks Srl, Rome, Italy).[19, 20] The 5 Movit units (which can be networked with up to 15 other units if necessary), wireless send data to a receiving device (the receiver) connected to a personal computer (Acer Aspire F15 – Intel Core I7, 16 Gb RAM). Specifically, we acquired data from the internal 3-axis digital-output accelerometers, which have a programmable full-scale range of ±2 g, ±4 g, ±8 g and ±16 g, and integrates a 16-bit A/D converter, enabling simultaneous sampling of accelerometers without requiring an external multiplexer. Data rate can range within 4 Hz–1000 Hz.

The 5 Movit units were housed as it follows:

- In a belt and located at the subject's spine level, between the second and the fifth lumbar vertebra (L2 and L5);
- in two belts located on the right leg, at the medial third of the femur and the distal third of the tibia;
- in two belts located on the left leg, at the medial third of the femur and the distal third of the tibia.

The personal computer runs proprietary software (termed Captiks Motion Studio SDK, CMS, by Captiks Srl) for motion analysis so that pitch (x) roll (y) and yaw (z) signals are A/D converted and further normalized, within 0–1 range.

To provide a high-speed video footage a Casio Exilim EX-ZR 100, set at 240 fps, has been used. The relevant data were processed using the Kinovea 0.8.27 software.

Statistical analysis

Data were processed by carrying out a descriptive analysis, providing the mean, the standard deviation and the and 95% confidence intervals (95% CIs). The assumption of normality was assessed using the Shapiro-Wilk test. To evaluate the gender differences in the kinematics of the considered phases, analyzed during the instep kicking, a *t*-Test was carried out for independent samples and the effect size was obtained by calculating the Cohen's d.

The following values will be considered: d=0.20 small effect, d=0.50 medium effect, d=0.80 large effect and d>1 huge effect.

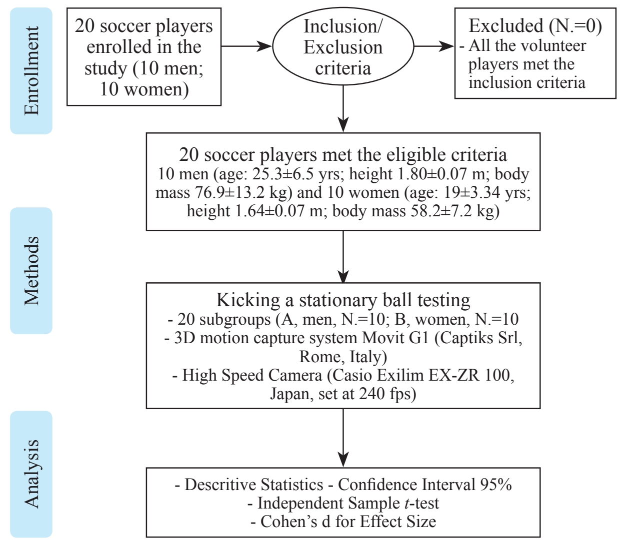


Figure 4.—Flow-chart diagram summarizing the study protocol.

The value of statistical significance was accepted with P≤0.05. The corresponding P values are given for each analysis.

IBM SPSS Statistics 25 and Microsoft Excel were used for all statistical procedures.

A flow-chart diagram summarizing the study protocol is provided in Figure 4.

Results

The anthropometric data of the subjects who participated in this study were analyzed under a statistical standpoint. Significant gender differences (P<0.05 and Cohen d Cohen>1) are reported in Table I.

The kinematics of the investigated anatomical segments, analyzed during the three significant stages of kicking instep are reported in Tables II, III, IV. Mean values±standard deviations, the 95% Interval Confidence for the mean together with the t-Test values are provided.

TABLE I.—*Samples anthropometrics and gender differences.*

	Men M±SD	Women M±SD	*t*-test for independent samples	
			t; df; P value	Cohen's d
Height (m)	1.80±0.07	1.64±0.07	5.02; 18; 0.001 *	2.26 *
Weight (kg)	76,9±13.2	58,2±7.2	3.93; 18; 0.001 *	1.75 *

Cohen *d*=0.20 small effect, *d*=0.50 medium effect, *d*=0.80 large effect and *d*>1 huge effect
*significant P values.

TABLE II.—*Stage 1: descriptive statistics and* t-*test for independent sample: men* vs. *women.*

	Men		Women		*t*-test for independent samples	
	M±SD	95% IC for the mean Upper case; Lower case	M±SD	95% IC for the mean Upper case; Lower case	t; df; P value	Cohen's d
Hip Extension (°)	-5.25±6.96	0.10; -10.61	-11.09±13.01	-1.80; -20.40	1.28; 18; 0.22	0.57
Knee bending of the kicking leg (°)	158.55±12.26	167.97; 149.13	165.39±9.09	171.85; 165.85	-1.29; 18; 0.21	-0.58
Supporting leg knee extension (°)	127.34±17.09	140.48; 114.20	123.95±13.70	133.76; 114.15	0.52; 18; 0.61	0.23
Pelvis acceleration (g)	0.74±0.42	1.06; 0.41	0.68±0.26	0.86; 0.50	0.30; 18; 0.77	0.12

Cohen's d=0.20 small effect, d=0.50 medium effect, d=0.80 large effect and d>1 huge effect.

TABLE III.—*Phase 2: descriptive statistics and* t-*test for independent sample: men* vs. *women.*

	Men		Women		*t*-test for independent samples	
	M±SD	95% IC for the mean Upper case; Lower case	M±SD	95% IC for the mean Upper case; Lower case	t; df; p-value	Cohen's d
Hip Extension (°)	-12.10±9.09	-5.11; -19.08	-30.74±13.25	-21.26; -40.22	3.53; 17; 0.03 *	1.64 *
Knee bending of the kicking leg (°)	84.07±14.75	95.41; 72.73	84.48±11.21	92.51; 76.46	0.81; 18; 0.94	0.03
Supporting leg knee extension (°)	156.44±7.40	162.12; 150.75	161.24±5.53	165.19; 157.27	-1.48; 18; 0.15	-0.66
Pelvis acceleration (g)	2.52±0.82	3.15; 1.90	2.17±0.32	2.40; 1.95	0.87; 11.49; 0.40	0.39

Cohen's d=0.20 small effect, d=0.50 medium effect, d=0.80 large effect and d>1 huge effect.
*Significant P values.

TABLE IV.—*Phase 3: descriptive statistics and* t-*test for independent sample: men vs. women.*

	Men		Women		*t*-test for independent samples	
	M±SD	95% IC for the mean Upper case; Lower case	M±SD	95% IC for the mean Upper case; Lower case	t; df; P value	Cohen's d
Kicking leg peak acceleration;	11.50±1.61	12.73; 10.25	11.76±1.09	12.55; 10.99	-0.38; 18; 0.71	-0.16
Pelvis acceleration (g)	2.93±1.23	3.88; 1.99	2.37±0.52	2.74; 1.99	1.06; 12.27; 0.31	0.48

Cohen's d=0.20 small effect, d=0.50 medium effect, d=0.80 large effect and d>1 huge effect

Table II shows the results of:

- hip extension of the leg kicking the ball;
- knee bending of the kicking leg;
- supporting leg knee extension;
- pelvis acceleration

at the moment in which the kicking leg is in the loading phase and the supporting leg is still in the flight phase (stage 1).

In Table III, the variables that were analyzed at the instant when the foot of the supporting leg touches the ground, before the impact with the ball (stage 2) were the same as in Table II.

Table IV shows the results of:

- kicking leg peak acceleration;
- pelvis acceleration

at the moment of the impact of the foot of the kicking leg with the ball (stage 3).

From these results, it can be seen that the values of the hip extension of the kicking leg, in stage 2, are significantly higher in women (-30.74°) than in men (-12.09°) with $P<0.05$ and an effect size of 1.64.

Other differences in the acceleration of the pelvis, in all the three analyzed stages, although not statistically significant, have been found. These accelerations are always greater in men. On the other hand, the acceleration of the kicking leg, detected in stage 3) is comparable, with a slightly higher value recorded in women, although not statistically significant.

The hip extension of the kicking leg, considered in stage 1, is slightly greater in women, with an effect size of 0.57, indicating a medium effect. No significant gender differences were found in bending of the kicking leg and the extension of the supporting leg at the different stages investigated (stage 1 and 2).

The speed of ball immediately after the kicking has been computed and processed to find possible differences between genders.[21] The relevant results are provided

TABLE V.—*Initial speed of the ball recorded immediately after the ball impact of the kicking foot: men* vs. *women.*

	Men		Women		*t*-test for independent samples	
	M±SD	95% IC for the mean Upper case; Lower case	M±SD	95% IC for the mean Upper case; Lower case	t; df; P value	Cohen's d
Speed ($m \cdot s^{-1}$)	25.88±3.68	29.56; 24.34	21.87±2.75	24.64; 20.57	4.36; 47; <0.001	1.23

Cohen's d=0.20 small effect, d=0.50 medium effect, d=0.80 large effect and d>1 huge effect.

in Table V. These results are in line with those found by other researchers,[13] highlighting a meaningful difference (P<0.001; d=1.23) in ball speeds between genders.

Discussion

The biomechanics of instep soccer kick has been largely investigated, by the means of different instruments of measurement, both in-field and in a lab setting. These results are reported by numerous studies. Nevertheless, a certain lack of investigations, referring to women's soccer and its comparison with the men's soccer, has been observed. Soccer research in exercise science has focused on men's soccer, while women's soccer has been underrepresented in training studies, as well as in studies focusing on physiological variables.[22] Considering the rapid development of women's soccer and the level of technical specialization required to perform at the highest level, it seems very opportune to investigate the skill of instep kicking deeper, especially through in-field researches, so to provide the specific technical model of instep kicking to the women's soccer coaches.

Considering that the popularity and professionalism of females soccer has increased markedly, few authors have examined the kinematics gender differences in instep soccer kicking in recent years.[3, 13, 23-29] What has emerged is that when women kick the ball, at some phases, they have a kinematics that differs from that of men, *i.e.* a wider maximum extension of the hip and a greater abduction of the hip at the time of impact with the ball, and a greater adduction in the hip of the supporting limb during the phases of back swing, leg cocking and acceleration.

Some authors[13, 30] found gender differences between soccer players, referring to the technical abilities and the anthropometrics features. Female soccer players showed better values than males in juggling test but worse in speed dribbling with ball and in shooting, as we did. Differences between gender in height and weight but no in BMI were also found. Considering gender differences in soccer performance, cut-off used for male cannot apply to female because utilization of the same exercise and/or application of the same training volume might cause poor training effects.

In a study carried out by Brooks *et al.* in women soccer[22] body composition, muscular strength, explosive power, aerobic power, acceleration, speed, and agility were tested in each athlete participating in the study. Knee torque (KT) and hip torque (HT) were also measured on both legs. Kicking accuracy and velocity (KV) were examined. A correlation was found between KT and KV (r=0.93), as well as vertical jump and KV (r=0.91). Aerobic power (r=0.93), agility (r=0.88), and vertical jump (r=0.84) were highly correlated to Body Fat%. These data suggest that significant relationships do exist between peak knee and hip torque, agility, lean body mass, strength, and explosive power with soccer-specific variables such as kick velocity (KV).

Men have been shown to have a maximum linear speed of the knee and hip, and a maximum angular speed of the hip, knee and ankle greater than women do. All these factors are important because they affect what is the outcome of the shot; in fact, the speed of the ball kicked by women is lower than the speed of the ball kicked by men.[7] However, these are just some of the factors that affect the instep kicking; in fact, the latter suffers a strong conditioning given by the lower muscle mass of the lower limbs of women, and also by the difference in the shape of the pelvis, wider in women that leads to a different level of muscle pattern activation of the muscles involved. On the basis of the results obtained in this study, it is possible to confirm, using a 3D motion capture system and high-speed recording, that there are significant gender differences (P<0.05) in the hip extension during the kicking instep, detected at the instant when the foot of the supporting leg touches the ground, (*i.e.* during the maximum extension phase of the kicking leg or backswing) before the ball impact (stage 2) and the ball velocity, immediately after the ball impact (Table V).

The relevance of these differences are witnessed by the huge effect sizes we computed (Cohen d=1.64 and 1.23 respectively).

Women showed an average hip extension of -30.74°, while men showed an average hip extension of -12.09° (Table III). These results, in line with what already highlighted in the research carried out by Smith and Gilleard in 2016,[31] imply the acceptance of the hypothesis we tested.

A difference of moderate magnitude, with an effect size of 0.57, also occurred in the hip extension of the leg kicking the ball, in stage 1 (Table II).

This increased articular Hip Range of Motion (ROM), shown by women may be due to several factors:

- on average, from an anatomical point of view, women have a greater capsular-ligamentous laxity, due to the different constitution of the tendon muscle tissue;
- on average, women are likely to have more lumbar lordosis than men;
- on average, the woman's pelvis is wider than that of the man, and the head of the femur tends to have a greater capacity for excursion because it tends to favor a valgus knee.

Moreover, although not significant, differences in the acceleration of the pelvis emerged in all three phases we analyzed; a greater acceleration produced by male subjects can contribute to the final result of the shot. In fact, in the study by Katis *et al.*[8] it was shown that a higher speed of the ball kicked by men – as we found in our study too – may be due to a higher articular acceleration.

Finally, by analyzing the anthropometric data of the subjects who participated in this study, a significant gender difference ($P<0.05$ and Cohen d Cohen>1) can be seen (Table I). These differences could help explain the greater power in kicking the ball generally shown by males, compared to women. In fact, based on what reported by Brophy et al in 2010[23] the greater muscle mass of the lower limbs in men and the greater length of the limbs - it may lead to have a more advantageous lever - can contribute to the speed of the ball after impact.

Limitation of this study

A limit of this research is certainly given by the sample size we achieved in our testing; to have a clearer picture of the differences between males and females in soccer kicking instep, it would be necessary to analyze a larger sample and possibly made up of professional players. Another possible limitation we should underline is represented by the difference in years of soccer experience found in the sample, due to probably the differences in ages, between genders.

Conclusions

The results obtained in this research, have shown that the kinematics of soccer kicking instep, differ in some significant stages between males and females. In particular, the greater extension of the hip shown by the women, contributes negatively to the final result of the kick, as it reduces the ability to maximize the speed of the foot in contact with the ball, leading to a reduction in the speed of the ball itself, as reported by Smith and Gilleard in 2016[31] and confirmed by the present study, carried out availing of a novel 3D motion capture system. These results, together with the greater pelvic acceleration shown by men compared to women, highlight the need to develop a gender-differentiated training model, in order to improve the kicking technique in women and to reduce the likelihood, currently higher than for men, of kicking related injuries such as anterior cruciate ligament injuries and knee over-extensions.[13]

References

1. Rađa A, Kuvačić G, De Giorgio A, Sellami M, Ardigò LP, Bragazzi NL, *et al.* The ball kicking speed: A new, efficient performance indicator in youth soccer. PLoS One 2019;14:e0217101.

2. Woods CT, Raynor AJ, Bruce L, McDonald Z, Robertson S. The application of a multi-dimensional assessment approach to talent identification in Australian football. J Sports Sci 2016;34:1340–5.

3. Langhout R, Weber M, Tak I, Lenssen T. Timing characteristics of body segments during the maximal instep kick in experienced football players. J Sports Med Phys Fitness 2016;56:849–56.

4. Chew-Bullock TS, Anderson DI, Hamel KA, Gorelick ML, Wallace SA, Sidaway B. Kicking performance in relation to balance ability over the support leg. Hum Mov Sci 2012;31:1615–23.

5. Andersen TB, Dörge HC. The influence of speed of approach and accuracy constraint on the maximal speed of the ball in soccer kicking. Scand J Med Sci Sports 2011;21:79–84.

6. Ali A. Measuring soccer skill performance: a review. Scand J Med Sci Sports 2011;21:170–83.

7. Pereira Santiago PR, Palucci Vieira LH, Barbieri FA, Moura FA, Exel Santana J, de Andrade VL, *et al.* Comparison of the Kinematic Patterns of Kick Between Brazilian and Japanese Young Soccer Players. Asian J Sports Med 2016;7:e33645.

8. Katis A, Kellis E, Lees A. Age and gender differences in kinematics of powerful instep kicks in soccer. Sports Biomech 2015;14:287–99.

9. Katis A, Amiridis I, Kellis E, Lees A. Recovery of powerful kick biomechanics after intense running fatigue in male and female soccer players. Asian J Sports Med 2014;5:e24013.

10. Kapidžić A, Huremović T, Biberovic A. Kinematic analysis of the instep kick in youth soccer players. J Hum Kinet 2014;42:81–90.

11. Juárez D, Mallo J, De Subijana C, Navarro E. Kinematic analysis of kicking in young top-class soccer players. J Sports Med Phys Fitness 2011;51:366–73.

12. Lees A, Asai T, Andersen TB, Nunome H, Sterzing T. The biomechanics of kicking in soccer: a review. J Sports Sci 2010;28:805–17.

13. Barfield WR, Kirkendall DT, Yu B. Kinematic instep kicking differences between elite female and male soccer players. J Sports Sci Med 2002;1:72–9.

14. Baumgart C, Hoppe MW, Freiwald J. Different endurance characteristics of female and male german soccer players. Biol Sport 2014;31:227–32.

15. Pollard R, Gómez MA. Comparison of home advantage in men's and women's football leagues in Europe. Eur J Sport Sci 2014;14(Suppl 1):S77–83.

16. Bradley PS, Dellal A, Mohr M, Castellano J, Wilkie A. Gender differences in match performance characteristics of soccer players competing in the UEFA Champions League. Hum Mov Sci 2014;33:159–71.

17. Ruscello B, Esposito M, Fusco C, Ceccarelli C, Pomponi S, Filetti C, *et al.* Acute effects of two different initial heart rates on testing the repeated sprint ability in elite women soccer players. J Sports Med Phys Fitness 2020;60:527–35.

18. Ruscello B, Esposito M, Partipilo F, Di Cicco D, Filetti C, Pantanella L, *et al.* Exercise-to-rest ratios in repeated sprint ability training in women's soccer. J Sports Med Phys Fitness 2018;58:1790–9.

19. Costantini G, Casali D, Paolizzo F, Alessandrini M, Micarelli A, Viziano A, *et al.* Towards the enhancement of body standing balance recovery by means of a wireless audio-biofeedback system. Med Eng Phys 2018;54:74–81.

20. Ricci M, Terribili M, Giannini F, Errico V, Pallotti A, Galasso C, *et al.* Wearable-based electronics to objectively support diagnosis of motor impairments in school-aged children. J Biomech 2019;83:243–52.

21. Alcock A, Gilleard W, Brown N AT, Baker J, Hunter A. Initial ball flight characteristics of curve and instep kicks in elite women's football. J Appl Biomech 2012;28:70–7.

22. Brooks KA, Clark SL, Dawes JJ. Isokinetic Strength and Performance in Collegiate Women's Soccer. J Nov Physiother 2013;Suppl 3:1.

23. Brophy RH, Backus S, Kraszewski AP, Steele BC, Ma Y, Osei D, *et al.* Differences between sexes in lower extremity alignment and muscle activation during soccer kick. J Bone Joint Surg Am 2010;92:2050–8.

24. Li Y, Alexander M, Glazebrook C, Leiter J. Quantifying Inter-Segmental Coordination during the Instep Soccer Kicks. Int J Exerc Sci 2016;9:646–56.

25. Augustus S, Mundy P, Smith N. Support leg action can contribute to maximal instep soccer kick performance: an intervention study. J Sports Sci 2017;35:89–98.

26. Langhout R, Tak I, van der Westen R, Lenssen T. Range of motion of body segments is larger during the maximal instep kick than during the submaximal kick in experienced football players. J Sports Med Phys Fitness 2017;57:388–95.

27. Hunter AH, Angilletta MJ Jr, Pavlic T, Lichtwark G, Wilson RS. Modeling the two-dimensional accuracy of soccer kicks. J Biomech 2018;72:159–66.

28. Nunome H, Inoue K, Watanabe K, Iga T, Akima H. Dynamics of submaximal effort soccer instep kicking. J Sports Sci 2018;36:2588–95.

29. Peacock JC, Ball K. The influence of joint rigidity on impact efficiency and ball velocity in football kicking. J Biomech 2018;71:245–50.

30. Borman KM, Kurdek LA. Gender differences associated with playing high school varsity soccer. J Youth Adolesc 1987;16:379–400.

31. Smith T, Gilleard W. Three-dimensional analysis of a lofted instep kick by male and female footballers. Eur J Sport Sci 2016;16:57–64.

Conflicts of interest.—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Acknowledgements.—The authors wish to thank for their precious help all the players participating to the study and the engineer Laura Antenucci for her precious help and assistance.

History.—Manuscript accepted: May 5, 2020. - Manuscript revised: April 27, 2020. - Manuscript received: December 21, 2019.

© 2021 EDIZIONI MINERVA MEDICA
Online version at http://www.minervamedica.it

The Journal of Sports Medicine and Physical Fitness 2021 May;61(5):656-65
DOI: 10.23736/S0022-4707.21.11850-X

ORIGINAL ARTICLE

EXERCISE PHYSIOLOGY AND BIOMECHANICS

Fitness profiles of elite male Italian teams handball players

Bruno RUSCELLO [1, 2, 3, 4, 5] *, Carlo CASTAGNA [1, 5], Riccardo CARBONARO [1, 5],
Paolo Roberto GABRIELLI [1, 4, 5], Stefano D'OTTAVIO [1, 4, 5, 6]

[1]School of Sport Sciences and Exercise, Faculty of Medicine and Surgery, Tor Vergata University, Rome, Italy; [2]School of Sports and Exercise Sciences, San Raffaele University, Rome, Italy; [3]Department of Industrial Engineering, Faculty of Engineering, Tor Vergata University, Rome, Italy; [4]LUISS SportLab, LUISS University, Rome, Italy; [5]Italian Team Handball Federation (Federazione Italiana Giuoco Handball), Technical Department, Performance Unit, Rome, Italy; [6]Department of Clinical Science and Translational Medicine, Faculty of Medicine and Surgery, Tor Vergata University, Rome, Italy

*Corresponding author: Bruno Ruscello, School of Sport Sciences and Exercise, Faculty of Medicine and Surgery, Tor Vergata University, Via Montpellier 1, 00133 Rome, Italy. E-mail: bruno.ruscello@uniroma2.it

ABSTRACT

BACKGROUND: The aim of this study was to examine the fitness profile of the Italian national male Team-Handball players of different competitive level.
METHODS: Forty-one male handball players from the senior (N.=21, height 1.90±0.06m, body mass 94.04±11.59kg, BMI 26.13±2.45) to the junior category (N.=20, height 1.86±0.06m, body weight 84.99±12.52kg, BMI: 24.56±3.35) Italian National Teams participated in this study. Players were tested for lower and upper limbs muscle strength, change of direction ability and specific endurance. Lower limbs explosive strength was assessed with squat (SJ) countermovement (CMJ), stiff leg (stiffness) jumps. Explosive strength was assessed by measuring kinematic aspects of squat and bench exercises. Change of direction ability was assessed with the 505 test. The Yo-Yo intermittent recovery test (YYIR1) was considered for specific endurance.
RESULTS: Large and significant differences ($d>1$; partial $\eta^2>0.14$; $P<0.01$) between senior and junior national team players were found in anthropometrics, jumping, power, sprint, agility, and aerobic fitness (junior body weight accounting for 10% less than the senior one, P=0.021; SJ and CMJ in juniors smaller than the seniors by 15% and 12%, P=0.000 and P=0.001, respectively). Similar differences were found among positional roles (goalkeepers, backs, centers, pivots, wings), suggesting practical implications for training.
CONCLUSIONS: The differences between the competitive level and the playing role in relevant handball performance were reported in Italian national team players. The magnitude of the differences suggests the need of individual training approach when dealing with the young handball players.

(*Cite this article as*: Ruscello B, Castagna C, Carbonaro R, Gabrielli PR, D'Ottavio S. Fitness profiles of elite male Italian teams handball players. J Sports Med Phys Fitness 2021;61:656-65. DOI: 10.23736/S0022-4707.21.11850-X)

KEY WORDS: Team sports; Aptitude; Muscle strength; Sports.

Team handball (TH) is a popular team sport with professional leagues in many countries, and major international championships are held regularly, including the Olympic Games.[1] It is an intermittent and strenuous contact sport, the successful performance of which depends on the ability to perform repeated explosive muscular contractions required for jumping, sprinting, turning, changing directions, and throwing a ball.[2-4] Elite players' handball studies reported performance differences amongst player.[5] Differences being observed in body size, speed, and lower limb power and handgrip strength.[6]

Hermassi *et al.*[7] reported significant playing role (*i.e.*, backs, pivots, wings) differences in neuromuscular and metabolic indicators of handball performance, in players of two different competitive leagues. Pivots were the players with the highest throwing velocity and wings were the fastest (15, 30 m sprint), strongest (countermovement jump), and most enduring (Yo-Yo intermittent recovery test, YYIR1) players. Backs showed consistently the lowest throwing velocity and sprint performance. According to these authors, the anthropometric differences between playing levels and playing positions may indicate the advantageous characteristics that the respective position demands. Whereas the playing position differences in physical fitness characteristics may indicate training specificity.

Other studies that investigated differences in anthropometry and physiological performance characteristics between playing positions in elite senior players[8-10] reported wings as being lower and lighter than the rest of the handball players.[11-13] No clear across the playing roles differences in physiological performance variables were reported warranting further studies.[5, 14-21]

The aim of this study was to examine the possible differences, under a fitness standpoint and in relation to the different positional roles, between senior and junior male handball players, belonging to the Italian national teams.

Accordingly, the aims were: 1) to examine the anthropometric and physiological performance characteristics in male junior and senior national players; and 2) to compare the anthropometry and the physiological performance characteristics between court playing positions in male junior and senior Handball players. The study also aimed at providing the fitness profiles of these elite players, to establish some normative values able to inform the training process of developing sub-elite players.

Materials and methods

Experimental Approach to the problem

An observational study was designed to verify the given hypotheses. The measures obtained by testing were dependent variables, whereas different factors, such as age group and positional roles, were set as independent ones. Before performing the experimental procedures, face validity was established using expert judgment procedures.

Subjects

Forty-one male handball players from the Italian Senior (N.=21; height 1.90±0.06 m; body mass 94.04±11.59 kg; BMI: 26.13±2.45 kg·m^{-2}); and Under 21 (N.=20; height 1.86±0.06 m; body mass 84.99±12.52 kg; BMI: 24.56±3.35 kg·m^{-2}) National Teams participated in this study.

All subjects in the study had a minimum of 5 years' experience in a professional handball club. Over the previous year, the players usually trained 5 to 7 times per week. Both, Senior and Junior players may be considered elite level for their age group and competed at their respective international level. Before undergoing assessment, all players with previous or chronic injures did not fulfil the eligibility criteria and were not considered. The methodology used was approved by the Ethics Committee of Tor Vergata University, Faculty of Medicine and Surgery (Rome, Italy) and conformed to the policy statement with respect to the Declaration of Helsinki. All participants and their parents were informed of the risk and benefits of the procedure and signed an informed consent for participation in the study.

Experimental procedures and instrumentation

Data were collected during the preparation period for the season 2019-2020, (October 2019). The experimental stage consisted of two different phases. On day 1, the participants underwent the strength assessments (squat jump [SJ], counter movement jump [CMJ], stiff-leg jump test over seven repeated jumps [ST]; squat test with 50% body mass [ST-BW50%] at the Smith Machine; bench press with 50% body mass [BP-BM50%]).[22] On day 2, the participants underwent the agility and speed assessments (COD 505 test)[23] and the aerobic performance test (YYIR1). A recovery time of 48 hours was granted between day 1 and day 2 to reduce the effect of fatigue. In order to avoid any circadian influences on testing, all the assessments were carried out at the same time each day.

To ensure familiarization with the procedures, participants conducted trial tests, spanning three weeks prior to testing.

Strength and power testing were performed in an indoor gym under stable environmental conditions (9.30-12.00 a.m., 21±0.5° C average temperature and 50±2% relative humidity). The COD 505 and YYIR1 tests were performed on an indoor court homologated for international handball competitions. Players wore shoes usually adopted during competitions. Participants refrained from any heavy training in the two days prior to testing. On testing day 1, Body Mass (BM) was measured to compute BM50%. During day 1, all players performed a general standardized warm up comprising 5 min cycling or running on treadmill, 3 min ballistic stretching exercises, submaximal jumping (1×8 repetitions) in sequence. Before ST-BM50% and BP-BM50% tests, players performed the required motor tasks with lighter weights and self-selected speed. During day 2, all players completed a general warm up comprising 5 min jogging, 3 min ballistic stretching, 20-30 m striding at gradually increasing speeds and 10-20 m accelerations, including sharp COD at 90° and180°.

Jump testing

All jumping assessments were recorded using the Optojump electronic system (Microgate, Bolzano, Italy), using the Bosco *et al*. protocol.[24] After the standardized warm-up, each player performed three SJ and CMJ as specific test prime.[24-35] Players were requested to keep the hands in contact with the waist (fixed arms) during SJ and CMJ. Participant performed the SJ from a 90° squat position according to the protocol dictated by Bosco *et al*.[24] Knee angle was set with the use of a handheld goniometer (Chinesport Goniometer, Udine, Italy). Best performances for SJ and CMJ were recorded for statistical analyses. To evaluate lower-leg reactive strength players performed a repeated straight-knees on the spot vertical jumping test consisting of seven repetitions. Best performances in contact time, flight time and estimated height of jumping were considered as ST variables.

Power testing

Upper and lower limbs power was assessed considering ST-BM50% and BP-BM50%, respectively.

Between players normalization was promoted with a barbell load corresponding to 50% of the individual body mass. Force, Velocity and Maximum Power were measured by the means of the Gyko device (Microgate),[36, 37] directly mounted on the barbell.

First test consisted of a Squat exercise done with the BM50% extra load. The aim of the test was to rapidly extend the knees (concentric contraction) starting from a squatting position with 90° knee bending (to measure that, a professional goniometer has been used).

Second testing consisted of a rapid extension of the arms while pushing up the barbell as usually done in the barbell bench press.[38, 39] Participants performed three trials for each testing routine and the best results were considered for the consequent statistical analysis.

Sprinting and agility testing

Participants performed a maximal “505” sprinting test (with a 180° change of direction) with left and right turns.[40] They were positioned at 15 m from a turning point and timing gates were placed 10 m from the starting point and 5 m from the turning point (Witty System, Microgate). The players accelerated from the start, through the timing gates, turning 180° at the 15-m mark and sprinted back through the timing gates. They self-administered their starting. They were encouraged to perform the sprint as fast as possible until the last gate.[41] Subjects completed 4 alternate trials, turning off their left and right foot, separated by a 2-3-minute passive rest period.[42-45] Only attempts whereby the subject’s foot crossed the 15-m mark were recorded. Times were recorded to the nearest 0.01 seconds with the quickest of the 4 attempts used.

Although, the 505 test has been identified as a reliable test,[46] it has been suggested that using the total time to complete the test as a measure of COD may not necessarily accurately represent the COD ability of a player.[47] Thus, a player who is fast linearly may still perform well in a COD test, as their sprinting ability could mask any deficiency in COD ability. Therefore, in addition to reporting total time for the 505 test, the COD deficit was calculated for each player, using the following equation: COD deficit = mean 505 time - mean 10 m time.[47]

Thus, the COD deficit % for both sides was calculated as the ratio between average 10 m time and the 505 time,[47] according to this formula:

$$\text{COD deficit \%} = [1 - (10\text{ m} / \text{COD 505})] \times 100$$

Specific endurance

The YYIR1 test was performed as outlined by Krustrup *et al*.[48] A standardized warm up prior to testing was comprised of 10 min of low intensity running, which involved basic run-throughs at an increasing tempo, dynamic stretching, and change of direction activities. The YYIR1 was considered completed if the participant twice failed to reach the finish line in time (objective evaluation) or felt unable to complete another shuttle at the dictated speed (subjective evaluation). The total distance covered during the YYIR1 test was considered as the test “score.”[7, 49]

Statistical analysis

Data are presented as the mean and standard deviation (M±SD) and 95% confidence interval for the mean (CI95%). The assumption of normality was assessed using the Shapiro-Wilk test. To find significant differences among the collected measures performing different testing (dependent variables), the different groups (senior players *vs*. junior players) and the Positional Roles were set as independent variables, and independent sample t-Test and analysis of variance (ANOVA) were then performed. In t-Test the CI95% for the differences are also provided. In ANOVA, subsequent post hoc tests performed with Bonferroni’s correction of significance level were provided. To evaluate possible association between variables, a regression analysis was performed. The values of r, R^2 and line functions are provided. The value of statistical significance was accepted as P≤0.05. IBM SPSS (SPSS Inc., Chicago, IL, USA) 25.0 for Windows was used to analyze and process the collected data. The corresponding p values were provided for each analysis (P≤0.05). The effect size (ES) was determined, and the threshold values for Cohen's ES statistics were classified as trivial (0.0-0.19), small (0.2-0.59), moderate (0.6-1.1), large (1.2-1.9) and very large (>2.0) in *t*-testing.[50] Effect Size (ES) in ANOVA was computed as partial η^2, to assess meaningfulness of differences, with partial $\eta^2<0.01$, $0.01<$ partial $\eta^2<0.06$, $0.06<$ partial $\eta^2<0.14$ and partial $\eta^2>0.14$, as trivial, small, moderate, and large ES, respectively.

Results

Descriptive values of parameters measured and computed – anthropometrics and jumping, power, sprint and agility, aerobic fitness testing – are shown in Table I, II, III, IV, V, together with the analyses of the differences between Senior and Junior players (independent *t*-test). In anthropometrics (Table I), body mass values significantly differ between categories with a moderate amplitude (P=0.021; d=0.75).

Fitness profiles and comparison between groups

In jumping tests (Table II), the values of SJ and CMJ (for both the flight time and the height) significantly differ with a large amplitude (P<0.01; d>1). So does the Stiffness Jump frequency (P=0.01; d=1.17).

In power testing (Table II), all the recorded values, except for the squat speed, significantly differ in senior and junior players, with a large amplitude, highlighting the relevance of these parameters in discriminating the adult players from the younger ones.

We also performed a regression analysis associating the Squat power values and the Bench Press ones, in senior and junior players, respectively (Figure 1, 2). The r values ranging from 0.78, (P<0.001) in senior players and 0.26 (P=0.27) in junior players. These analyses revealed an interesting pattern in senior players, where it seems that a harmonic and balanced growth in power both in upper and in lower limbs occurred (R^2=0.60). Differently appears the situation with the junior players, where the R^2 value of 0.06 witnesses of an independent growth of these body segments, thus setting proper goals in conditioning training, for this age group.

TABLE I.—*Anthropometrics.*

	Senior elite players m±SD [CI95%]	Junior elite players m±SD [CI95%]	Senior *vs*. junior *t*; df; P; ES [CI95% for differences]
Height (m)	1.90 ±0.06* [1.87 - 1.93]	1.86±0.06* [1.83 - 1.89]	1.93; 39; 0.061; 0.66 [0.00 - 0.07]
Body mass (Kg)	94.04±11.60* [88.76 - 99.31]	84.99±12.52* [79.13 - 90.85]	2.40; 39; 0.021;* 0.75 [1.43 - 16.66]
BMI (Kg·m-2)	26.13±2.45* [25.01 - 27.29]	24.56±3.35* [22.99 - 26.13]	1.72; 39; 0.093; 0.53 [-0.27 - 3.42]

P: P value; *t*: independent *t*-test; df: degree of freedom; ES: effect size as Cohen d; m: mean; SD: standard deviation; CI95%: confidence interval for the mean 95%.
*Statistically significant.

TABLE II.—*Jumping and power tests: group profiles and comparison senior-junior players.*

	Senior elite players m±SD [CI95%]	Junior elite players m±SD [CI95%]	Senior *vs*. junior t; df; P; ES [CI95% for differences]
SJ ^{FT} (s)	0.513±0.034 [0.498 - 0.529]	0.473±0.031 [0.458 - 0.487]	3.99; 39; 0.000;* 1.22* [0.020 - 0.061]
SJ ^{H} (m)	0.325±0.042 [0.305 - 0.344]	0.275±0.036 [0.258 - 0.292]	4.00; 39; 0.000;* 1.28* [2.445 - 7.444]
CMJ ^{FT} (s)	0.602±0.03 [0.586 - 0.617]	0.566±0.032 [0.550 - 0.581]	3.49; 39; 0.001;* 1.09* [0.015 - 0.057]
CMJ ^{H} (m)	0.446±0.051 [0.422 - 0.469]	0.393±0.043 [0.373 - 0.413]	3.55; 39; 0.001;* 1.12* [2.267 - 8.270]
Stiffness ^{CT} (s)	0.211±0.032 [0.197 - 0.226]	0.225±0.034 [0.209 - 0.241]	1.32; 39; 0.194; 0.42 [-0.034 - 0.007]
Stiffness ^{H} (m)	0.337±0.077 [0.301 - 0.372]	0.361±0.051 [0.337 - 0.385]	1.19; 39; 0.240; 0.36 [-6.632 - 1.711]
Stiffness power (w·Kg-1)	45.47±8.04 [41.81 - 49.13]	45.21±7.47 [41.71 - 48.70]	0.11; 39; 0.913; 0.03 [-4.645 - 5.177]
Stiffness jump frequency (Hz)	1.429±0.114 [1.377 - 1.481]	1.309±0.089 [1.266 - 1.351]	3.73; 39; 0.001;* 1.17* [0.055 - 0.185]
Stiffness Index	1.591±0.256 [1.474 - 1.707]	1.640±0.343 [1.479 - 1.801]	0.52; 39; 0.605; 0.16 [-0.240 - 0.141]
Squat power (w)	381.40±71.43 [348.71 - 414.10]	257.60±73.29 [223.30 - 291.90]	5.46; 39; 0.000;* 1.71* [77.95 - 169.65]
Squat speed (m·s-1)	0.934±0.150 [0.865 - 1.002]	0.863±0.127 [0.803 - 0.922]	1.62; 39; 0.112; 0.51 [-0.017 - 0.158]
Squat force (N)	644.84±101.77 [598.52 - 691.17]	481.40±98.77 [435.17 - 527.63]	5.21; 39; 0.000;* 1.62* [100.04 - 226.84]
Bench press power (w)	279.28±70.43 [247.22 - 311.35]	178.59±50.99 [154.73 - 202.46]	5.22; 39; 0.000;* 1.64* [61.67 - 139.70]
Bench press speed (m·s-1)	0.768±0.114 [0.716 - 0.819]	0.607±0.184 [0.521 - 0.692]	3.39; 39; 0.002;* 1.05* [0.065 - 0.256]
Bench press force (N)	459.71±81.99 [422.39 - 497.04]	355.31±67.65 [323.64 - 386.97]	4.43; 39; 0.000;* 1.38* [56.78 - 152.02]

SJ: squat jump; CMJ: countermovement jump; FT: flight time; H: height; CT: contact time; *t*: independent *t*-test; df: degree of freedom; P: P value; ES: effect size as Cohen d; m: mean; SD: standard deviation; CI 95%: confidence interval for the mean 95%.
*Statistically significant.

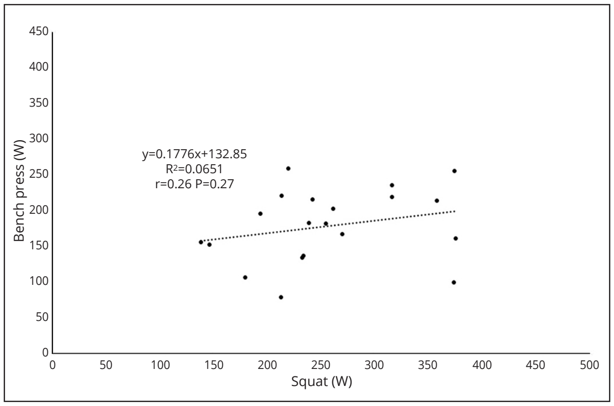


Figure 1.—Regression analysis between squat and bench press: power (W) – senior players.

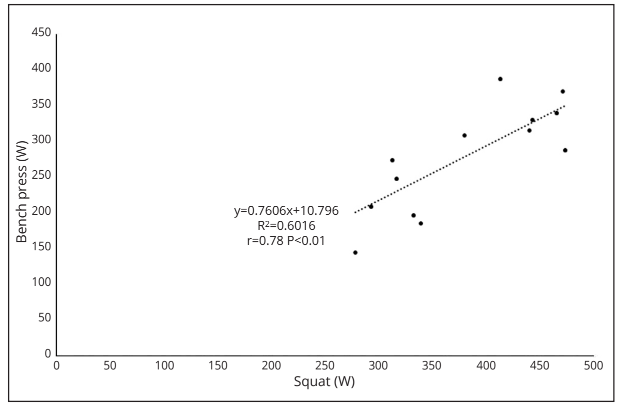


Figure 2.—Regression analysis between squat and bench press: power (W) – junior players.

These concepts are reinforced by the assessment of a simple ratio between upper limbs power and lower limbs, performed both in senior and junior players, according to this formula:

Power % Ratio = [Bench Press Power/Squat Power] * 100

The ratios we found were 73.22% and 69.32% for Senior and Junior players, respectively.

In Sprint and Agility tests (Table III), no significant differences were found between groups, except for the tri-

Table III.—*Sprint, agility (505) and fitness tests: group profiles and comparison senior-junior players.*

	Senior elite player m±SD [CI95%]	Junior elite players m±SD [CI95%]	Senior *vs.* junior t; df; p; ES [CI95% for differences]
505 RT - 10 m (s)	1.859±0.106 [1.794-1.933]	1.878±0.067 [1.846-1.910]	0.63; 31; 0.527; 0.21 [-0.080 - 0.042]
505 RT - COD (s)	2.348±0.159 [2.246-2.458]	2.363±0.130 [2.301-2.424]	0.28; 31; 0.776; 0.10 [-0.118 - 0.088]
505 RT - TT (s)	4.207±0.238 [4.059-4.373]	4.241 ±0.164 [4.164-4.318]	0.48; 31; 0.633; 0.16 [-0.176 - 0.109]
505 RT - COD DEF (s)	0.489±0.129 [0.402-0.573]	0.484±0.126 [0.425-0.543]	0.10; 31; 0.918; 0.03 [-0.087 - 0.097]
505 RT - COD DEF (%)	20.66±4.60 [17.52-23.62]	20.32±4.46 [18.23-22.40]	0.21; 31; 0.834; 0.07 [18.37 - 22.54]
505 LT - 10 m (s)	1.823±0.095 [1.762-1.884]	1.893±0.076 [1.857-1.929]	2.29; 30; 0.029;* 0.81* [-0.132 - -0.007]
505 LT - COD (s)	2.299±0.159 [2.197-2.400]	2.330±0.125 [2.271-2.388]	0.60; 30; 0.548; 0.21 [-0.134 - 0.072]
505 LT - TT (s)	4.122±0.221 [3.981-4.263]	4.223 ±0.164 [4.146-4.300]	1.47; 30; 0.151; 0.52 [-0.241 - 0.039]
505 LT - COD DEF (s)	0.475±0.141 [0.385-0.565]	0.436±0.126 [0.377-0.495]	0.81; 30; 0.422; 0.29 [-0.059 - 0.138]
505 LT - COD DEF (%)	20.47±5.19 [17.17-23.76]	18.60±4.70 [16.39-20.80]	1.04; 30; 0.303; 0.37 [-1.77 - 5.51]
IR1 Yo-Yo: speed (km·h^{-1})	15.97±0.80 [15.59-16.35]	15.32±0.61 [15.04-15.64]	2.94; 38; 0.006;* 0.91* [0.19 - 1.10]
IR1 Yo-Yo: distance (m)	1538.00±493.74 [1306.91-1769.08]	1143.15±362.78 [968.30-1318.01]	2.87; 38; 0.007;* 0.90* [152.57 - 741.02]

505 RT: 505 right turn; 505 RT - COD: right turn changes of direction; 505 RT COD DEF: COD Deficit; 505 LT: 505 left turn; 505 LT - COD: left turn changes of direction; 505 LT COD DEF: COD deficit; *t*: independent *t*-test; df: degree of freedom; P: P value; ES: effect size as Cohen d; m: mean; SD: standard deviation; CI 95%: confidence interval for the mean 95%.
*Statistically significant.

Table IV.—*Anthropometrics per positional roles and comparisons.*

	Goalkeeper m±SD	Back m±SD	Center m±SD	Pivot m±SD	Wing m±SD	ANOVA (F; df; P; p. η^2; power)
Height (m)	1.92±0.07	1.89±0.04	1.89±0.08	1.88±0.03	1.83±0.07	2.41; 4,41; 0.067; 0.21;* 0.63
Body mass (Kg)	95.02±10.35	90.14±13.54	90.90±4.46	98.73±11.03	80.13±11.06	2.82; 4,41; 0.039;* 0.23;* 0.71
BMI (Kg·m^{-2})	25.73±1.80	25.08±3.30	25.84±1.68	28.04±3.18	23.85±2.47	2.13; 4,41; 0.097; 0.19;* 0.57

SD: standard deviation; m: mean; F: F ANOVA; df: degree of freedom; P: P value; p. η^2: effect size as partial η^2 squared; power: statistical power.
*Statistically significant.

als over 10 meters performed before turning on the left (P=0.029; d=0.81).

In aerobic performance, estimated through the IR1 yo-yo test (Table IV), significant differences between groups were found, with a certain amplitude (d≥0.90). We then performed a one-way analysis of variance to establish possible role-related differences among the players. We considered five positional roles: the goalkeeper, the back, the center, the pivot and the wing as independent variables and all the testing results, including the anthropometrics, as the dependent ones. All the relevant results are provided in Table VI.

Anthropometrics

Table IV shows the anthropometrics recorded and sorted by positional roles (m±SD). Significant differences were found, with a large amplitude, in weight measures. We underline the differences in all the recorded parameters found in the wings compared to all the other positional role.

Fitness profiles and comparison among positional roles

Table V and Table VI report the differences found in all the physical testing, underlining several different role-related profiles. P values and partial eta square are significant and

TABLE V.—*Jumping and power tests: positional role profiles and comparison.*

	Goalkeeper m±SD	Back m±SD	Center m±SD	Pivot m±SD	Wing m±SD	ANOVA (F; df; P; p. η²; power)
SJ FT (s)	0.461±0.042	0.505±0.034	0.511±0.023	0.451±0.027	0.511±0.028	5.56; 4,41; 0.001;* 0.38;* 0.96
SJ H (m)	0.262±0.048	0.314±0.042	0.320±0.029	0.251±0.029	0.320±0.036	4.92; 4,41; 0.003;* 0.35;* 0.93
CMJ FT (s)	0.572±0.046	0.590±0.033	0.595±0.010	0.544±0.041	0.603±0.030	3.17; 4,41; 0.025;* 0.26;* 0.77
CMJ H (m)	0.404±0.068	0.427±0.049	0.434±0.014	0.364±0.053	0.446±0.045	2.89; 4,41; 0.036;* 0.24;* 0.72
Stiffness CT (s)	0.241±0.048	0.219±0.034	0.195±0.023	0.213±0.028	0.219±0.029	1.13; 4,41; 0.359; 0.11; 0.32
Stiffness H (m)	0.350±0.031	0.343±0.070	0.307±0.064	0.342±0.074	0.377±0.045	0.89; 4,41; 0.479; 0.09; 0.25
Stiffness power ($w \cdot Kg^{-1}$)	43.17±6.63	44.19±7.83	43.60±5.60	44.58±9.11	49.44±7.61	0.97; 4,41; 0.438; 0.09; 0.27
Stiffness jump Frequency (Hz)	1.32±0.07	1.37±0.14	1.48±0.11	1.36±0.13	1.35±0.09	1.19; 4,41; 0.333; 0.12; 0.33
Stiffness Index	1.50±0.30	1.58±0.32	1.57±0.14	1.63±0.40	1.73±0.29	0.61; 4,41; 0.660; 0.06; 0.18
Squat power (w)	325.53±81.37	327.56±112.42	314.02±81.38	354.81±86.61	290.79±89.35	0.44; 4,36; 0.777; 0.05; 0.141
Squat speed ($m \cdot s^{-1}$)	0.940±0.119	0.867±0.162	0.855±0.082	0.930±0.155	0.929±0.136	0.55; 4,36; 0.699; 0.06; 0.168
Squat force (N)	576.83±115.51	577.64±147.97	563.30±51.22	576.60±102.47	533.05±152.65	0.19; 4,36; 0.938; 0.02; 0.087
Bench press power (w)	216.67±65.90	215.52±96.66	282.53±73.18	242.77±74.78	231.84±62.03	0.62; 4,36; 0.651; 0.06; 0.18
Bench press speed ($m \cdot s^{-1}$)	0.634±0.168	0.629±0.187	0.785±0.049	0.641±0.161	0.804±0.121	2.52; 4,36; 0.058; 0.22; 0.65
Bench press force (N)	399.44±57.18	409.51±117.08	424.747±55.93	443.12±71.48	385.30±85.22	0.40; 4,36; 0.810; 0.04; 0.13

SD: standard deviation; m: mean; F: F ANOVA; df: degree of freedom; P: P value; p. η²: effect size as partial η²; power: statistical power.
*Statistically significant.

TABLE VI.—*Sprint and agility test (COD 505) and fitness test (IR1 Yo-Yo): positional role profiles and comparison.*

	Goalkeeper m±SD	Back m±SD	Center m±SD	Pivot m±SD	Wing m±SD	ANOVA (F; df; P; p. η²; power)
505 RT - 10 m (s)	1.94±0.06	1.84±0.08	1.86±0.07	1.89±0.08	1.87±0.07	1.22; 4,32; 0.325; 0.15;* 0.33
505 RT - COD (s)	2.30±0.18	2.38±0.12	2.29±0.13	2.44±0.17	0.27±0.09	1.51; 4,32; 0.227; 0.18;* 0.40
505 RT - TT (s)	4.24±0.19	4.23±0.20	4.16±0.20	4.34±0.24	4.15±0.11	0.77; 4,32; 0.553; 0.10; 0.21
505 RT - COD DEF (s)	0.36±0.19	0.54±0.08	0.43±0.07	0.55±0.12	0.39±0.12	3.60; 4,32; 0.018;* 0.35;* 0.81
505 RT - COD DEF (%)	15.47±6.65	22.43±2.53	18.53±2.49	22.26±3.59	17.23±4.77	4.15; 4,32; 0.009;* 0.38;* 0.86
505 LT - 10 m (s)	1.94±0.08	1.84±0.09	1.89±0.05	1.90±0.09	1.82±0.09	1.61; 4,32; 0.200; 0.19;* 0.43
505 LT - COD (s)	2.36±0.12	2.33±0.14	2.19±0.08	2.39±0.16	2.25±0.05	1.63; 4,32; 0.196; 0.19;* 0.43
505 LT - TT (s)	4.29±0.13	4.17±0.21	4.07±0.12	4.29±0.22	4.06±0.09	1.69; 4,32; 0.182; 0.20;* 0.48
505 LT - COD DEF (s)	0.42±0.16	0.48±0.12	0.30±0.05	0.49±0.15	0.43±0.12	1.49; 4,32; 0.233; 0.18; 0.40
505 LT - COD DEF (%)	17.65±6.06	20.61±4.32	13.60±20.06	20.26±5.29	19.23±5.06	1.54; 4,32; 0.218; 0.18; 0.41
IR1 Yo-Yo: speed ($km \cdot h^{-1}$)	15.37±0.25	15.27±0.82	16.37±0.25	15.67±0.75	16.10±0.66	3.40; 4,39; 0.019;* 0.29;* 0.80
IR1 Yo-Yo: distance (m)	1050.00±140.00	1114.67±476.14	1780.00±200.00	1380.00±396.58	1616.00±439.47	3.82; 4,39; 0.011;* 0.31;* 0.85

SD: standard deviation; m: mean; 505 RT: 505 right turn; 505 RT - COD: right turn changes of direction; 505 RT COD DEF: COD Deficit 505 LT: 505 left turn; 505 LT - COD: left turn changes of direction; 505 LT COD DEF: COD Deficit; F: F ANOVA; df: degree of freedom; P: P value; p. η²: effect size as partial η²; power: statistical power
*Statistically significant.

large in squat jump and in countermovement jump (SJ, CMJ) for both flight time and height ($P<0.05$; $\eta^2>0.14$). Some effect sizes, reported as η^2 in bench press speed, seems to have some practical implications. Some differences emerged ($P<0.05$; $\eta^2>0.14$) suggesting practical implications. In this context the centers and the wings seem to have a better aerobic condition than the other roles.

Discussion

To our knowledge this is the first study that analyzed the fitness profile of Italian elite handball players. The results revealed significant and practical differences between competitive level and playing roles across relevant handball variables.

Team handball has a complex dynamic structure, where the level of specialization required for different roles is very high.[51-53] This level of specialization requires special attention when designing training interventions aimed at the specific development of certain game skills, being them physical, technical or tactical. In our study we considered five different roles, assuming similar demands for comparable roles.[4] Actually, we should also consider the requests from different game systems, where players might be called to develop different motor tasks depending on the game tactic adopted. The technical staff must therefore have a deep knowledge of the skills required to the different players in relation to the role and the game system, to optimize their performance, through proper training routines. The same concept applies to the coaching procedures to be considered when dealing with the junior players or the senior ones, considering the different maturity status. We should reinforce the concept that in order to maximize the outcome of any training process, coaches should be aware of the importance of the individualization, the specificity and the progressivity principles of training.[54, 55]

Anthropometrics

Anthropometrics values seems to confirm the relevance of such measures on the maturity status of the players (*i.e.,* senior *vs*. junior players); in this context, weight measures are the most discriminating ones. Anthropometrics play an important role in drawing role-related profiles, being the wings the shortest and the lightest players with a smaller BMI, among the others. The observed effect size values suggest of practical implications of these findings in the process of training and selecting players. To sum up, anthropometrics is important in handball, as reported in several studies[56-59] highlighting different body sizes to be selected and specialized for positional role-related, purposes (*i.e.,* bigger sizes in Pivots and Goalkeepers, lighter and shorter ones in Wings; Table IV). It seems of a practical implication the difference we found in body mass between senior and junior players (Table I), thus considering the relevance of a certain bodybuilding to be designed in adult players, while maintaining BMI within a substantial parity between ages.

Strength of lower limbs

Explosive strength of lower limbs measured through the Bosco's jumping test protocols,[24, 30-32, 60] revealed a substantial superiority of the senior players compared with the Junior ones, in SJ and in CMJ. Explosive strength of lower limbs is a major goal to be achieved through the opportune methodologies of training over the fundamental period of growth of young players.[61, 62]

Positional role-related differences were also observed (Table V), suggesting specific path of training while dealing with these motor abilities. Dynamic and explosive strength in lower limbs are crucial components in handball performance,[63, 64] witnessing the relevance of some related skills, such as sprinting, jumping and bouncing (Table II, V). The significance and the magnitude of the differences we found between ages ($P<0.001$; $d>1$) in SJ and CMJ suggest practical implications to be considered when designing plurennial training plans.

Power

Senior players lower and upper limbs power values were significantly ($P<0,001$) and practically ($d>1$ large magnitude), higher than Junior players ($P<0,001$). This suggesting specific goals to be achieved when dealing with young elite-players' training. This result is reinforced by the regression analysis we performed, where correlated upper and lower limbs power values differed significantly between senior and junior players (Figure 1, 2). No significant differences were found among positional roles in power values, suggesting equal relevance of power variables across the playing roles.[63]

Lower and upper limbs power is crucial in handball performance.[63] Indeed, the ability to move fast over the court to win opponent resistance and to throw with efficacy the ball with speed and precision are fundamental in handball.[63] The large magnitude in differences found between competitive levels ($d>1$) suggests the need of specific and intensive training aimed at properly develop these relevant abilities in youth handball.[65]

Sprinting and agility

No significant differences were found between senior and junior players while considering several parameters describing sprinting and agility skills, indicating these abilities as the most important in this sport discipline under a physical standpoint (Table III).[66-68] Significant differences were found in the ability of sprinting and in agility tasks (*i.e.,* turning rapidly or changing of direction) while referred to the positional roles (Table VI). This aspect suggests practical implications in designing and administering training processes. The ability to sprint and accelerate and to change direction with agility is crucial in handball.[66-68] Most of the practices and drills designed for training purposes rely on the exploitation of these motor skills. The absence of differences between senior and junior players in these abilities sustain the relevance of sprinting and agility skills, as the primary performance component since the very childhood of players. The coordinative nature of agility suggests the need of an early intervention on this ability (*i.e.,* 6-14 years),[69, 70] together with the proper development of muscle power, this latter to be designed in later stages.

Aerobic fitness

The aerobic performance tested through the YYIR1 revealed interesting differences between ages (senior *vs*. junior players; Table III) and among positional roles (Table VI). The aerobic components of handball, although not primarily involved in the physiological pathways while performing at high intensity, as it happens with the anaerobic ones, are nonetheless very important in handball, as suggested by several authors.[6, 13, 71] These differences highlight the need of a robust aerobic fitness, especially in wings and in centers. In the specific context of Italian handballers, the recorded values denote not optimal levels reached by these players when compared to other international handball players.[72, 73] A general aerobic fitness seems to be relevant to determine an excellent status of the players in terms of efficiency during games and tournaments. Therefore, the need of designing specific training programs aimed at improving this capacity is emphasized.

Conclusions

Based on the present results, the current performance profiles of Italian elite handball players, analyzed under the standpoints of age (senior *vs*. junior players) and the positional roles, are provided. The differences we found and their magnitude, confirm the need of individual approach of training, especially when dealing with the young handball players, to properly develop the physical abilities required for this sport discipline, such as explosive strength, power, sprinting abilities, and agility. Very important seems to be the aerobic components of performance, in order to keep a high level of efficiency, especially for the positive effects on repeated sprint ability,[74, 75] both in the game and in tournaments.

References

1. Wagner H, Finkenzeller T, Würth S, von Duvillard SP. Individual and team performance in team-handball: a review. J Sports Sci Med 2014;13:808–16.

2. Bragazzi NL, Rouissi M, Hermassi S, Chamari K. Resistance Training and Handball Players' Isokinetic, Isometric and Maximal Strength, Muscle Power and Throwing Ball Velocity: A Systematic Review and Meta-Analysis. Int J Environ Res Public Health 2020;17:E2663.

3. Rannou F, Prioux J, Zouhal H, Gratas-Delamarche A, Delamarche P. Physiological profile of handball players. J Sports Med Phys Fitness 2001;41:349–53.

4. Sporis G, Vuleta D, Vuleta D Jr, Milanović D. Fitness profiling in handball: physical and physiological characteristics of elite players. Coll Antropol 2010;34:1009–14.

5. Massuca L, Branco B, Miarka B, Fragoso I. Physical Fitness Attributes of Team-Handball Players are Related to Playing Position and Performance Level. Asian J Sports Med 2015;6:e24712.

6. Rousanoglou EN, Noutsos KS, Bayios IA. Playing level and playing position differences of anthropometric and physical fitness characteristics in elite junior handball players. J Sports Med Phys Fitness 2014;54:611–21.

7. Hermassi S, Laudner K, Schwesig R. Playing Level and Position Differences in Body Characteristics and Physical Fitness Performance Among Male Team Handball Players. Front Bioeng Biotechnol 2019;7:149.

8. Chaouachi A, Brughelli M, Levin G, Boudhina NB, Cronin J, Chamari K. Anthropometric, physiological and performance characteristics of elite team-handball players. J Sports Sci 2009;27:151–7.

9. Ghobadi H, Rajabi H, Farzad B, Bayati M, Jeffreys I. Anthropometry of World-Class Elite Handball Players According to the Playing Position: Reports From Men's Handball World Championship 2013. J Hum Kinet 2013;39:213–20.

10. Krüger K, Pilat C, Uckert K, Frech T, Mooren FC. Physical performance profile of handball players is related to playing position and playing class. J Strength Cond Res 2014;28:117–25.

11. Nikolaidis PT, Ingebrigtsen J, Póvoas SC, Moss S, Torres-Luque G. Physical and physiological characteristics in male team handball players by playing position - Does age matter? J Sports Med Phys Fitness 2015;55:297–304.

12. Póvoas SC, Ascensão AA, Magalhães J, Seabra AF, Krustrup P, Soares JM, *et al.* Physiological demands of elite team handball with special reference to playing position. J Strength Cond Res 2014;28:430–42.

13. Póvoas SC, Seabra AF, Ascensão AA, Magalhães J, Soares JM, Rebelo AN. Physical and physiological demands of elite team handball. J Strength Cond Res 2012;26:3365–75.

14. Massuça L, Fragoso I. Morphological characteristics of adult male handball players considering five levels of performance and playing position. Coll Antropol 2015;39:109–18.

15. Massuça LM, Fragoso I, Teles J. Attributes of top elite team-handball players. J Strength Cond Res 2014;28:178–86.

16. Moss SL, McWhannell N, Michalsik LB, Twist C. Anthropometric and physical performance characteristics of top-elite, elite and non-elite youth female team handball players. J Sports Sci 2015;33:1780–9.

17. Michalsik LB, Aagaard P, Madsen K. Technical activity profile and influence of body anthropometry on playing performance in female elite team handball. J Strength Cond Res 2015;29:1126–38.

18. Michalsik LB, Madsen K, Aagaard P. Technical match characteristics and influence of body anthropometry on playing performance in male elite team handball. J Strength Cond Res 2015;29:416–28.

19. Michalsik LB, Aagaard P. Physical demands in elite team handball: comparisons between male and female players. J Sports Med Phys Fitness 2015;55:878–91.

20. Michalsik LB, Madsen K, Aagaard P. Physiological capacity and physical testing in male elite team handball. J Sports Med Phys Fitness 2015;55:415–29.

21. Michalsik LB, Aagaard P, Madsen K. Locomotion characteristics and match-induced impairments in physical performance in male elite team handball players. Int J Sports Med 2013;34:590–9.

22. Castagna C, Chaouachi A, Rampinini E, Chamari K, Impellizzeri F. Aerobic and explosive power performance of elite italian regional-level basketball players. J Strength Cond Res 2009;23:1982–7.

23. Lockie RG, Liu TM, Stage AA, Lazar A, Giuliano DV, Hurley JM, *et al.* Assessing Repeated-Sprint Ability in Division I Collegiate Women Soccer Players. J Strength Cond Res 2020;34:2015–23.

24. Komi PV, Bosco C. Utilization of stored elastic energy in leg extensor muscles by men and women. Med Sci Sports 1978;10:261–5.

25. Bosco C, Komi PV, Tihanyi J, Fekete G, Apor P. Mechanical power test and fiber composition of human leg extensor muscles. Eur J Appl Physiol Occup Physiol 1983;51:129–35.

26. Bosco C, Luhtanen P, Komi PV. A simple method for measurement of mechanical power in jumping. Eur J Appl Physiol Occup Physiol 1983;50:273–82.

27. Bosco C, Tihanyi J, Komi PV, Fekete G, Apor P. Store and recoil of elastic energy in slow and fast types of human skeletal muscles. Acta Physiol Scand 1982;116:343–9.

28. Bosco C, Tarkka I, Komi PV. Effect of elastic energy and myoelectrical potentiation of triceps surae during stretch-shortening cycle exercise. Int J Sports Med 1982;3:137–40.

29. Bosco C, Viitasalo JT, Komi PV, Luhtanen P. Combined effect of elastic energy and myoelectrical potentiation during stretch-shortening cycle exercise. Acta Physiol Scand 1982;114:557–65.

30. Bosco C, Ito A, Komi PV, Luhtanen P, Rahkila P, Rusko H, *et al.* Neuromuscular function and mechanical efficiency of human leg extensor muscles during jumping exercises. Acta Physiol Scand 1982;114:543–50.

31. Bosco C, Komi PV, Ito A. Prestretch potentiation of human skeletal muscle during ballistic movement. Acta Physiol Scand 1981;111:135–40.

32. Bosco C, Komi PV. Mechanical characteristics and fiber composition of human leg extensor muscles. Eur J Appl Physiol Occup Physiol 1979;41:275–84.

33. Bosco C, Komi PV. Potentiation of the mechanical behavior of the human skeletal muscle through prestretching. Acta Physiol Scand 1979;106:467–72.

34. Bosco C, Montanari G, Tarkka I, Latteri F, Cozzi M, Iachelli G, *et al.* The effect of pre-stretch on mechanical efficiency of human skeletal muscle. Acta Physiol Scand 1987;131:323–9.

35. Bosco C, Montanari G, Ribacchi R, Giovenali P, Latteri F, Iachelli G, *et al.* Relationship between the efficiency of muscular work during jumping and the energetics of running. Eur J Appl Physiol Occup Physiol 1987;56:138–43.

36. Arede J, Figueira B, Gonzalo-Skok O, Leite N. Validity and reliability of Gyko Sport for the measurement of barbell velocity on the bench-press exercise. J Sports Med Phys Fitness 2019;59:1651–8.

37. Lesinski M, Muehlbauer T, Granacher U. Concurrent validity of the Gyko inertial sensor system for the assessment of vertical jump height in female sub-elite youth soccer players. BMC Sports Sci Med Rehabil 2016;8:35.

38. Król H, Golas A, Sobota G. Complex analysis of movement in evaluation of flat bench press performance. Acta Bioeng Biomech 2010;12:93–8.

39. Stock MS, Beck TW, DeFreitas JM, Dillon MA. Test-retest reliability of barbell velocity during the free-weight bench-press exercise. J Strength Cond Res 2011;25:171–7.

40. Emmonds S, Nicholson G, Begg C, Jones B, Bissas A. Importance of Physical Qualities for Speed and Change of Direction Ability in Elite Female Soccer Players. J Strength Cond Res 2019;33:1669–77.

41. Buchheit M, Simpson BM, Peltola E, Mendez-Villanueva A. Assessing maximal sprinting speed in highly trained young soccer players. Int J Sports Physiol Perform 2012;7:76–8.

42. Ruscello B, Esposito M, Partipilo F, Di Cicco D, Filetti C, Pantanella L, *et al.* Exercise-to-rest ratios in repeated sprint ability training in women's soccer. J Sports Med Phys Fitness 2018;58:1790–9.

43. Ruscello B, Partipilo F, Pantanella L, Esposito M, D'Ottavio S. The optimal exercise to rest ratios in repeated sprint ability training in youth soccer players. J Sports Med Phys Fitness 2016;56:1465–75.

44. Ruscello B, Briotti G, Tozzo N, Partipilo F, Taraborelli M, Zeppetella A, *et al.* Acute effects of two different initial heart rates on testing the Repeated Sprint Ability in young soccer players. J Sports Med Phys Fitness 2015;55:1082–90.

45. Ruscello B, Tozzo N, Briotti G, Padua E, Ponzetti F, D'Ottavio S. Influence of the number of trials and the exercise to rest ratio in repeated sprint ability, with changes of direction and orientation. J Strength Cond Res 2013;27:1904–19.

46. Sayers MG. Influence of Test Distance on Change of Direction Speed Test Results. J Strength Cond Res 2015;29:2412–6.

47. Nimphius S, Callaghan SJ, Spiteri T, Lockie RG. Change of Direction Deficit: A More Isolated Measure of Change of Direction Performance Than Total 505 Time. J Strength Cond Res 2016;30:3024–32.

48. Krustrup P, Mohr M, Amstrup T, Rysgaard T, Johansen J, Steensberg A, *et al.* The yo-yo intermittent recovery test: physiological response, reliability, and validity. Med Sci Sports Exerc 2003;35:697–705.

49. Castagna C, Impellizzeri FM, Chamari K, Carlomagno D, Rampinini E. Aerobic fitness and yo-yo continuous and intermittent tests performances in soccer players: a correlation study. J Strength Cond Res 2006;20:320–5.

50. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 2009;41:3–13.

51. Teques P, Araújo D, Seifert L, Del Campo VL, Davids K. The resonant system: linking brain-body-environment in sport performance□. Prog Brain Res 2017;234:33–52.

52. Araújo D, Davids K. Team Synergies in Sport: theory and Measures. Front Psychol 2016;7:1449.

53. Fonseca S, Milho J, Travassos B, Araújo D. Spatial dynamics of team sports exposed by Voronoi diagrams. Hum Mov Sci 2012;31:1652–9.

54. Woods CT, McKeown I, Shuttleworth RJ, Davids K, Robertson S. Training programme designs in professional team sport: an ecological dynamics exemplar. Hum Mov Sci 2019;66:318–26.

55. Stone M, Plisk S, Collins D. Training principles: evaluation of modes and methods of resistance training—a coaching perspective. Sports Biomech 2002;1:79–103.

56. Cichy I, Dudkowski A, Kociuba M, Ignasiak Z, Sebastjan A, Kochan K, *et al.* Sex Differences in Body Composition Changes after Preseason Training in Elite Handball Players. Int J Environ Res Public Health 2020;17:E3880.

57. Ohlendorf D, Salzer S, Haensel R, Rey J, Maltry L, Holzgreve F, *et al.* Influence of typical handball characteristics on upper body posture and postural control in male handball players. BMC Sports Sci Med Rehabil 2020;12:4.

58. Lijewski M, Burdukiewicz A, Pietraszewska J, Stachoń A, Andrzejewska J, Chromik K. Anthropometric and strength profiles of professional handball players in relation to their playing position - multivariate analysis. Acta Bioeng Biomech 2019;21:147–55.

59. Camacho-Cardenosa A, Camacho-Cardenosa M, González-Custodio A, Martínez-Guardado I, Timón R, Olcina G, *et al.* Anthropometric and Physical Performance of Youth Handball Players: The Role of the Relative Age. Sports (Basel) 2018;6:E47.

60. Viitasalo JT, Bosco C. Electromechanical behaviour of human muscles in vertical jumps. Eur J Appl Physiol Occup Physiol 1982;48:253–61.

61. Tillaar RV, Roaas TV, Oranchuk D. Comparison of effects of training order of explosive strength and plyometrics training on different physical abilities in adolescent handball players. Biol Sport 2020;37:239–46.

62. McQuilliam SJ, Clark DR, Erskine RM, Brownlee TE. Free-Weight Resistance Training in Youth Athletes: A Narrative Review. Sports Med 2020;50:1567–80.

63. Bøgild P, Jensen K, Kvorning T. Physiological Performance Characteristics of Danish National Team Handball Players 1990-2016: Implications on Position-Specific Strength and Conditioning Training. J Strength Cond Res 2020;34:1555–63.

64. Wagner H, Fuchs PX, von Duvillard SP. Specific physiological and biomechanical performance in elite, sub-elite and in non-elite male team handball players. J Sports Med Phys Fitness 2018;58:73–81.

65. Spieszny M, Zubik M. Modification of Strength Training Programs in Handball Players and its Influence on Power During the Competitive Period. J Hum Kinet 2018;63:149–60.

66. Rühlemann A, Mayer C, Haversath M, Jäger M. Functional Knee Performance Differences in Handball are Depending on Playing Class. Int J Sports Med 2020;41:652–60.

67. Negra Y, Chaabene H, Hammami M, Amara S, Sammoud S, Mkaouer B, *et al.* Agility in Young Athletes: Is It a Different Ability From Speed and Power? J Strength Cond Res 2017;31:727–35.

68. Spasic M, Krolo A, Zenic N, Delextrat A, Sekulic D. Reactive Agility Performance in Handball; Development and Evaluation of a Sport-Specific Measurement Protocol. J Sports Sci Med 2015;14:501–6.

69. Wagner H, Sperl B, Bell JW, von Duvillard SP. Testing Specific Physical Performance in Male Team Handball Players and the Relationship to General Tests in Team Sports. J Strength Cond Res 2019;33:1056–64.

70. Solum M, Lorås H, Pedersen AV. A Golden Age for Motor Skill Learning? Learning of an Unfamiliar Motor Task in 10-Year-Olds, Young Adults, and Adults, When Starting From Similar Baselines. Front Psychol 2020;11:538.

71. Michalsik LB, Madsen K, Aagaard P. Match performance and physiological capacity of female elite team handball players. Int J Sports Med 2014;35:595–607.

72. Hermassi S, Aouadi R, Khalifa R, van den Tillaar R, Shephard RJ, Chelly MS. Relationships between the yo-yo intermittent recovery test and anaerobic performance tests in adolescent handball players. J Hum Kinet 2015;45:197–205.

73. Schmitz B, Pfeifer C, Kreitz K, Borowski M, Faldum A, Brand SM. The Yo-Yo Intermittent Tests: A Systematic Review and Structured Compendium of Test Results. Front Physiol 2018;9:870.

74. Bishop D, Girard O, Mendez-Villanueva A. Repeated-sprint ability - part II: recommendations for training. Sports Med 2011;41:741–56.

75. Girard O, Mendez-Villanueva A, Bishop D. Repeated-sprint ability - part I: factors contributing to fatigue. Sports Med 2011;41:673–94.

Conflicts of interest.—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions.—Bruno Ruscello, Carlo Castagna, Stefano D'ottavio. Methodology: Bruno Ruscello, Carlo Castagna and Stefano D'Ottavio have given substantial contributions to study conception and supervision and to formal analysis; Bruno Ruscello, Carlo Castagna, Riccardo Carbonaro, Paolo R. Gabrielli and Stefano D'Ottavio gave contributions to investigation; Bruno Ruscello, Riccardo Carbonaro and Paolo R. Gabrielli have given contributions to data curation; Bruno Ruscello and Carlo Castagna contributed to manuscript original draft preparation and to manuscript revision and editing. All authors read and approved the final version of the manuscript.

Acknowledgements.—The authors acknowledge the head coach Riccardo Trillini and coach Giuseppe Tedesco for their precious contributions to this study and all the players and the technical staff belonging to the Italian Handball National Teams, participating in this study.

History.—Article first published online: January 22, 2021. - Manuscript accepted: January 8, 2021. - Manuscript revised: December 17, 2020. - Manuscript received: October 6, 2020.

© 2021 EDIZIONI MINERVA MEDICA
Online version at https://www.minervamedica.it

The Journal of Sports Medicine and Physical Fitness 2022 May;62(5):618-25
DOI: 10.23736/S0022-4707.21.12282-0

ORIGINAL ARTICLE
EXERCISE PHYSIOLOGY AND BIOMECHANICS

Talent development environments in elite taekwondo population: a study within an Italian context

Gennaro APOLLARO [1] *, Laura PANTANELLA [1], Mario ESPOSITO [1], Bruno RUSCELLO [1, 2, 3, 4]

[1]School of Sport Sciences and Exercise, Faculty of Medicine and Surgery, Tor Vergata University, Rome, Italy; [2]School of Sports and Exercise Sciences, Vita-Salute San Raffaele University, Rome, Italy; [3]Department of Industrial Engineering, Faculty of Engineering, Tor Vergata University, Rome, Italy; [4]LUISS SportLab, LUISS University, Rome, Italy

*Corresponding author: Gennaro Apollaro, School of Sport Sciences and Exercise, Faculty of Medicine and Surgery, Tor Vergata University, Via Montpellier 1, 00133 Rome, Italy. E-mail: gen.2012.ita@hotmail.com

ABSTRACT

BACKGROUND: The aim of this study was to analyze the quality perception of the main talent development environments within the elite taekwondo population, through the Talent Development Environment Questionnaire (TDEQ-5).
METHODS: The TDEQ-5 was given to 107 top level athletes from the Italian National Team and from 12 domestic clubs. An exploratory factor analysis (EFA) was carried out and the descriptive statistics were measured for all the individual item scores; for each factor the independent *t*-tests were carried out to identify differences in scores between the National and the Club environments.
RESULTS: The EFA revealed four principal components (56.68%). These four factors reported good reliability values (α= from 0.63 to 0.93) and significant correlations. The development environments were positively perceived by the athletes, with factor 1 being the highest performing component and factor 2 the weakest. Factor 1 was identified as the strength of the Club environment, while factor 2 as the area of improvement for the National environment. The scale values of factors 1, 2 and 3 were significantly higher ($P<0.01$) in the Club environment. The item-by-item analysis revealed the presence of three strengths and six areas of improvement in the national environment, eleven strengths and no areas of improvement in the Club environment.
CONCLUSIONS: Our study highlights the strengths and weaknesses of the different development environments surveyed and may allow to plan targeted interventions to increase the perception of quality of the talent development environments, thus allowing the stakeholders to optimize their work.

(*Cite this article as:* Apollaro G, Pantanella L, Esposito M, Ruscello B. Talent development environments in elite taekwondo population: a study within an Italian context. J Sports Med Phys Fitness 2022;62:618-25. DOI: 10.23736/S0022-4707.21.12282-0)

Key words: Aptitude; Education; Sports; Exercise.

For several years, researchers have stressed the importance of understanding the processes of talent development, rather than identification and selection, as recruiting athletes who distinguish themselves in certain parameters at a given time, is not the most productive and sustainable methodology.[1-6] Indeed, several studies have shown that this is illusory because of the complexity of implementing it, especially in periods of prepubertal or puberty growth.[7-10]

Therefore, the researchers turned their attention to understand the environmental characteristics of effective talent development because the environment, and the way in which it is configured and may support talent development, is considered a determining factor for sporting success.[11-16]

Martindale *et al.*[17] based on interviews with athletes, coaches and sports psychologists, developed the Talent Development Environment Questionnaire (TDEQ), a Likert scale psychometric questionnaire, to quantify and understand athletes' perceptions of the quality of development environments, with the aim of monitoring and strengthening talent development practices. The questionnaire consists of 59 items grouped into 7 factors including: "long-term development focus," "quality preparation," "communication," "understanding the athlete," "support network," "challenging and supportive environment," "long-term development fundamentals." Martindale *et al.*,[18] studying the ecological validity of the questionnaire, found that "quality preparation" and "athlete understanding" were the main discriminating factors in the effectiveness of British sports academies of swimming and rugby in terms of progression of players to the senior elite level.

The development of TDEQ has led several researchers to use it to fill gaps in multiple research areas: for example, Wang *et al.*[19] used it to study the impact of environmental factors on athletes' goals, Li *et al.*[20] to explore the relationship between the talent development environment and mental toughness. Other studies focused on reviewing the factorial structure of TDEQ with the aim of improving its psychometric properties as the factor "long-term development focus" contained a large number of items and, in addition, there was a conceptual overlap between some factors. From the study by Wang *et al.*,[19] a 6-factor structure emerged with 36 items studied, subsequently, by Li *et al.*[21] through exploratory and confirmatory factorial analysis, because it was a relatively new scale. The exploratory factorial analysis led to a 5-factor structure with 28 items and good reliability (α= from 0.79 to 0.86), called the Talent Development Environment Questionnaire (TDEQ-5). The five factors were labelled as: "long-term development focus," "alignment of expectations," "communication," "holistic quality preparation" and "support network." However, the authors, although they concluded that TDEQ-5 was an easier questionnaire to use to assess talent development environments, suggested further examining its psychometric properties in future research.

The relevance of a specific tool for assessing the influence of the environment on talent development processes was highlighted by several researchers from several countries who, at the same time, stressed the absence of such a tool for their language. To this end, it was considered appropriate and efficient to adapt the TDEQ as a known, valid and reliable tool to assess the main characteristics of talent development environments in different national contexts;[22-27] thus, allowing intercultural comparisons and to further examine the psychometric properties of the questionnaire both in its original form[17] and in subsequent versions.[19, 21]

In line with the above, the objective of this study was to develop a first Italian version of TDEQ-5[21] to analyze its psychometric properties and to study the perception of the quality of the main talent development environments, within the elite taekwondo population, in athletes belonging to the National Team of the Italian Taekwondo Federation (FITA) and to some of the best national Amateur Sports Associations (ASA) or domestic Clubs.

Materials and methods

Participants

One hundred and seven (107) black belt taekwondo athletes (age: 19.66±3.90 years), belonging to the junior and senior categories volunteered to participate in this study. Specifically, one part of the population consisted of 47 athletes (age: 19.98±2.68 years) of the Italian National Team; the other part of the population included 60 athletes (age=19.46±4.68 years) of twelve ASA, affiliated with FITA for the 2018/2019 season, from four Italian regions (Calabria =3; Puglia =4; Lazio =4; Veneto =1).

In line with the characteristics for which the questionnaire was designed,[17, 19, 21] all participants were considered athletes with identified potential, engaged in development and in active competitive national and / or international competitions, in the season 2018/2019. Secondly, ASAs were recruited from northern (N=1), central (N=4) and southern (N=7) regions to involve geographically diverse development environments. Details of the population composition by development environment are given in Table I.

Written informed consent was obtained from all the participants after familiarization and explanation of the benefit and risks involved in the procedures of this study. All participants were informed that they were free to withdraw from the study at any time without penalty. The Institutional Research Board (the Ethical Committee of the School of Sports and Exercise Sciences, Tor Vergata University, Rome, Italy, Faculty of Medicine and Surgery) approved our research protocol and provided clearance for the procedures before the commencement of this study. All procedures were carried out in accordance with the Declaration of Helsinki of the World Medical Association[28] as regards the conduct of clinical research.

TABLE I.—*Sample biodata.*

Variables	Total sample (N.=107)	National team (N.=47)	ASA (N.=60)
Male, N. (%)	59 (55.1%)	26 (55.3%)	33 (55%)
Female, N. (%)	48 (44.9%)	21 (44.7%)	27 (45%)
Beginning age (years; M±SD)	7.79±4.1	7.13±2.82	8.32±4.90

Measures

Talent Development Environment Questionnaire-5

The Talent Development Environment Questionnaire (TDEQ-5)[21] is a 6-point Likert Scale psychometric questionnaire (1= "strongly disagree;" 6= "strongly agree") with five main factors so labeled. Factor 1 – "long-term development:" six items related to the extent to which the development programs are specifically designed to facilitate the long-term success of the athletes (*e.g.*, "My training is specifically designed to help me develop effectively in the long term"). Factor 2 – "holistic quality preparation:" seven items (all formulated in a negative way) relating to the extent to which the intervention programs are prepared both inside and outside the sports facilities (*e.g.*, "I am rarely encouraged to plan for how I would deal with things that might go wrong"). Factor 3 – "support network:" six items related to the extent to which a coherent, accessible and wide-ranging support network is available to the athletes in all areas (*e.g.*, "I can pop in to see my coach or other support staff whenever I need to"). Factor 4 – "communication:" four items related to the extent to which the coach communicates effectively with the athlete in both formal and informal contexts (*e.g.*, "My coach and I regularly talk about things I need to do to progress to the top level in my sport"). Factor 5 – "alignment of expectations:" five items relating to the extent to which the objectives for sports development are consistently set and aligned (*e.g.*, "The advice my parents give me fits well with the advice I get from my coaches").

The TDEQ-5 was translated from English into Italian by the authors of this study, independently. With the aim of producing a conceptually and semantically comprehensible translation, equivalent to the original questionnaire, they discussed the translations about some words, concepts and terms used, in order to eventually agree on a single version. After, an intermediate step of backward translation of the Italian TDEQ-5 was carried out to create a comparison with the original English TDEQ-5 and detect any misunderstandings or inaccuracies in the translation process.[22] The next step was a short cognitive interview[29] with a sample of ten subjects (15-25 years old) to verify the comprehensibility of the scale in general ("Did you have difficulty filling in the questionnaire?") and of the items ("Which questions did you have difficulty understanding?" "Did they all seem understandable to you?"). No subsequent changes were requested.

Procedures

The questionnaires were administered to the National Team in the period of December 2018 - January 2019, during four technical meetings, held in this time frame. The compilation was completed at the Giulio Onesti Olympic Training Center in Rome, Italy, before the morning training session, under the supervision of the coach and the researchers. Unlike the National Team, the ASA athletes filled in the questionnaire online, using "Google Modules," to facilitate the involvement of geographically different development environments. The questionnaires were administered in the period from December 2018 to January 2019, in conjunction with that of the National Team.

Statistical analysis

The Exploratory Factor Analysis (EFA) was carried out with the principal component analysis (PCA) extraction method on the overall population (N.=107) to find the latent factors in all the proposed items (N.=28); the Promax oblique rotation method (k=4) was used to make the factorial solution more interpretable.[30] In order to evaluate the reliability of the individual factors, a reliability analysis was carried out by calculating Cronbach's alpha (α). Pearson's correlation was calculated to determine the relationship between the individual factors. Descriptive statistics (mean±standard deviation) were measured for all individual item scores and for each factor (negatively formulated items were counted in reverse). Independent sample *t*-tests were performed to identify possible differences between the two analyzed development environments and to determine the magnitude of the effect of the differences the Cohen's *d* was calculated, with the following values: $d<0.20$; $0.21<d<0.50$; $0.51<d<0.80$; $0.81<d<1$; $d > 1$, considered respectively as null, small, medium, large and giant effects. Statistical significance was accepted with $P<0.05$. All the data were tabulated in a spreadsheet designed for this purpose in Microsoft Excel for Windows (Microsoft Corp., Redmond, WA, USA) and then processed using the IBM SPSS 25 software (SPSS Inc., Chicago, IL, USA).

Results

Principal component analysis

Bartlett's sphericity test was significant [$\chi^2(378)=1599.30$; $P<0.0001$], thus allowing to reject the null hypothesis that the correlation matrix was an identity matrix, while the KMO sample adequacy index was satisfactory (0.90). From the PCA, seven factors emerged that explained

TABLE II.—*Principal component analysis: variance explained.*

Factor	Initial eigenvalues			Extraction sums of squared			Rotation
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total
1	11.26	40.20	40.20	11.26	40.20	40.20	10.16
2	1.87	6.66	46.86	1.87	6.66	46.86	7.18
3	1.53	5.46	52.32	1.53	5.46	52.32	6.17
4	1.22	4.36	56.68	1.22	4.36	56.68	3.92
5	1.11	3.95	60.63	1.11	3.95	60.63	4.82
6	1.05	3.73	64.36	1.05	3.73	64.36	2.00
7	1.02	3.63	67.99	1.02	3.63	67.99	1.33

Extraction method: principal component analysis.

TABLE III.—*Principal component analysis: pattern matrix.*

Items	Factor						
	1	2	3	4	5	6	7
Item 25	0.86						
Item 19	0.83						
Item 22	0.83						
Item 28	0.78						
Item 21	0.76						
Item 26	0.76						
Item 7	0.71						
Item 8	0.61						
Item 17	0.60						
Item 13	0.60						
Item 6	0.57						
Item 5		0.74					
Item 3		0.74					
Item 11		0.71					
Item 16		0.42					
Item 27		0.38					
Item 20			0.74				
Item 15			0.68				
Item 24			0.57				
Item 14			0.47				
Item 9				0.90			
Item 18				0.87			
Item 1				0.39			
Item 23					0.85		
Item 12					0.63		
Item 2						0.93	
Item 4						0.44	
Item 10							0.89

67.99% of the variance, with saturations not less than 0.38. However, from the saturation matrix a strong representativeness of the original structure of TDEQ-5 was identified, within the first four factors, that explained most of the variance (56.68%) (Table II, III).

Italian TDEQ version

For interpretation purposes, in this exploratory phase it was decided not to exclude any item and not to factor in with a number of items less than or equal to three. Therefore, item 23 was included in the third factor, item 12 in the fourth factor and items 2, 4 and 10 in the second factor, because they had a good semantic affinity with these factors.[17, 19, 21]

These four factors, so organized, have been labeled:

- factor 1 – "long-term development," which combines the two factors "long-term development" and "communication" of the original questionnaire in one dimension and includes eleven items (two formulated in a negative way) related to the extent to which the coach and staff specifically design development programs and communicate successfully to facilitate the long-term success of the athletes;
- factor 2 – "holistic quality preparation" includes four items of the "holistic quality preparation" of the original questionnaire with a total of eight items (four formulated in a negative way), related to the extent to which the intervention programs are prepared both inside and outside the sports facilities;
- factor 3 – "alignment of expectations" includes three items of the "alignment of expectations" factor of the original questionnaire, with a total of five items related to the extent to which the goals for sports development are consistently set and aligned;
- factor 4 – "support network" contains three "support network" items from the original questionnaire with a total of four items (one negatively formulated) related to the extent to which a consistent, accessible and broad-based support network is available to the athlete.

The reliability and correlation analyses of the Italian version of the TDEQ are shown in Table IV.

TABLE IV.—*Reliability analysis and correlation coefficients of the Italian TDEQ version.*

Variables	N.	α	1	2	3	4
TDEQ-5 (Total Scale)	28	0.93				
1. Long-term development	11	0.93		0.72**	0.76**	0.51**
2. Holistic quality preparation	8	0.75			0.66**	0.54**
3. Alignment of expectations	5	0.74				0.45**
4. Support network	4	0.63				

*P<0.05; **P<0.01.

Descriptive statistics

Descriptive statistics have been calculated for all individual item scores and for each factor[31-33] given the recommendation to use item scores together with factor scores in practical applications of TDEQ.[17, 18] Items with a score of five or higher were classified as strengths of the development environment while items with a score of four or lower were classified as areas of improvement of the development environment. The total score of each factor was calculated by adding the degrees of agreement of each item. The four factors and their respective items are discussed later and in detail in Supplementary Digital Material 1: Supplementary Table I.

Discussion

Currently, the care and development of talent is one of the central themes in international sports culture debate;[34-36] but to our knowledge, this is the first study that aims at studying the quality perception of the talent development environments within an Italian context. To this purpose, the TDEQ-5[21] has been used as an internationally known, valid and reliable tool[22-27] to develop a first Italian version to analyze its psychometric properties and to study the perception of the quality of the main talent development environments, within the elite taekwondo population, in athletes belonging to the National Team of FITA and to some of the best national ASA or domestic Clubs.

In recent years, the short version of the TDEQ by Li *et al.*[21] has been proposed and adapted in different cultural and sporting contexts, with the aim of studying its psychometric properties and quantifying athletes' perceptions by analyzing individual item and factor scores, identifying the strengths and weaknesses of developmental environments and comparing athletes of different ages and performance levels. Thomas *et al.*[26] analyzed the factorial structure of the TDEQ-5 to assess the development environments of talented youth track and field athletes in the Caribbean region; confirmatory factor analysis revealed adequate model fit of a re-specified model and moderate to low reliability in the five subscales, with the factors "long-term development focus" and "alignment of expectations" below the adequate value of 0.60. In contrast, Gangsø *et al.*[27] investigated the Norwegian junior-elite football players' perception of their talent development environment using an early Norwegian version of the TDEQ-5; all five subscales presented adequate to good reliability values. In our study, sufficient to excellent reliability was reported on the four subscales with values similar to those reported in the Norwegian (α= from 0.68 to 0.82;[27]) and English (α= from 0.79 to 0.86;[21]) versions.

Specifically, factor 1 – "long-term development" was perceived as the most performing component of development environments in the overall population. The athletes stated that staff members seem to be in perfect tune with what is perceived as the best for them and to design specifically training processes aimed at helping them to develop effectively in the long term. This factor, analyzed in the two development environments, emerged as the strength of the ASA's environment with average scores of five or more in nine out of eleven items. On the contrary, the National environment provides an effective "long-term development," although with some areas of possible improvement. In particular, these results are in line with what emerged in young Caribbean track and field athletes[26] in that the factor "long-term development" was not only perceived very positively by these athletes but also presented four strength points as in our taekwondo population. In addition, very high scores on the factor "long-term development" were also given by the Norwegian junior elite footballers[27] and the English elite football academy players[31] confirming this factor as one of the key strengths of all high-level environments engaged in the care and development of talent.

Secondly, factor 2 – "holistic quality preparation" was identified as the least performing component of the development environments in the overall population. Within this factor, athletes do not perceive that their coaches make time available to talk to their parents about them and what they are trying to achieve: this situation is particularly evident in the national environment, representing its weakest point. In fact, this factor emerged as an area of improvement in the National environment with average scores of four or less in three of eight items, in line with what emerged from the item-by-item analysis in young Caribbean track and field athletes[26] with three areas of improvement. Although the total scale score is below the other three dimensions, it is overall acceptable and in line with findings in other studies.[27, 31]

Thirdly, factor 3 – "alignment of expectations" is a component of development environments that worked well in the overall population. In particular, athletes have stated that they spend most of their time developing skills and abilities that coaches say they will need to compete successfully at the highest level or professionally and to be involved in most decisions about their sports development. This factor also worked quite well in the young Caribbean track and field athletes[26] and in the Norwegian junior elite footballers,[27] presenting, in both cases, scores similar to the "communication" factor, which has in the Italian version been included in the factor "long-term development." these findings highlight the importance placed by coaches and staff on effective communication to facilitate the long-term success of athletes and the importance of setting and aligning goals for sports development.[14-16, 37, 38]

Finally, factor 4 – "support network" was perceived as a solid component of the development environments in the overall population. Athletes are guaranteed the opportunity to meet their coach or another member of the technical staff when they need to and to have access to a variety of different types of professionals to help them in their sports development. These results are in line with that perceived by Norwegian junior elite footballers,[27] elite youth football academy English players[31] and professional female footballers[32] but in disagreement with that found in young Caribbean track and field athletes[26] where, with an average score of 3.78, the factor "support network" was considered the least functioning component of the environment. The authors argued that this substantial difference with other elite sporting contexts could be due to the fact that in more advanced sporting nations talent development is conducted through specialized organizations unlike in the Caribbean context.

The main findings of this study showed that the development environments, overall, are equipped with a technical staff capable of designing excellent development programs, communicating effectively with the athlete, preparing appropriate intervention programs, consistently organizing goals for sports development and providing a solid support network for the athletes. This high perception of developmental environments by the elite taekwondo population identified in the five dimensions could be justified by the fact that taekwondo only became an official Olympic sport two decades ago, relatively later than other combat sports,[39] increasing the interest of national federations at the highest level in investing resources in this discipline in recent years as it has been confirmed as one of the 25 core sports for the Tokyo 2020 Olympic Games.[40] In this direction, the FITA in recent years has launched a program called "search, selection and preparation (S.S.&P.)" with the aim of selecting athletes on whom to invest federal resources in order to implement the identified physical and technical-tactical potential to compete at the highest levels.[41, 42] The strength of this program, in line with current research,[7-10] is that identification does not guarantee progress in the process unless supported by ongoing development and monitoring of the athlete by the ASAs and the National team.[41, 42] To this end, in addition to the results from the item-by-item analysis of the scale and the strengths and weaknesses of the environments, professionals engaged at the highest level in this combat sport are encouraged to pay attention to the significant differences found in the "long-term development," "holistic quality preparation" and "alignment of expectations" factors between the ASA environment and the National environment. Similar differences were reported in Norwegian junior elite footballers[27] where the scale values "holistic quality preparation," "communication" and "alignment of expectations" were able to discriminate athletes from Norwegian football academies ranked in the top five and the bottom five. Therefore, the planning of targeted interventions to standardize and improve the perception of these specific environmental factors, monitoring the impact of interventions over time through the use of the TDEQ,[33] with the aim of facilitating the transition of athletes from the ASA environment to the National environment and optimizing the programs and resources put in place to achieve sporting excellence, assumes a relevant and practical importance.

Limitations of the study

Although this Italian version of TDEQ presents a strong representativeness of the original structure of TDEQ-5 within the first four factors and a good reliability in the four subscales, further studies should be carried out to evaluate the factorial structure (*e.g.*, confirmatory factor analysis) and investigate other psychometric properties (*e.g.*, test-retest). The first factor does not seem to discriminate between the two subscales "long-term development" and "communication" of the original questionnaire. In addition, factors five, six and seven include a number of items less than or equal to two, resulting in interpretation difficulties. This may be related to the fact that the TDEQ has been recognized by the authors as having gender-related limitations, cultural needs and specific characteristics of sport as it is designed as a generic tool to monitor talent development in sports;[17, 19, 21] as such, its application may not be sensitive to the specific environmental characteristics of a given sport.[31, 32]

Lastly, we know that athletes in both environments have been practicing this discipline since the age of 7.79±4.14, so they have about 10-14 years of experience in their ASA. Specifically, since our goal was to provide a general overview of the quality of the main talent development environments within the Italian taekwondo, we have not investigated about the quantity of experiences (years, number of collegiate meetings, etc.) of the sample belonging to the National Team. Therefore, the significant differences we found could be influenced by the degree of experience of the athletes of the National Team within this environment, as the questionnaires were administered during four collegiate meetings and during these meetings new athletes of national interest joined in this specific environment. Therefore, it seems very opportune for future studies the analysis of the variability of perceptions about the same development environment, not only in the National environment but also in the ASA environment, with reference to the geographical distribution.[23]

Conclusions

The main objective of this study was to provide an initial insight into talent development environments in an unexplored cultural context such as Italy. To this end, we developed a first version of the TDEQ-5 to analyze its psychometric properties and to quantify the perception of the quality of the main development environments within the elite taekwondo population. Our results evidencing the strengths and weaknesses of the different development environments surveyed thus allowing the stakeholders who find themselves governing national / international and Club environments (*e.g.*, coaches, trainers, managers, sport psychologists) to plan targeted interventions to optimize the programs and resources put in place to achieve sporting excellence. Moreover, this data adds to the studies that have proposed and adapted the TDEQ in an increasing number of cultural and sporting contexts,[21-27] allowing a comparison on a global scale and underlining the importance given to the care of the sporting environment. In fact, in line with what has also been verified by other authors,[11-17, 37, 38] the results we obtained make us understand how we can worry more advantageously on the management of the environment, of which the training facilities (*e.g.*, specific sports training environments, family, school) are subject to human management and, therefore, perfectible and always improvable.

References

1. Vaeyens R, Güllich A, Warr CR, Philippaerts R. Talent identification and promotion programmes of Olympic athletes. J Sports Sci 2009;27:1367–80.

2. Jayanthi N, Pinkham C, Dugas L, Patrick B, Labella C. Sports specialization in young athletes: evidence-based recommendations. Sports Health 2013;5:251–7.

3. Myer GD, Jayanthi N, Difiori JP, Faigenbaum AD, Kiefer AW, Logerstedt D, *et al.* Sport Specialization, Part I: Does Early Sports Specialization Increase Negative Outcomes and Reduce the Opportunity for Success in Young Athletes? Sports Health 2015;7:437–42.

4. Myer GD, Jayanthi N, DiFiori JP, Faigenbaum AD, Kiefer AW, Logerstedt D, *et al.* Sports Specialization, Part II: Alternative Solutions to Early Sport Specialization in Youth Athletes. Sports Health 2016;8:65–73.

5. Fabricant PD, Lakomkin N, Sugimoto D, Tepolt FA, Stracciolini A, Kocher MS. Youth sports specialization and musculoskeletal injury: a systematic review of the literature. Phys Sportsmed 2016;44:257–62.

6. Jayanthi NA, Post EG, Laury TC, Fabricant PD. Health Consequences of Youth Sport Specialization. J Athl Train 2019;54:1040–9.

7. Cobley S, Baker J, Wattie N, McKenna J. Annual age-grouping and athlete development: a meta-analytical review of relative age effects in sport. Sports Med 2009;39:235–56.

8. Deprez D, Coutts AJ, Fransen J, Deconinck F, Lenoir M, Vaeyens R, *et al.* Relative age, biological maturation and anaerobic characteristics in elite youth soccer players. Int J Sports Med 2013;34:897–903.

9. Romann M, Fuchslocher J. The need to consider relative age effects in women's talent development process. Percept Mot Skills 2014;118:651–62.

10. Andronikos G, Elumaro AI, Westbury T, Martindale RJ. Relative age effect: implications for effective practice. J Sports Sci 2016;34:1124–31.

11. Martindale RJ, Collins D, Daubney J. Talent development: A guide for practice and research within sport. Quest 2005;57:353–75.

12. Martindale RJ, Collins D, Abraham A. Effective talent development: the elite coach perspective within UK sport. J Appl Sport Psychol 2007;19:187–206.

13. Martindale RJ, Mortimer P. Talent development environments: Key considerations for effective practice. In Collins D, Richards H, Button A, editors. Performance psychology: a practitioner's guide. Oxford: Elsevier; 2010.

14. Henriksen K, Stambulova N, Roessler KK. Holistic approach to athletic talent development environments: A successful sailing milieu. Psychol Sport Exerc 2010;11:212–22.

15. Henriksen K, Stambulova N, Roessler KK. Riding the wave of an expert: A successful talent development environment in kayaking. Sport Psychol 2011;25:341–62.

16. Larsen CH, Alfermann D, Henriksen K, Christensen MK. Successful talent development in soccer: the characteristics of the environment. Sport Exerc Perform Psychol 2013;2:190–206.

17. Martindale RJ, Collins D, Wang JC, McNeill M, Lee KS, Sproule J, *et al.* Development of the talent development environment questionnaire for sport. J Sports Sci 2010;28:1209–21.

18. Martindale RJ, Collins D, Douglas C, Whike A. Examining the ecological validity of the Talent Development Environment Questionnaire. J Sports Sci 2013;31:41–7.

19. Wang CK, Sproule J, McNeill M, Martindale JJ, Lee KS. Impact of the Talent Development Environment on Achievement Goals and Life Aspirations in Singapore. J Appl Sport Psychol 2011;23:263–76.

20. Li C, Martindale R, Sun Y. Relationships between talent development environments and mental toughness: the role of basic psychological need satisfaction. J Sports Sci 2019;37:2057–65.

21. Li C, Wang CK, Pyun Y, Martindale R. Further development of the talent development environment questionnaire for sport. J Sports Sci 2015;33:1831–43.

22. Brazo-Sayavera J, Olivares PR, Andronikos G, Martindale RJ. Spanish version of the Talent Development Environment Questionnaire for sport: cultural adaptation and initial validation. PLoS One 2017;12:e0177721.

23. Costa AM, Grazina C, Miragaia D, Crisóstomo L, de Carvalho PG. Contexto de desenvolvimento desportivo em clubes de natação: um estudo preliminar sobre as perceções dos nadadores portugueses. Rev Iberoam Psicol Ejerc Deporte 2017;12:231–6.

24. Siekańska M, Wojtowicz A. Polish version of research based Model of Sport Talent Development Environment and adaptation of Talent Development Environment Questionnaire. Studies in Sport Humanities. 2017;22:7–17.

25. Li C, Martindale R, Wu Y, Si G. Psychometric properties of the Talent Development Environment Questionnaire with Chinese talented athletes. J Sports Sci 2018;36:79–85.

26. Thomas CE, Abbott G, Gastin PB, Main LC. Construct validity and reliability of the Talent Development Environment Questionnaire in Caribbean youth track and field athletes. PLoS One 2020;15:e0227815.

27. Gangsø K, Aspvik NP, Mehus I, Høigaard R, Sæther SA. Talent Development Environments in Football: Comparing the Top-Five and Bottom-Five-Ranked Football Academies in Norway. Int J Environ Res Public Health 2021;18:1321.

28. World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. JAMA 2013;310:2191–4.

29. Conrad F, Blair J, Tracy E. Verbal reports are data! A theorical approach to cognitive interviews. FCSM; 1999 [Internet]. Available from: https://nces.ed.gov/FCSM/pdf/V_B_Conrad1_FCSM1999.pdf [cited 2021, Dec 09].

30. Rennie K. Exploratory and confirmatory rotation strategies in exploratory factor analysis. Proceedings of the Annual Meeting of the Southwest Educational Research Association; 1997 Jan 23; Austin, TX, USA.

31. Mills A, Butt J, Maynard I, Harwood C. Examining the Development Environments of Elite English Football Academies: The Players' Perspective. Int J Sports Sci Coaching 2014;9:1457–72.

32. Gledhill A, Harwood C. Toward an Understanding of Players' Perceptions of Talent Development Environments in UK Female Football. J Appl Sport Psychol 2019;31:105–15.

33. Hall AJ, Jones LJ, Martindale RJ. The Talent Development Environment Questionnaire as a Tool to Drive Excellence in Elite Sport Environments. Int Sport Coach J. 2019;6:187.

34. Sarmento H, Anguera MT, Pereira A, Araújo D. Talent Identification and Development in Male Football: A Systematic Review. Sports Med 2018;48:907–31.

35. Koopmann T, Faber I, Baker J, Schorer J. Assessing Technical Skills in Talented Youth Athletes: A Systematic Review. Sports Med 2020;50:1593–611.

36. Baker J, Wilson S, Johnston K, Dehghansai N, Koenigsberg A, de Vegt S, *et al.* Talent Research in Sport 1990-2018: A Scoping Review. Front Psychol 2020;11:607710.

37. Henriksen K, Larsen CH, Christensen MK. Looking at success from its opposite pole: the case of a talent development golf environment in Denmark. Int J Sport Exerc Psychol 2014;12:134–49.

38. Flatgård G, Larsen CH, Sæther S. Talent development environment in a professional football club in Norway. Scand J Sport Exerc Psychol. 2020;2:8–15.

39. Sports: summer sports/winter sports. International Olympic Committee; 2021 [Internet]. Available from: https://www.olympic.org/sports [cited 2021, Dec 09].

40. Vision M. Strategy. World Taekwondo; 2021 [Internet]. Available from: http://www.worldtaekwondo.org/about-wt/about.html [cited 2021, Dec 09].

41. Search, Selection, and Preparation. Presentazione; Federazione Italiana Taekwondo; 2021 [Internet]. Available from: https://www.taekwondoitalia.it/images/S.S._P._presentazione.pdf [cited 2021, Dec 09].

42. Search, Selection, and Preparation: modalità di accesso e di selezione per l'inserimento nelle classi "P.1 - P.2 - P.3." Federazione Italiana Taekwondo; 2021 [Internet]. Available from: https://www.taekwondoitalia.it/images/documenti/S.S.P._Regolamento.pdf [cited 2021, Dec 09].

Conflicts of interest.—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions.—Gennaro Apollaro and Bruno Ruscello have given substantial contributions to the conception or the design of the manuscript, Gennaro Apollaro, Bruno Ruscello, Laura Pantanella and Mario Esposito to data acquisition, analysis and interpretation, Gennaro Apollaro, Laura Pantanella, Mario Esposito and Bruno Ruscello to manuscript writing, Gennaro Apollaro to manuscript critical revision. All authors read and approved the final version of the manuscript.

Acknowledgements.—The authors would like to acknowledge the Taekwondo athletes for their participation in this study, the Federal Councilor of the Italian Taekwondo Federation Prof. Salvatore Chiodo, the physical trainers of the Italian National Taekwondo Team Diego Grisoli and Francesco Zambrella, and all the coaches for their assistance in data collection.

History.—Article first published online: April 19, 2021. - Manuscript accepted: April 12, 2021. - Manuscript revised: April 6, 2021. - Manuscript received: January 20, 2021.

Supplementary data.—For supplementary materials, please see the HTML version of this article at www.minervamedica.it

The Journal of Sports Medicine and Physical Fitness
EDIZIONI MINERVA MEDICA

Exploring the age of taekwondo athletes in the Olympic Games: an analysis from Sydney 2000 to Rio 2016

Gennaro APOLLARO, Bruno RUSCELLO

The Journal of Sports Medicine and Physical Fitness 2021 Nov 25
DOI: 10.23736/S0022-4707.21.12768-9

Article type: Original Article

Article first published online: November 25, 2021
Manuscript accepted: October 11, 2021
Manuscript revised: September 28, 2021
Manuscript received: April 26, 2021

Exploring the age of taekwondo athletes in the Olympic Games: an analysis from Sydney 2000 to Rio 2016

Gennaro APOLLARO[1]* and Bruno RUSCELLO[1,2,3,4]

[1] School of Sport Sciences and Exercise, Faculty of Medicine and Surgery, University “Tor Vergata” – Rome, Italy

[2] School of Sports and Exercise Sciences, “San Raffaele” University – Rome, Italy

[3] Department of Industrial Engineering, Faculty of Engineering, “Tor Vergata” University – Rome, Italy

[4] LUISS SportLab – LUISS University, Rome, Italy

*** Corresponding Author**: Gennaro Apollaro. School of Sport Sciences and Exercise, Faculty of Medicine and Surgery, University “Tor Vergata”, Rome, Italy. Via Montpellier 1, 00133 Rome – Italy.
E-mail: gen.2012.ita@hotmail.com – ORCID: https://orcid.org/0000-0002-0427-037X

Abstract

BACKGROUND: The aim of this study was to quantify the age at which taekwondo athletes competed in the Olympic Games and to provide initial insights into weight category changes over time. **METHODS**: For the first analysis, the study included all 611 taekwondo athletes who competed in the Olympics between 2000 and 2016; for each sex, a three-way ANOVA (edition of Olympic Games, competitive achievement, weight category) was performed to detect differences in the age of athletes. For the second analysis, we considered all 109 taekwondo athletes who took part in more than one edition of the Olympics between 2000 and 2016; chi-squared goodness of fit tests were performed to study the number of participations and changes in weight category of these athletes. **RESULTS**: Female athletes, with a mean age of 23.8 ± 4.1 years, are significantly younger (p=0.001) than their male counterparts, with a mean age of 25.1 ± 3.9 years. In weight category, lighter athletes being younger than heavier ones in both females (22.7 ± 3.7 vs 24.5 ± 4.2 yrs., p=0.04) and males (23.6 ± 3.8 vs 26.7 ± 3.8 yrs., p=0.001; 24.2 ± 3.5 vs 26.7 ± 3.8 yrs., p=0.001). When an athlete reaches Olympic competition several times, he/she generally competes in the same weight category (p=0.001) and takes part in two consecutive editions (p=0.001). Heavier athletes have greater longevity at Olympic level than lighter athletes (p=0.002). **CONCLUSIONS**: The current data provides important information for national federations engaged in the selection of athletes for Olympic competitions.

Key words: Olympic games; Long-term development; Weight category; Combat sports.

Introduction

The age of peak competitive performance may vary between athletes in different sports and events, depending on the specific skills and attributes required for success in a particular event [1]. In sports such as track & field, the age of peak performance is determined by personal record performances where performance measurement is based on centimetres or seconds [1,2,3]. On the contrary, as recently highlighted [4], in combat sports the World Championships and Olympic Games are considered the two most important indicators of professional success for athletes, since there is no measurement used to establish world record performances.

Combat sports account for an important part of the medals awarded at the Summer Olympics. The current schedule of the Olympic Games includes fencing, boxing, taekwondo, karate, judo, Greco-Roman wrestling and freestyle wrestling. However, the inclusion of these sports in the Olympic programmes has followed different paths over time; fencing and wrestling were already present in the programme of the 1896 Olympic Games while karate was introduced at the 2020 Olympic Games [5]. In this context, a broad knowledge about the characteristics of combat sports athletes of different ages and performance levels is crucial [6] to provide, to the coaches and the national federations, important information to optimize long-term development and decision-making processes when selecting athletes for major competitions [7-9].

After participating in the 1988 Seoul Olympic Games and the 1992 Barcelona Olympic Games as a demonstration sport, taekwondo became an official Olympic sport at the 2000 Sydney Olympic Games. Under the leadership of World Taekwondo, which regulates Olympic competitions and World Championships, taekwondo has gained popularity over time and confirmation as one of the 25 core sports for the Tokyo 2020 Olympic Games [10-11]. Combat sports, such as taekwondo, involve an oppositional relationship between two athletes striving to win the match [12]; consequently, many aspects are considered important to achieve successful competitive performance in taekwondo, including a high degree of technical-tactical competence supported by physiological, psychological [13-16] and sport context-specific components such as periodization strategies [17-18] and nutritional preparation [19-20]. The various rule changes that have taken place over the last decade [21-23], impacting on the kinematic and physiological profile of the fight [24-25], have made taekwondo an even more dynamic sport.

Although some studies have investigated the profiles [26-29] and the effect of relative age [30-31] of Olympic taekwondo athletes, no previous study has investigated the age at which taekwondo athletes competed in the Olympic Games, considering all editions of participation, competitive achievement and weight category. In judo, Franchini *et al.* [4] explored the age at which athletes participated in World Championships and Olympic Games, over a 25-year interval, taking into account achievement performance and weight category in the analysis. The authors reported that generally female athletes, with a mean age of 24.9 ± 3.9 years, were significantly younger than their male counterparts, with a mean age of 25.4 ± 3.8 years.

In line with the above, the objectives of the present study were 1) to examine the age at which taekwondo athletes competed in the Olympic Games, 2) to compare the age of taekwondo athletes who won medals, placed 5th/7th and were defeated in the eliminatory phases, 3) to compare the age of taekwondo athletes in different weight categories, 4) to monitor taekwondo athletes who have taken part in multiple editions of the Olympic Games for changes in weight category over time and 5) to examine whether there was a change in the age category distribution over the period of taekwondo's participation in the Olympic Games.

Methods

Participants and data collection

The present study included all 611 taekwondo athletes (females = 300; males = 311) who competed in the 5 Olympics between 2000 and 2016. Birth dates, competitive achievements and weight categories were collected from publicly available online sources (www.olympic.org and www.olympiandatabase.com). The use of data from open access sites has been previously described in other studies [4,30,32] and there are no ethical issues involved in the analysis and interpretation of the data used as these were obtained in a secondary form and not from direct experimentation.

Procedures

Taekwondo athletes were divided by gender (female and male), edition of the Olympic Games (Sydney 2000, Athens 2004, Beijing 2008, London 2012, Rio 2016), competitive achievement (1st-3rd placers, i.e. one gold, one silver and one or two bronze medal winners; 5th and 7th placers, i.e. defeated in the repechage and bronze medal matches; 9th placers and below, i.e. defeated in the eliminatory phases), weight category (flyweight, featherweight, middleweight and heavyweight) and age category (< 20 years, 20-25 years, 25-30 years and > 30 years).

Statistical analysis

Data were tabulated and organized in a Microsoft Excel worksheet and then reported and analysed using IBM SPSS 25 software (SPSS Inc., Chicago, IL). Based on previous studies [30-31] that did not find the relative age effect in the Olympic taekwondo population (from Sydney 2000 to Rio 2016), the age of each athlete was calculated as follows: year of the Olympic edition - year of birth of the athlete = age of athlete. For each variable, the normality of the data distribution was examined using a Shapiro–Wilk test. Descriptive statistics (Mean ± Standard Deviation [95% confidence intervals]) were used to summarize the collected data and were presented when considered relevant. A Student's t-test for independent samples was used to compare male and female athletes. The Effect Size (ES) was determined, and the threshold values for Cohen's ES statistics were classified as trivial (0.0 – 0.19), small (0.2 – 0.59), moderate (0.6 – 1.1), large (1.2 – 1.9) and very large (> 2.0) (33). As this analysis revealed age differences between the sexes, each group was analysed separately (4). Thus, for each sex, a three-way ANOVA (edition of Olympic Games, competitive achievement and weight category) was performed with Tukey's post-hoc tests, when appropriate, to detect significant differences in the age of athletes from different groups; ES in ANOVA was computed as partial η^2, with partial $\eta^2 < 0.01$, $0.01 <$ partial $\eta^2 < 0.06$, $0.06 <$ partial $\eta^2 < 0.14$ and partial $\eta^2 > 0.14$, as trivial, small, moderate, and large ES, respectively (34). Chi-squared (χ^2) goodness of fit tests and odds ratio (95% confidence intervals) were performed to study the athletes who took part in more than one edition of the Olympic Games; chi-square (χ^2) tests of independence were performed to identify the association between edition of the Olympic Games and the age categories. For these analyzes, ES was reported using Cramer's V as small (0.06 - 0.17), medium (0.18 - 0.29) and large (> 0.30) (35). Statistical significance was accepted at $p < 0.05$.

Results

Female taekwondo athletes were younger (23.8 ± 4.1 years) than male taekwondo athletes (25.1 ± 3.9 years) (t = 4.01, p = 0.001, d = 0.33, small, confidence interval of the differences = 0.67; 1.95).

For female taekwondo athletes, no main effects were found for edition of the Olympic Games ($F_{2,240} = 0.96$; p = 0.43, $\eta^2_p = 0.02$, small) and competitive achievement ($F_{2,240} = 0.99$; p = 0.37, $\eta^2_p = 0.01$, small). However, main effects were found by weight category ($F_{3,240} = 2.9$; p = 0.04, $\eta^2_p = 0.03$, small) (Table I).

Female taekwondo athletes in the flyweight category were younger (p = 0.04) than those in the heavyweight category (Table I).

Table I. - *Descriptive statistics (M ± SD [95% CI]) of the chronological age (years) of female taekwondo athletes according to Olympic edition, competitive achievement and weight category.*

	Olympic edition				
	Sydney 2000	**Athens 2004**	**Beijing 2008**	**London 2012**	**Rio 2016**
Female taekwondo athletes (N = 300)	24.4 ± 4.5 [23.1 - 25.7]	23.5 ± 4 [22.5 - 24.5]	23.1 ± 4.2 [22.1 - 24.2]	23.6 ± 3.8 [22.6 - 24.5]	24.5 ± 4.1 [23.5 - 25.5]
	Competition achievement				
	1st-3rd	**5th / 7th**	**≥ 9th**		
	23.3 ± 3.2 [22.6 - 24.1]	24.3 ± 4.6 [23.3 - 25.3]	23.8 ± 4.3 [23.1 - 24.5]		
	Weight category				
	-49kg "Fly"	**-57kg "Feather"**	**-67kg "Middle"**	**+67kg "Heavy"**	
	22.7 ± 3.7[a] [21.9 - 23.6]	23.6 ± 3.8 [22.7 - 24.5]	24.4 ± 4.5 [23.3 - 25.4]	24.5 ± 4.2 [23.6 - 25.5]	

Notes: 1st-3rd: one gold, one silver and one or two bronze medal winners, 5th / 7th: defeated in the repechage and bronze medal matches, ≥ 9th: defeated in the eliminatory phases. [a]Significantly younger (p = 0.04) when compared to heavyweight category.

For male taekwondo athletes, there was no main effect by edition of the Olympic games ($F_{4,251} = 0.37$; $p = 0.85$, $\eta^2_p = 0.01$, small) and by competitive achievement ($F_{2,251} = 1.75$; $p = 0.16$, $\eta^2_p = 0.01$, small). However, main effects by weight category were also found for male taekwondo athletes ($F_{3,251} = 9.11$; $p = 0.001$, $\eta^2_p = 0.1$, moderate) (Table II).

Male taekwondo athletes in the flyweight category were younger than those in the middleweight (p = 0.001) and heavyweight (p = 0.001) categories. Athletes in the featherweight category were younger than those in the middleweight (p = 0.02) and heavyweight (p = 0.001) categories (Table II).

Table II. - *Descriptive statistics (M ± SD [95% CI]) of the chronological age (years) of male taekwondo athletes according to Olympic edition, competitive achievement and weight category.*

	Olympic edition				
	Sydney 2000	**Athens 2004**	**Beijing 2008**	**London 2012**	**Rio 2016**
Male taekwondo athletes (N = 311)	25 ± 4 [23.9 - 26.1]	25.2 ± 3.5 [24.3 - 26.1]	25.3 ± 4.1 [24.2 - 26.3]	25.4 ± 3.9 [24.5 - 26.4]	24.7 ± 4.3 [23.6 - 25.7]
	Competition achievement				
	1st-3rd	**5th / 7th**	**≥ 9th**		
	24.4 ± 3.3 [23.7 - 25.2]	25.7 ± 4.1 [24.8 - 26.5]	25.1 ± 4.1 [24.5 - 25.8]		
	Weight category				
	-58kg "Fly"	**-68kg "Feather"**	**-80kg "Middle"**	**+80kg "Heavy"**	
	23.6 ± 3.8^a [22.7 - 24.4]	24.2 ± 3.5^b [23.4 - 25]	26 ± 3.9 [25.1 - 26.9]	26.7 ± 3.8 [25.9 - 27.6]	

Notes: 1st-3rd: one gold, one silver and one or two bronze medal winners, 5th / 7th: defeated in the repechage and bronze medal matches, ≥ 9th: defeated in the eliminatory phases. [a]Significantly younger when compared to middleweight (p = 0.001) and heavyweight (p = 0.001) categories, [b]significantly younger when compared to middleweight (p = 0.02) and heavyweight (p = 0.001) categories.

Considering the main effects found for the weight category, we then considered all the athletes who took part in more than one edition of the Olympic Games for further analysis. This study included 109 athletes for a total of 242 participations out of 611 Olympic passes (39.61%).

For the first analysis, 1) we compared athletes who took part in more than one edition of the Olympic Games keeping the same weight category over time with athletes who took part in more than one edition of the Olympic Games changing weight category over time and 2) we compared athletes who took part in 2 consecutive editions (i.e., one four-year period) with athletes who took part in 2 non-consecutive or in ≥ 3 consecutive editions (i.e., two or more four-year periods) (the details of the athletes are shown in Figure I).

A difference was observed between athletes who took part in several editions of the Olympic Games keeping the same weight category over time and athletes who took part in several editions of the Olympic Games changing weight category over time (76.15% vs 23.85%; $\chi^2_{(1)} = 29.807$; p = 0.001; V = 0.52, large; OR = 3.19, 95% CI = 1.79-5.69); at the same time a difference was observed between athletes who took part in 2 consecutive editions and athletes who took part in 2 non-consecutive editions or in ≥ 3 consecutive editions (74.31% vs 25.69%; $\chi^2_{(1)} = 25.771$; p = 0.001; V = 0.49, large; OR = 2.89, 95% CI = 1.63-5.12).

In the second analysis, 1) considering the athletes who took part in 2 consecutive editions, we compared the athletes of the lighter categories (fly and feather) with the athletes of the heavier categories (middle and heavy) and 2) considering the athletes who took part in 2 non-consecutive or in ≥ 3 consecutive editions, we compared the athletes of the lighter categories (fly and feather) with the athletes of the heavier categories (middle and heavy). For this analysis, the athletes were divided into two groups (light and heavy) on the basis of the main effects found for the weight category and the athletes who changed category over time were placed in a group taking into consideration their last participation (the details of the athletes are shown in Figure I).

No difference was reported between the athletes of the lighter and heavier categories considering the athletes who took part in 2 consecutive editions (50.62% vs 49.38%; $\chi^2_{(1)} = 0.012$; $p = 0.912$; V = 0.01, small; OR = 1.03, 95% CI = 0.55-1.90); on the contrary, a difference was reported between the athletes of the lighter categories and the athletes of the heavier categories considering the athletes who took part in 2 non-consecutive editions or in ≥ 3 consecutive editions (21.43% vs. 78.57%; $\chi^2_{(1)} = 9.143$; $p = 0.002$; V = 0.57, large; OR = 3.67, 95% CI = 1.14-11.79).

Figure I near here

Figure I. – *a) Female taekwondo athletes (N = 44) and b) male taekwondo athletes (N = 39) who have taken part in several editions of the Olympic Games while maintaining the same weight category over time; c) Female taekwondo athletes (N = 11) and d) male taekwondo athletes (N = 15) who took part in more than one edition of the Olympic Games changing weight category over time.* Notes: In figures I (c) and I (d), the arrow pointing upwards to the right indicates that the athlete participated in a higher weight category in his/her successive edition, the arrow pointing downwards to the right indicates that the athlete participated in a lower weight category in his/her successive edition, the arrow pointing to the right indicates that the athlete kept the same weight category in his/her successive edition.

No association was shown between edition of the Olympic Games and age category for both females ($\chi^2_{(12)} = 14.181$; $p = 0.289$; V = 0.13, small) (Figure II (a)) and males ($\chi^2_{(12)} = 7.666$; $p = 0.811$; V = 0.09, small) (Figure II (b)).

Figure II near here

Figure II. – *Age category distribution (%) over time for a) female taekwondo athletes and b) male taekwondo athletes at the Olympic Games (2000-2016).*

Discussion

To our knowledge, this is the first study that has analysed the age at which taekwondo athletes competed in the Olympic Games considering all editions of taekwondo participation in the Olympic Games, competitive achievement and weight category. The main findings concerned the weight category where, regardless of gender, lighter athletes are younger than heavier ones. No difference in age was found between all editions of participation and in final classification for both female and male athletes. Overall, taekwondo athletes are most represented in the 20-25 age category with the same percentage in both sexes; in females the < 20 age category has a similar value to the 25-30 age category, while in males the < 20 age category has a similar value to the > 30 age category.

Franchini *et al.* [(4)], exploring the age at which judo athletes participated in the World Championships and Olympic Games between 1993 and 2018, involved the last six Olympic Games participations in the analysis by considering the same variables used in our study, thus allowing a direct comparison between these two Olympic combat sports.

Specifically, no age difference was found when comparing all editions of taekwondo participation in the Olympic Games in both sexes. In judo, only the female athletes who took part in the London 2012 and Rio 2016 Olympics were significantly older than the female athletes who participated in the Atlanta 1996 Olympics, while no significant difference emerged for their male counterparts. These results appear to be in line as in both judo and taekwondo, compared since the Sydney 2000 Olympics when taekwondo became an Olympic sport, no age difference was found between the editions.

Our data did not reveal any age difference regarding the competitive achievement in both sexes. In judo (considering both the World Championships and the Olympic Games), only significantly younger female athletes performed worse in the preliminary rounds, whereas no significant difference emerged for their male counterparts. According to the authors, this could be the consequence of the important selectivity of these events in terms of participation where probably only athletes who are successful in high-level preparatory competitions manage to reach such important competitions. Taekwondo also uses a highly selective qualification system for the Olympic Games, which until the London 2012 Olympic Games was based on world and continental qualification competitions, while since the Rio 2016 Olympic Games on world ranking and continental qualification competitions [(36-37)]. In judo, the world ranking-based qualification system for the Olympic Games was first used at the 2012 London Olympics [(38)]. Franchini & Julio [(32)] studied how long-term and short-term performance in competitions valid to gain world ranking points predict performance for the Olympic Games. The authors identified that 24% and 26% of judo performances at the London 2012 Olympic Games, for females and males respectively, could be predicted by variables derived from world ranking. In contrast, in taekwondo, no studies have investigated how point and qualifying competitions influence selectivity and success in the Olympic Games, and future studies should investigate this aspect to justify the absence of age differences in the final classification of the Olympic Games.

With regard to weight category, it is important to note that our data is in line with what emerged in judo (considering both the World Championships and the Olympic Games) where lighter athletes are generally younger than heavier athletes in both sexes. A first hypothesis discussed by the researchers, which attempts to explain the age differences in the weight category, revolves around the process of rapid weight loss in the pre-competition period where it would appear that elite judo athletes use more aggressive methods particularly at the beginning of their careers [(39)]. In taekwondo it would also appear that elite athletes begin to lose weight at younger ages in order to compete at the highest level, confirming evidence from judo that competition at high levels is associated with worsened weight management behaviours [(19,39)].

A second hypothesis in judo is that athletes change their weight category as they age. Although this is a common observation and recently highlighted in taekwondo, where older athletes tend to abandon the passive model in favour of not losing weight at all [(20)], no previous study has shown this change in weight categories in combat sports. In this regard, another objective of the present study was to monitor taekwondo athletes who took part in multiple editions of the Olympic Games for changes in weight category over time.

The most important results show that, generally, when a taekwondo athlete reaches the Olympic competition more than once in his career, he competes in the same weight category and takes part in two consecutive editions. Secondly, athletes in the lighter categories seem to have more difficulty in reaching Olympic competition more than twice in their career. In this regard, considering that taekwondo athletes at the Olympic level compete in four weight categories while in other international competitions (such as World Championships and ranking competitions) in eight weight categories, the hypothesis is that athletes, when unable to maintain the Olympic weight category of their first participation, will compete in adjacent weight categories during the four-year period [(23,37)], and then return to the same Olympic weight category in their next participation and retain a likely competitive advantage. The possible difficulties resulting from similar long-term weight management and the greater competitiveness in term of participants in the selection process of the lighter categories could represent a barrier for these athletes and result in shorter Olympic careers. In contrast, double participation in two Olympic four-year terms and three or more consecutive participations seem to be more characteristic of athletes competing in the heavier categories. The hypothesis is that heavier athletes have greater longevity at Olympic level than lighter athletes, probably due to less competitiveness in these categories and easier weight management. Another important hypothesis to consider could stem from the differences found in technical-tactical behaviors in taekwondo athletes of different weight categories who participated in the 2012 London Olympics [40]. This study found that both male and female athletes in the lighter categories (fly and feather) performed more anticipated, posterior and linear actions at both impact zones (head and trunk) with the left and front leg than those in the heavier categories (middle and heavy). Specifically, lighter female athletes performed more indirect actions, anticipated and posterior counterattacks, linear actions, to the head and trunk, with the left leg and open guard than heavier athletes. Conversely, heavier female athletes performed more defensive actions (blocks and cuts) than lighter ones because these defensive actions do not require a global move to perform them. Lighter male athletes performed more actions (direct, indirect, back, circular, spin, at the head and trunk, left and right leg, front and back and closed guard) than heavier athletes. This tendency of the heavier male and female athletes in performing fewer actions has also been reported at other competitive levels [41-42] and has been attributed to the higher energy demands in heavier athletes to perform kicks and punches, due to the greater mass in the arms and legs, resulting in a lower fight pace and longer recovery times compared to the lighter athletes [43-44]. These differences found in the technical-tactical behaviors, between the athletes of the lighter categories and the athletes of the heavier categories, could have a different impact on the physiological level in the long term and consequently on the duration of the athlete's competitive career, so the relationship between these factors in taekwondo deserves particular attention and further research in the future.

This twofold and divergent aspect in the duration of the Olympic career, found by comparing the lightest and heaviest athletes in our study, may provide more of an explanation for the fact that lighter athletes are generally younger than heavier athletes in the Olympic taekwondo population, rather than the common observation that athletes change their weight category as they age. However, it seems relevant to highlight that the possible reasons for age differences in weight category may be unique to the context analysed. Judo athletes, for example, compete in seven weight categories in both Olympic and world competition, unlike taekwondo. Therefore, weight management during the four-year period may be influenced by the specific regulations of each discipline and, to this end, future studies are encouraged to investigate this aspect in different combat sports and competitive levels.

Finally, our data showed no significant change in the different age categories in either gender. In judo, only for female athletes there was a significant increase in the 25-30 years category and a significant decrease in the 20-25 years category from the Atlanta 1996 Olympics to the Rio 2016 Olympics, in parallel with a significant and progressive decrease in the < 20 years category. These progressive increases in the age of female athletes were justified by the authors as a potential increase in competitiveness over time as women's judo was introduced to the Olympic Games 20 years after men's judo [5]. Therefore, considering that taekwondo is a younger Olympic sport than judo and most

Olympic combat sports and that it was introduced to the Olympic Games in parallel for both sexes, the absence of changes in the different age categories will have to be interpreted in the long term, also taking into consideration future participations of taekwondo in the Olympic Games.

Conclusions

The present study is the first to investigate the age at which taekwondo athletes competed in the Olympic Games and the first to provide initial insights into weight category changes over time. Female taekwondo athletes, with a mean age of 23.8 ± 4.1 years, are significantly younger than their male counterparts, with a mean age of 25.1 ± 3.9 years. Regardless of gender, no difference in age was found between all editions of participation, in the final classification and no significant change occurred in the different age categories. The main results concerned the weight category where, generally, lighter athletes are younger than heavier ones. When a taekwondo athlete reaches the Olympic competition several times in his career, he/she generally competes in the same weight category and takes part in two consecutive editions. Athletes in the lighter categories seem to have more difficulty in reaching Olympic competition more than twice in their career. In contrast, double participation in two Olympic four-year terms and three or more consecutive participations seem to be more characteristic of athletes competing in the heavier categories. This twofold aspect could provide more justification for the fact that lighter athletes are generally younger than heavier athletes in the Olympic taekwondo population. The current data derived from the study of all taekwondo participations in the Olympic Games not only provides additional knowledge about this increasingly popular combat sport, but also important information for national federations engaged at the highest level in the selection of athletes and long-term development processes for Olympic competitions.

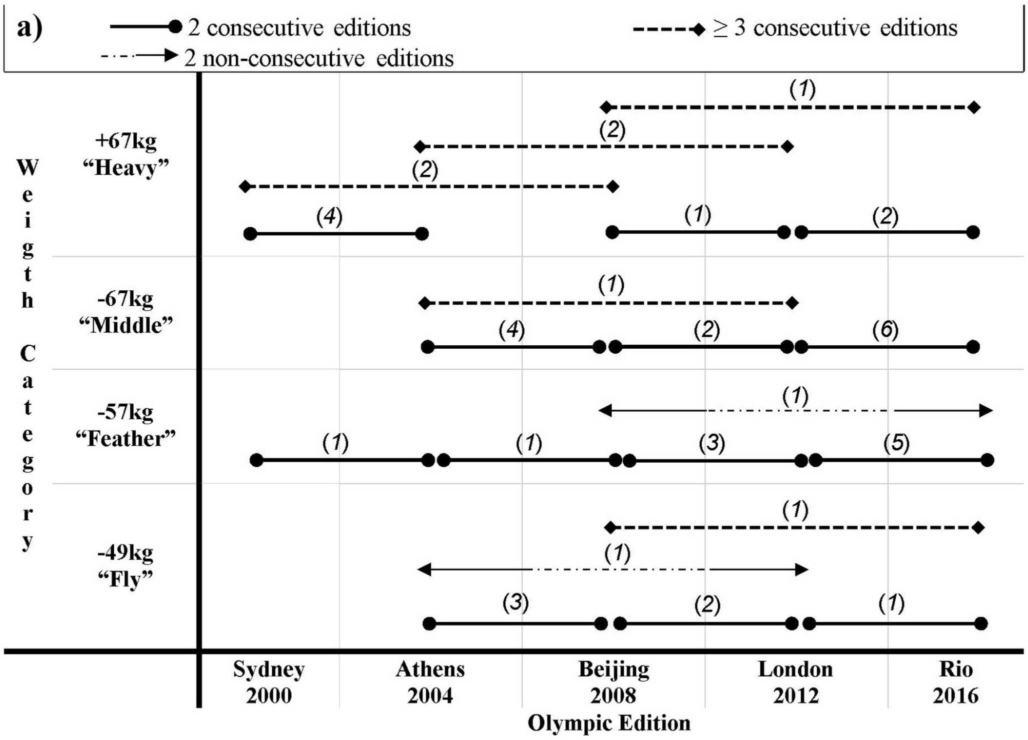
Author contributions. - Gennaro APOLLARO and Bruno RUSCELLO have given substantial contributions to the conception or the design of the manuscript, Gennaro APOLLARO and Bruno RUSCELLO to acquisition, analysis and interpretation of the data. All authors have participated to drafting the manuscript, Gennaro APOLLARO revised it critically. All authors read and approved the final version of the manuscript.

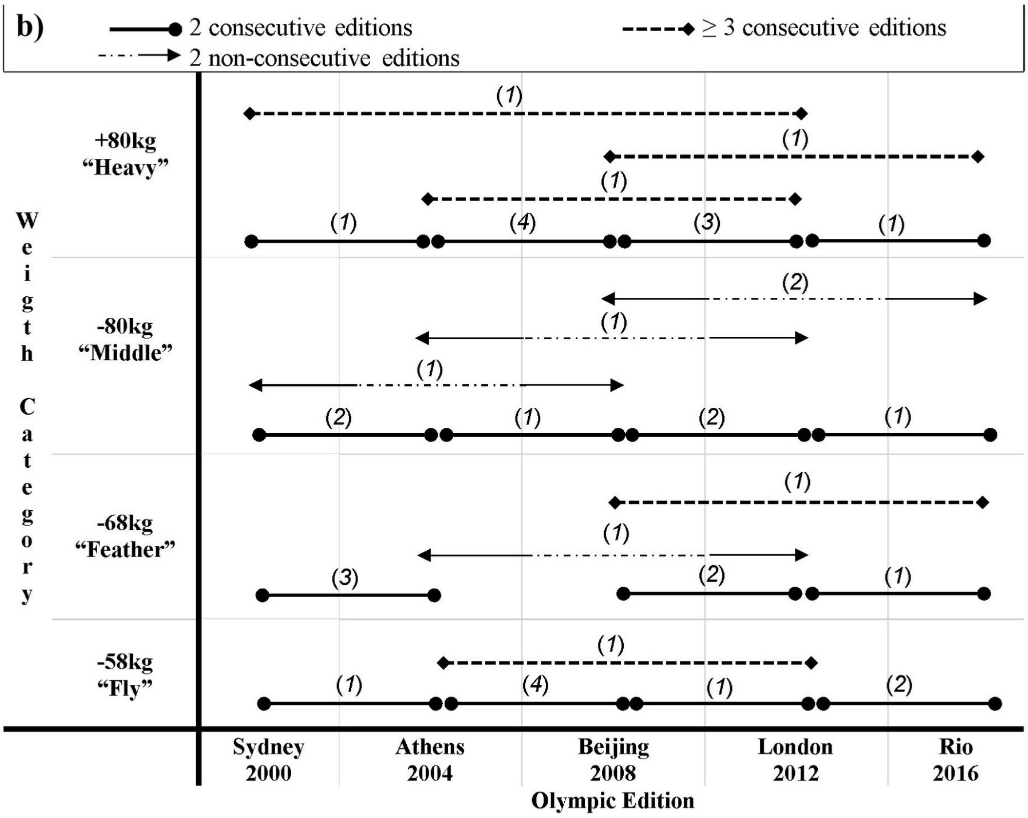
REFERENCES

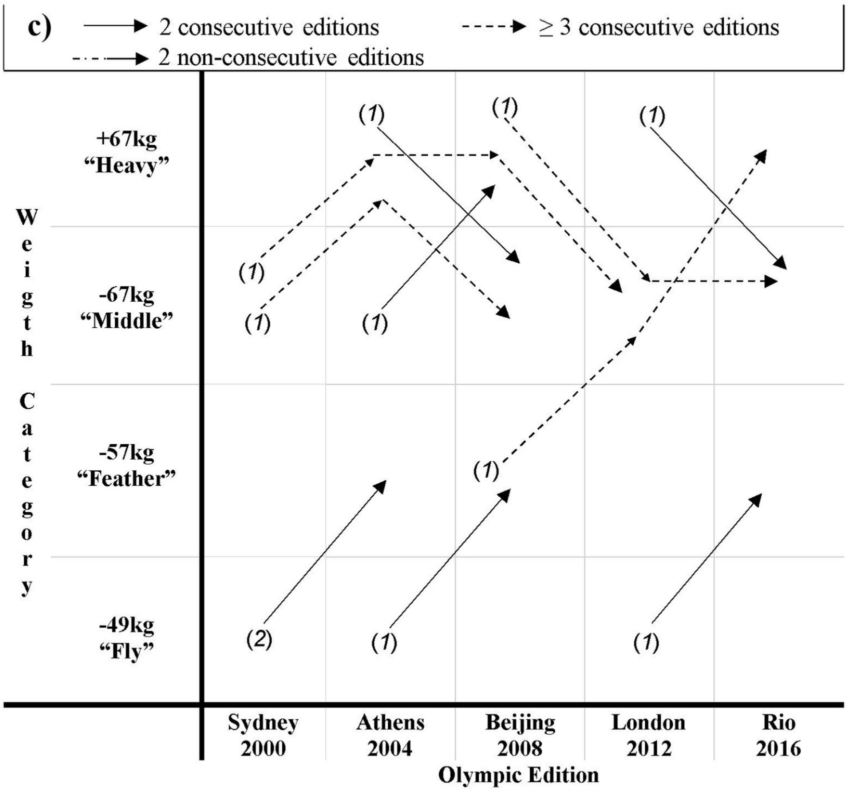
1. Allen SV, Hopkins WG. Age of Peak Competitive Performance of Elite Athletes: A Systematic Review. Sports Med. 2015;45:1431-41.
2. Longo AF, Siffredi CR, Cardey ML, Aquilino GD, Lentini NA. Age of peak performance in Olympic sports: a comparative research among disciplines. J Hum Sport Exerc. 2016;11:31–41.
3. Haugen TA, Solberg PA, Foster C, Morán-Navarro R, Breitschädel F, Hopkins WG. Peak Age and Performance Progression in World-Class Track-and-Field Athletes. Int J Sports Physiol Perform. 2018;13:1122-1129.
4. Franchini E, Fukuda DH, Lopes-Silva JP. Tracking 25 years of judo results from the World Championships and Olympic Games: Age and competitive achievement. J Sports Sci. 2020;38:1531-1538.
5. International Olympic Committee [Internet]. Sports: summer sports/winter sports; 2021 [cited 2021 Mar 1]. Available from: https://www.olympic.org/sports.
6. Norjali Wazir MRW, Van Hiel M, Mostaert M, Deconinck FJA, Pion J, Lenoir M. Identification of elite performance characteristics in a small sample of taekwondo athletes. PLoS One. 2019;14:e0217358.
7. Vaeyens R, Güllich A, Warr CR, Philippaerts R. Talent identification and promotion programmes of Olympic athletes. J Sports Sci. 2009;27:1367–1380.
8. Ford P, De Ste Croix M, Lloyd R, Meyers R, Moosavi M, Oliver J, Till K, Williams C. The long-term athlete development model: physiological evidence and application. J Sports Sci. 2011;29:389-402.
9. Rees T, Hardy L, Güllich A, Abernethy B, Côté J, Woodman T, Montgomery H, Laing S, Warr C. The Great British Medalists Project: A Review of Current Knowledge on the Development of the World's Best Sporting Talent. Sports Med. 2016;46:1041-58.
10. International Olympic Committee [Internet]. TAEKWONDO: History of Taekwondo at the Olympic Games; 2015 [cited 2021 Mar 1]. Available from: https://stillmed.olympic.org/AssetsDocs/OSC%20Section/pdf/QR_sports_summer/Sports_Olympiques_taekwondo_eng.pdf.
11. World Taekwondo [Internet]. Vision, Mission, Strategy; 2021 [cited 2021 Mar 1]. Available from: http://www.worldtaekwondo.org/about-wt/about.html.
12. Menescardi C, Ruiz L, Estevan I, Falcó, C. An update of sparring taekwondo's internal logic. Movimento. 2020;26:e26038.
13. Bridge CA, Ferreira da Silva Santos J, Chaabène H, Pieter W, Franchini E. Physical and physiological profiles of taekwondo athletes. Sports Med. 2014;44:713-33.
14. Chaabene H, Negra Y, Bouguezzi R, Capranica L, Franchini E, Prieske O, Hbacha H, Granacher U. Tests for the Assessment of Sport-Specific Performance in Olympic Combat Sports: A Systematic Review With Practical Recommendations. Front Physiol. 2018;9:386.
15. Franchini E, Cormack S, Takito MY. Effects of High-Intensity Interval Training on Olympic Combat Sports Athletes' Performance and Physiological Adaptation: A Systematic Review. J Strength Cond Res. 2019;33:242-252.

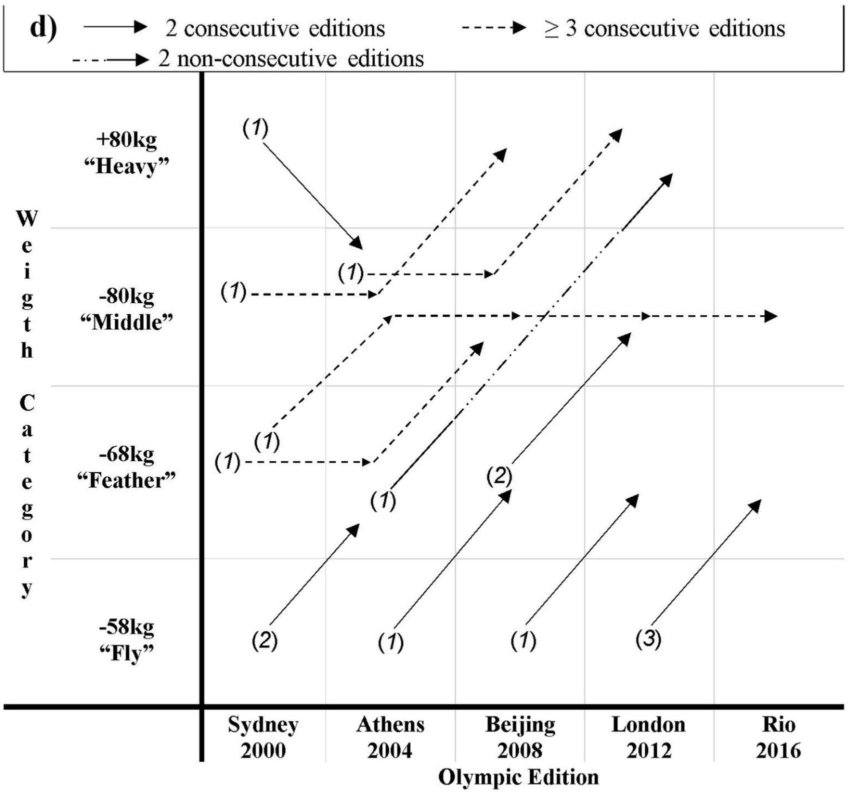
16. da Silva Santos JF, Dias Wilson V, Herrera-Valenzuela T, Sander Mansur Machado F. Time-Motion Analysis and Physiological Responses to Taekwondo Combat in Juvenile and Adult Athletes: A Systematic Review. Strength Cond J. 2020;42:103-121.
17. Ball N, Nolan E, Wheeler K. Anthropometrical, physiological, and tracked power profiles of elite taekwondo athletes 9 weeks before the Olympic competition phase. J Strength Cond Res. 2011;25:2752-63.
18. Carazo-Vargas P, González-Ravé J, Newton R, Moncada-Jiménez J. Periodization Model for Costa Rican Taekwondo Athletes. Strength Cond J. 2015;37:74-83.
19. da Silva Santos JF, Takito MY, Artioli GG, Franchini E. Weight loss practices in Taekwondo athletes of different competitive levels. J Exerc Rehabil. 2016;12:202-8.
20. Janiszewska K, Przybyłowicz KE. Pre-Competition Weight Loss Models in Taekwondo: Identification, Characteristics and Risk of Dehydration. Nutrients. 2020;12:2793.
21. Moenig U, Cho S, Song, H. The Modifications of Protective Gear, Rules and Regulations During Taekwondo's Evolution – From its Obscure Origins to the Olympics. Int J Hist Sport. 2012;29:1363-1381.
22. Moenig U. Rule and Equipment Modification Issues in World Taekwondo Federation (WTF) Competition. Ido Mov Culture. J Martial Arts Anthrop. 2015;15:3–12.
23. World Taekwondo [Internet]. Competition Rules & Interpretation; 2021 [cited 2021 Mar 1]. Available from: http://www.worldtaekwondo.org/rules-wt/rules.html.
24. Janowski M, Zieliński J, Kusy K. Exercise Response to Real Combat in Elite Taekwondo Athletes Before and After Competition Rule Changes. J Strength Cond Res 2019. [Epub ahead of print]
25. Janowski M, Zieliński J, Ciekot-Sołtysiak M, Schneider A, Kusy K. The Effect of Sports Rules Amendments on Exercise Intensity during Taekwondo-Specific Workouts. Int J Environ Res Public Health. 2020;17:6779.
26. Kazemi M, Waalen J, Morgan C, White AR. A profile of olympic taekwondo competitors. J Sports Sci Med. 2006;5:114-21.
27. Kazemi M, Casella C, Perri G. 2004 olympic tae kwon do athlete profile. J Can Chiropr Assoc. 2009;53:144-52.
28. Kazemi M, Perri G, Soave D. A profile of 2008 Olympic Taekwondo competitors. J Can Chiropr Assoc. 2010;54:243-9.
29. Kazemi M, Ong M, Pacis A, Tseng K. A profile of 2012 Olympic games taekwondo athletes. J Int Assoc Taekwondo Res. 2014;1:12–18.
30. Albuquerque MR, Lage GM, da Costa VT, Ferreira RM, Penna EM, Moraes LC, Malloy-Diniz LF. Relative age effect in Olympic Taekwondo athletes. Percept Mot Skills. 2012;114:461-8.
31. Campideli TS, Ferreira RM, Coelho EF, Penna EM, Panza PS, Werneck FZ. Relative age effect in Olympic combat sports athletes/ Efeito da idade relativa em atletas olimpicos de esportes de combate. Motricidade. 2018;14:279-286.
32. Franchini E, Julio UF. The Judo World Ranking List and the Performances in the 2012 London Olympics. Asian J Sports Med. 2015;6:e24045.
33. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 2009;41:3-13.
34. Cohen J. Statistical Power Anaylsis for the Behavioural Science, 2nd Edition. L. Erlbaum Associates; 1988.
35. Cramer H. Mathematical Methods of Statistics (PMS-9), Volume 9. Princeton University Press; 2016.
36. World Taekwondo [Internet]. Qualification System – Games of the XXXII Olympiad – Tokyo 2020; 2020 [cited 2021 Mar 1]. Available from: http://www.worldtaekwondo.org/wp-content/uploads/2017/09/FINAL-2020-01-06-Tokyo-2020-Qualification-System-Taekwondo-eng.pdf.

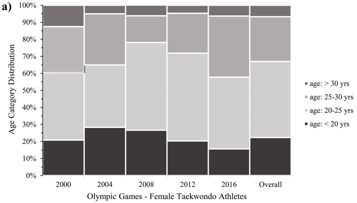
37. World Taekwondo [Internet]. WT Ranking Bylaw; 2021 [cited 2021 Mar 1]. Available from: http://www.worldtaekwondo.org/rules-wt/rules.html.
38. Ferreira Julio U, Panissa VL, Miarka B, Takito MY, Franchini E. Home advantage in judo: a study of the world ranking list. J Sports Sci. 2013;31:212-8.
39. Artioli GG, Gualano B, Franchini E, Scagliusi FB, Takesian M, Fuchs M, Lancha AH Jr. Prevalence, magnitude, and methods of rapid weight loss among judo competitors. Med Sci Sports Exerc. 2010 Mar;42:436-42.
40. Menescardi C, Liébana E, Falcó C. Why do female and male taekwondo athletes win the bout? An analysis based on the Olympic weight category and the result of the bout. RAMA. 2019;14:67-82.
41. Falco C, Landeo R, Menescardi C, Bermejo JL, Estevan I. Match analysis in a university taekwondo championship. Adv Phys Educ. 2012;2:28-31.
42. Mavi Var S. Technical analysis of 2007 and 2017 World Taekwondo Women and Men championship finals. Turk J Sport Exe. 2018;20:256–262.
43. Santos VG, Franchini E, Lima-Silva AE. Relationship between attack and skipping in Taekwondo contests. J Strength Cond Res. 2011;25:1743-51.
44. Menescardi C, Moya I, Ros C, Estevan I. Análisis del tiempo de lucha y no lucha en taekwondistas cadetes. Sportis Sci J. 2016;2:164-176.

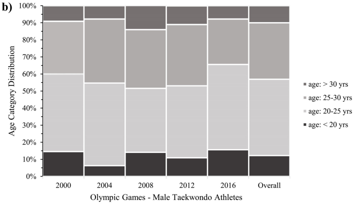

a)
2 consecutive editions
≥ 3 consecutive editions
2 non-consecutive editions
Weigth Category
+67kg "Heavy"
-67kg "Middle"
-57kg "Feather"
-49kg "Fly"
(1)
(2)
(2)
(4)
(1)
(2)
(1)
(4)
(2)
(6)
(1)
(1)
(1)
(3)
(5)
(1)
(1)
(3)
(2)
(1)
Sydney 2000
Athens 2004
Beijing 2008
London 2012
Rio 2016
Olympic Edition


b)
2 consecutive editions
≥ 3 consecutive editions
2 non-consecutive editions
Weigth Category
+80kg "Heavy"
-80kg "Middle"
-68kg "Feather"
-58kg "Fly"
(1)
(1)
(1)
(1)
(4)
(3)
(1)
(2)
(1)
(1)
(2)
(1)
(2)
(1)
(1)
(1)
(3)
(2)
(1)
(1)
(1)
(4)
(1)
(2)
Sydney 2000
Athens 2004
Beijing 2008
London 2012
Rio 2016
Olympic Edition


c)
2 consecutive editions
≥ 3 consecutive editions
2 non-consecutive editions
Weigth Category
+67kg "Heavy"
-67kg "Middle"
-57kg "Feather"
-49kg "Fly"
(1)
(2)
Sydney 2000
Athens 2004
Beijing 2008
London 2012
Rio 2016
Olympic Edition


d)
2 consecutive editions
≥ 3 consecutive editions
2 non-consecutive editions
Weigth Category
+80kg "Heavy"
-80kg "Middle"
-68kg "Feather"
-58kg "Fly"
(1)
(2)
(3)
Sydney 2000
Athens 2004
Beijing 2008
London 2012
Rio 2016
Olympic Edition


a)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Age Category Distribution
2000
2004
2008
2012
2016
Overall
Olympic Games - Female Taekwondo Athletes
age: > 30 yrs
age: 25-30 yrs
age: 20-25 yrs
age: < 20 yrs


b)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Age Category Distribution
2000
2004
2008
2012
2016
Overall
Olympic Games - Male Taekwondo Athletes
age: > 30 yrs
age: 25-30 yrs
age: 20-25 yrs
age: < 20 yrs

The Journal of Sports Medicine and Physical Fitness
EDIZIONI MINERVA MEDICA

Hypertrophic adaptations to a 6-week in-season barbell vs. flywheel squat added to regular soccer training

Cristoforo FILETTI, Bruno RUSCELLO, Italo LEO, Marco PORTA, Aldo CHIARI, Carlos Efrain MIRANDA, Vincenzo RAGO

The Journal of Sports Medicine and Physical Fitness 2022 Apr 12
DOI: 10.23736/S0022-4707.22.13793-X

Article type: Original Article

Article first published online: April 12, 2022
Manuscript accepted: March 31, 2022
Manuscript revised: March 4, 2022
Manuscript received: January 12, 2022

Title page

Original article

Hypertrophic adaptations to a 6-week in-season barbell vs. flywheel squat added to regular soccer training

Authors

Cristoforo Filetti[1,2,3,4], Bruno Ruscello[1, 2, 5, 6], Italo Leo[3,7,8], Marco Porta[2], Aldo Chiari[9], Carlos Miranda[10] , Vincenzo Rago[11*]

Authors' affiliations

[1]School of Sports and Exercise Sciences, Faculty of Medicine and Surgery, Tor Vergata University, Rome, Italy; [2]School of Sports and Exercise Sciences, San Raffaele University, Rome, Italy, [3]Unione Sportiva Salernitana 1919, Salerno, Italy; [4]Performance Department, FC Paris Saint Germain, Paris, France; [5]Department of Industrial Engineering, Faculty of Engineering, Tor Vergata University, Rome, Italy; [6] LUISS SportLab, LUISS University, Rome, Italy; [7]Departement of Human, Philosophical and Educational Sciences, University of Salerno, Salerno, Italy; [8]Department of Sport Rehab, Azienda Ospedaliera Universitaria "San Giovanni di Dio e Ruggi d'Aragona", Salerno, Italy; [9]Parthenope Sant'Antimo Basket, Napoli, Italy; [10]Querétaro Fútbol Club, Santiago de Querétaro, Mexico; [11]Faculty of Health and Sports sciences, Universidade Europeia, Lisbon.

***Corresponding author:** Vincenzo Rago

Kollinsgade 9, 6000 Kolding, Denmark

Contact: vincenzo.rago@live.com; +4561400965

Authors’ e-mails and Orcid ID

Author	E-mail	Orcid’ ID
Cristoforo Filetti	cris.86@hotmail.it	0000-0002-3931-7879
Bruno Ruscello	bruscello@alice.it	0000-0002-5381-9146
Italo Leo	italo.leo@tiscali.it	
Marco Porta	marcoporta83@gmail.com	
Aldo Chiari	aldoilcoach@gmail.com	
Carlos Miranda	efrainmdacfd@gmail.com	
Vincenzo Rago	vincenzo.rago@live.com	0000-0002-9445-4008

Acknowledgments

The authors are thankful to professor Mauro Testa for strongly assisting the collection of force and power data throughout video-analysis.

Hypertrophic adaptations to a 6-week in-season barbell vs. flywheel squat added to regular soccer training

Original research article

Abstract

BACKGROUND: The aim of this study was to compare the hypertrophic adaptations to barbell or flywheel squat exercise added to regular in-season soccer training. METHODS: Quadriceps' (rectus femoris [RF], vastus medialis [VM] and vastus lateralis [VL]) cross-sectional area (CSA) in its portions (proximal [PROX], middle [MID], and distal [DIST]) was measured on both legs before and after a 6-week barbell (80 to 90 % one-maximum repetition; *n*=7) or flywheel (0.0611 to 0.0811 Kg·m^2; *n*=7) in an U19 professional soccer team using a 3T magnetic resonance imagery. Both groups underwent 5 sets × 6 reps per session of squat separated by 3-min rest, while controlling the time under tension (within 0.5 and 0.8 s). RESULTS: The barbell squat group experienced moderate CSA increments in the VM_{MID} and the VL_{DIST} of the right leg (*d*=0.98–0.99). Additionally, the flywheel group experience large CSA increments in the RF_{MID}, VL_{PROX} and VL_{MID} of the right leg (*d*=1.00–1.84). On average, flywheel squat training largely produced greater force during exercise compared to the barbell squat training (29.2 vs. 12.2 N·kg^{-1}; *d*=5.95), whereas the barbell squat training produced moderately greater power output (10.5 vs. 9.7; *d*=0.52). CONCLUSIONS: Barbell squat training seems to be more effective for VM hypertrophy whereas flywheel squat triggers greater RF and VL hypertrophy as complementary to regular field-based soccer practice and competition within a short range of time (6 weeks) during the in-season. These findings can be considered also from either strength or reconditioning perspective based on the increase in the quadriceps muscles' CSA as mechanism underlying strength/power adaptations.

Keywords: testing, cross-sectional area, force, power, hypertrophy.

Introduction

Young soccer players cover 7000–10,000 m and change activity approximately every 4 s during an official match.1 To cope with these physical demands, players need adequate levels of muscle strength to achieve successful physical outcomes2 and reduce the risk of non-contact musculoskeletal injuries2. Particularly, thigh (hamstring or quadriceps) muscle tears are the most common muscle injuries in male soccer players and are associated with significant time loss and high financial costs for the player and clubs.3 It is therefore paramount that strength and conditioning coaches identify and optimize methods that can efficiently enhance muscle strength capacity of professional soccer players.2

The mechanisms underlying strength/power adaptations are largely associated with increases in the cross-sectional area (CSA) of the muscle (hypertrophy methods) among other factors (neural mechanisms).4,5 Collegiate-level soccer player exhibited similar CSA adaptations to a 6-week back squat program (3 sets of 75% one-repetition maximum [1RM]) of two different eccentric durations (2 vs. 4 s).6 Changes in morphology (i.e., anatomical CSA, muscle thickness) and architecture (i.e., fascicle length, pennation angles) in response to resistance training have been widely described in non-athletic populations,7 but available information in soccer players is currently limited to one study.6 However, the aforementioned study quantified the total thigh CSA using MRI, without considering the specific muscle regions.6 This could be of importance as a recent study in professional soccer players showed that different region-specific responses can be observed throughout MRI during different strength exercises.8 Additionally, CSA adaptations following resistance training have been attributed to the region-specific muscle activation assessed by the magnetic resonance images (MRI) during the training session.9,10 Thus, considering that specific muscle areas might be selectively activated during different strength exercises, it would be of interest to examine changes in specific muscle CSA after resistance training interventions.

A diverse range of either traditional resistance, plyometric11 or flywheel12 training interventions can effectively improve muscle strength, power, jump, and change of direction measures in male soccer players of varying competitive standards. Traditional resistance training programs involving free weights and weight stack machines based on the use of gravity-dependent loads have shown to achieve desirable structural and neural adaptions in athletes.13 Nonetheless, these training modalities are limited by the load lifted in the concentric phase and typically significantly underload the eccentric component of the exercise task.14 This is of importance given that the occurrence of thigh muscle strains in soccer is generally believed to be related with the presence of repetitive high force eccentric actions in soccer, such as the ones observed during high-speed running, where the lengthening demands placed on the muscle could exceed the mechanical limits of the tissue.[15] To date, studies comparing the effectiveness of traditional barbell vs. flywheel training have been conducted in non-athletic populations, showing that flywheel training may lead to superior[16] or similar[13,17] gains in muscle mass. Additionally, intervention studies comparing the effectiveness of barbell vs. flywheel training in soccer players have been conducted on field or laboratory-based performance test, without information available on skeletal muscles' structural adaptations.[11,12] Thus, it would be of interest to examine changes in muscles' CSA after either barbell or flywheel training in soccer players.

Based on the aforementioned information, the aim of this study was to compare the CSA effects of barbell or flywheel squat exercise added to regular in-season soccer training. A secondary aim was to compare the kinetic (force and power) responses during the squat exercise throughout the intervention.

Methods

Experimental approach to the problem

A randomized controlled design was adopted to compare the short-term (6 weeks) effects of the two different training protocols (barbell vs. flywheel) squat on the quadriceps' CSA during the in-season (April-May 2019). The training intervention consisted of 5 sets × 6 reps per session of squat separated by 3-min rest, while controlling the time under tension (within 0.5 and 0.8 s).[18] Quadriceps' (rectus femoris [RF], vastus medialis [VM] and vastus lateralis [VL]) cross-sectional area (CSA) in its portions (proximal [PROX], middle [MID], and distal [DIST]) was measured on both legs before and after a 6-week barbell or flywheel using a 3T MRI. Specifically, both groups underwent a baseline testing to assess the individual one-maximum repetition (1RM), then 6 familiarization sessions over a two-week period, pre-intervention MRI assessment, then the intervention which consisted of 16 sessions (3 sessions for the first 5 weeks, and one session in the last week), and finally a post-intervention MRI. Quadriceps' CSA was tested in the week before the commencement of the study, and in the last week of the intervention (2 days after the last session). A detailed description of the training intervention is reported in **table 1**.

During the intervention period, the participants were not involved in congested fixtures, and the intervention sessions were always performed on the match day plus 2, minus 4 and minus 2, before the players' regular soccer practice on the field (4 practice sessions per week). No further lower body resistance training was performed. A detailed description of the weekly program is reported in **table**

2. No control group was used since it would have resulted in an unethical and impactable approach, not suitable for the present in-season design.19

Table 1 and 2 near here

Subjects

Sixteen outfield professional U19 male soccer players from the same team competing in U19 Italian first league (*Campionato Primavera*) voluntarily participated in the present study. After exclusion of two players due to muscle injury throughout the intervention, 14 players (Mean ± standard deviation [SD]; age = 18 ± 1 years old, body mass = 76.2 ± 6.9 kg, height 182 ± 6 cm), were randomly assigned to barbell squat group (FW, *n*=7) or and flywheel squat group (FD, *n*=7). The players trained 4 times per week, for a total training volume of ~8 hours / week of soccer plus ~50 minutes of strength workout in the gym, and one competitive game per week. All the participants were injury-free during the last 8 weeks before the beginning of the study and had a minimum of 7-years professional football background. None of the players were involved with the first team' practice sessions for the whole period of the study. All players had the right foot as dominant.

The Institutional Board of the Faculty of Medicine, University Tor Vergata, Rome provided clearance for the procedures before the commencement of this study. Written informed consent was obtained from all the participants after familiarization and explanation of the benefit and risks involved in the procedures of this study. All participants were free to withdraw during the study period at any time without penalty. All procedures were conducted in accordance with ethical standards for sport sciences studies.20

Procedures

Magnetic Resonance Imagery

The CSA of the quadriceps muscles (RF, VM and VL), measurements of the thigh were performed on both legs (right leg was the dominant for all the subjects) using a 3T whole-body imager with surface phased-array coils (Siemens Magnetom Symphony TIM 1.5 T, Gradient 30mT/m, intensity 125 T/m/s slew rate) similarly to that described elsewhere.8,21 All the scans were performed with the subjects positioned inside the magnet, the thighs of both legs were kept parallel to the MRI table, and a custom-made foot-restrain device was used to standardize and fix limb position and to avoid any compression of thigh muscles. The players were supine on the MR-gurney with thighs covered with one 32- and 2 flexible 4-channel coils, respectively in the proximal and distal segments. 12 cross-sectional images of both thighs were obtained, starting at the distal margin of the ischial tuberosity. Acquisition time of the imaging sequence was 16 s. A parametric image was generated from transverse relaxation time mapping sequence using a workstation. Scout images and anatomical landmarks were obtained to ensure identical and time-efficient positioning in pre- and post- scans. Muscles' transverse relaxation time of the dominant leg (all right) were measured using OSIRIX program for review and display of DICOM images.

The total thickness of each of VM, RM and VL in its portions (PRO, MID and DIST) was assessed. Using the fat- suppressed images to detect any confounding artifact (i.e., vessels, fat), a circular region of interest was selected for individual muscles in each of the transverse relaxation time mapping images where muscles were visible. The vastus intermedius was not considered due to the impossibility to distinguish between vastus lateralis both anatomically and on MRI images , and its weak connection to soccer-specific tasks. All images were independently analyzed by one accredited radiologist, blinded to the origin of any image.

Training intervention

A standardized generic warm-up lasting approximately 20 min were performed by both intervention group. This consisted of approximately 5-min dynamic stretching, and half squat (3 sets of 10 repetitions body weight, separated by 45-s rest). Then, a specific activation was performed according to the specific group (see below). The participants of both groups were instructed to perform the concentric phase (knee and hip extension) and to reach approximately 90° of knee bending during the eccentric phase (knee and hip flexion) within 0.5 to 0.8 s. Environmental temperature was kept to 21 ± 1°C in the gym. A mirror was placed opposite to the participants to let them visually check their technique.

After the generic warm-up (described above), the barbell squat group performed a specific warm-up based on 70% of 1RM (which was directly determined previously using the procedure outlined by Sheppard & Triplett 22). During the intervention, training intensity (in kg) ranged from 80 and 90 % 1RM throughout the intervention (5% increases every 2 weeks starting at 80%, 85% and 90% in the 1st, 3rd, and 5th week, respectively). Each set was interspersed by 3 min of passive recovery. This training intensity and progression was in line with the American College of Sports Medicine which recommends 3-6 sets of 1-12 repetitions with 70-100% 1RM for advanced individuals.[23] As specific warm-up, the flywheel group performed two sets of 10 repetitions squats on the flywheel device (Desmotec D.11 device – Desmotec, Biella, Italy) with a fixed inertia of 0.006 $Kg \cdot m^2$ separated by 45-s rest between sets. During the intervention, intensity ranged from 0.0611 to 0.0811 $Kg \cdot m^2$, which was within the range of practical recommendations using flywheel exercise in athletes. 14 Rather than using a fixed inertia, we adopted an individualized inertia based on players' capacity. The participants were instructed to perform the concentric phase of the flywheel half squats with maximal velocity, and the eccentric phase until the thighs were parallel to the ground.[2,14] Each set was interspersed by 3 min of passive recovery. In addition to number of sets, repetitions and rest between sets, to ensure relatively comparable conditions between the two interventions, we standardized the time under tension between 0.5 to 0.8 s. This was based on a meta-analysis which indicated that hypertrophic adaptations occur in this range18 whereby acute exercise stress could vary between intervention group.24

Kinetic responses during exercise

Kinetic responses during the flywheel squat were recorded using a miniature compression load cell that measured force through the pull of the strap. Two contact panels were connected to a computer equipped with the dedicated software (D11-Full, Desmotec D-Soft, Desmotec, Biella, Italy) sampling at 25 Hz. The participant was connected to the device by a strap with one end tied to the device and the other to a waistcoat worn. The strap was tightened not to allow the respondent to move up. During the squat execution, the contact panels measured the force that the participant produces and which is read on the computer (good test-retest reliability; $\alpha = 0.889$).25

For the barbell squat, kinetic responses were recorded using a high-frequency Video Camera (Go Pro Hero 5, USA) sampling at 60 frames per second with a resolution of 1080 pixels. The camera was placed laterally at 1.6 m apart of the center of mass of each subject. Afterwards, the videos were analyzed using the BioMovie Software (Infolabmedia, Torino, Italy). The performance area was calibrated by calculating the pixels' size of the chosen one area, and trajectory of the barbell was automatically tracked by the video analysis software using specific purposeful algorithms based on the spatiotemporal parameters as similarly described by Sañudo, et al. 26. This allowed to calculate the force produced based on the barbell' acceleration and the weight lifted. Then, power was calculated by multiplying the instantaneous force with the corresponding speed every 0.01 s. The software generated an automated graph that synchronized itself to the video from which the force and power outputs were extrapolated. This system showed excellent levels of reproducibility (coefficient of variation < 4.5%).27 A sample kinetic data collection during the barbell squat was illustrated in **Figure 1**.

Average power ($W \cdot Kg^{-1}$) and the average force ($N \cdot Kg^{-1}$) produced during the squat execution were scaled by individual body mass and retained as indicators of kinetic responses during exercise. Average values between considering both concentric and eccentric phases were presented.

Figure 1 near here

Statistical Analysis

Before the commencement of the study, the hypothesis of no between-group differences in the pre-intervention CSA was tested ($P > 0.05$). Shapiro-Wilk test revealed that CSA data were normally distributed within each evaluation moment. A paired-sample t-test was used to compare muscle' CSA before and after the intervention (within groups), whereas an independent sample t-test to compare acute kinetic responses during exercise (between groups). The magnitude of differences (*d*) and associated 95% confidence intervals (95% CIs) were computed on t statistic and degrees of freedom,28 and interpreted according to Rhea's recommendation for strength training interventions of highly-trained individuals: trivial ($d < 0.25$), small ($d = 0.25–0.50$), moderate ($d = 0.50–1.00$), large ($d > 1.0$). When 95% confidence intervals overlapped positive and negative values, the effect was deemed to be unclear. To provide practical indications about changes in force and power output during the squat exercise, the smallest worthwhile change (SWC) was calculated by multiplying 0.3 by the between-subjects' CV.29

Data were presented as mean and 95% CI unless otherwise stated. Data analyses were performed in R software (R-4.1.1 for Windows; R core Team, Vienna, Austria).

Results

The barbell squat group experienced moderate CSA increments in the VM_{MID} and the VL_{DIST} of the right leg (*d* [95% CIs] = -0.99 [-1.92; -0.06] and -0.98 [-1.91; -0.05], respectively; $P < 0.05$) whereas no significant changes were observed in the left leg ($P > 0.05$). Additionally, the flywheel group experience large CSA increments in the RF_{MID}, VL_{PROX} and VL_{MID} (*d* [95% CIs] = -1.01 [-1.94; -0.08], -1.00 [-1.93; -0.07] and -1.84 [-2.83; -0.84], respectively; $P < 0.05$). A detailed description of CSA adaptations to barbell and flywheel squat training is reported in **table 3**.

For force output, the SWC was 0.34 and 0.86 $N \cdot kg^{-1}$, whereas for power output was 0.34 and 0.31 $W \cdot kg^{-1}$, for the barbell and flywheel squat respectively (**Figure 2**; see shaded area). On average, flywheel squat training largely produced greater force during exercise compared to the barbell squat training (29.2 ± 1.5 vs. 12.2 ± 0.1 N·kg^{-1}; *d* [95% CIs] = 5.95 [4.91; 6.98]; *P* < 0.001; **Figure 2A**). However, traditional barbell squat training produced moderately greater power output during exercise compared to flywheel squat training (10.5 ± 0.6 vs. 9.7 ± 0.5; *d* = 0.52 [0.09; 0.95]; *P* = 0.023; **Figure 2B**).

Table 3 and figure 2 near here

Discussion

This is the first study to examine CSA adaptations following traditional resistance (i.e., barbell) or flywheel squat training during the competitive period in professional young soccer players. Muscle hypertrophy is considered one important goal to be achieved in youth sport as a foundation for further improvements in strength and power.5,30 In this randomized controlled trial, we observed that U19 professional soccer players can benefit from either barbell and flywheel squat exercise added to regular training and competitive schedule three times per week. Both training interventions seem to promote meaningful CSA increments of dominant leg. Specifically, barbell squat seems to be more effective for VM hypertrophy whereas flywheel squat for RF and VL hypertrophy. These findings can be considered also from either strength or reconditioning perspective based on the increase in the quadriceps muscles' CSA as mechanism underlying strength/power adaptations.

The RF_{MID} adaptations of the right leg after flywheel squat training compared to the non-significant changes in RF muscle after barbell squat training might be explained by the greater RF use during flywheel compared to barbell squat.31 On the other hand, the barbell squat group experienced moderate increments in the CSA of the right VM_{MID}, whereas no significant VM adaptations were observed in the flywheel group. This seems to be in contrast to extensive studies reporting greater muscle use collected throughout MRI31 and activation throughout electromyography.32 Thus, further research is warranted to clarify greater increases in VM following barbell (isotonic) squat compared to flywheel squat. In this context, it is clear that regular soccer practice characterized by frequent kicking and associated stimulation of VM muscles, may have interfered with the training intervention. The flywheel group experience moderate increments in the CSA of the VL_{PROX} and VL_{MID}, whereas the barbell squat group increased the CSA of the VL_{DIST}. Our observed greater VL growth following flywheel training than barbell squat might be supported by the greater VL activation, and the resulting mechanical stress promoting hypertrophy.32-34 However, the aforementioned studies have been conducted in non-athletic populations underling the need of further research in soccer players or other athletic populations to better understand physiological factors leading to muscle hypertrophy.

It is not possible to directly compare free weights vs. iso-inertial exercise due their different inherent unit of measure to calibrate intensity (weight in kg vs. inertia in $Kg{\cdot}m^2$). Thus, to ensure relatively comparable conditions between the two interventions, we adopted a quasi-identical time under tension (0.5 to 0.8 s) with same number of sets, repetitions and rest between sets. This is of importance as different time under tension could positively (if longer) or negatively (if shorter) mediate intracellular anabolic signalling, promoting different hypertrophic responses.18

Based on the well-established association between strength- / power-based capacities and muscles' CSA, our findings might be comparable to other ones examining the effectiveness of barbell squat training in young soccer players during the in-season throughout 8 to 12 weeks as complementary of regular soccer training.11 In general, our findings are supported by extensive evidence supporting the usefulness of flywheel training to promote skeletal muscle adaptations in various healthy and athletic population.16 Specifically, significant increases in quadriceps muscle volume have been observed in healthy men aged 39 years old following a 5-week flywheel squat training (4 sets of 7 reps/session)33 as well as in 30–53 year men and women following 5-week unilateral leg extension flywheel training.34 Whereas a wide range of studies has proven the beneficial effects of squat-based flywheel training in soccer players,12 no information was available regarding changes in muscle size. Thus, it is challenging to compare our findings with the available published research in this area. Nonetheless, based on the well-established association between strength- / power-based capacities and muscles' CSA, our findings might be comparable to other ones examining the effectiveness of squat-based flywheel training in soccer players during the in-season. For example, improved isokinetic strength of the thigh muscles, change of direction capacity,19 jumping and linear sprinting ability, injury incidence and severity35 as well as body composition36 have been observed following flywheel training based on squat or leg curl exercise in soccer players.

The lack of significant changes in the non-dominant (left) leg could be explained by the fact that players were involved in an-season intervention, being less sensitive to resistance training compared to the pre-season or off-season.11 Additionally, the whole week load (including field training) could have resulted in load differences between players. Consequently, performance adaptations to a given training intervention could be mediated by the physiological demands imposed by field practice as recently revealed in an U19 professional soccer team.37

When directly comparing resistance training according to the eccentric emphasis, one study have examined changes in CSA following barbell squat training, demonstrating positive effects on

CSA irrespective of the eccentric duration (2 vs. 4 s).6 Additionally, a recent study showed that either barbell or flywheel squat training were equally effective in improving sprint time and jump height in amateur soccer players, whereas barbell squat promoted a more than two-fold larger increase in 1RM maximal partial squat strength than flywheel.38 Taken, together with our findings, this may suggest that both traditional resistance and eccentric training may promote similar performance and structural adaptations. However, further research is warranted to support our findings.

On average, flywheel squat training largely produced greater force during exercise compared to the barbell squat training, which could be attributed to higher electromyographic activity noted during the eccentric phase, which also result in greater mechanical stress and associated hypertrophic responses.32 Indeed, muscle activation during free weight exercise is far from maximal throughout the range of motion, except for the last repetition at the point of failure to raise the weight. In contrast, the inertia of flywheel offers unrestrained resistance in each action, evoking maximal or near-maximal activation throughout the set, with force progressively decreasing with fatigue.32 On the other hand, traditional barbell squat training produced moderately greater power output during exercise compared to flywheel squat training, which could be attributed to the movement speed during the concentric phase of the squat. Despite of the moderate-to-large effect sizes, our comparison in acute kinetic responses during exercise should interpreted with caution based on the different methodologies adopted to collect force and power data. Indeed, ergometer (flywheel) and 2D video-analysis (barbell) possess different measurement error, and thus data quality might be skewed by the different data collection methods employed. Thus, it is important that future studies adopt the same motion analysis system to compare acute kinetic / kinematic responses during exercise.

To our knowledge, this is the first randomized controlled trial to compare traditional barbell to flywheel squat added to regular soccer training. Such information is applicable for strength and conditioning coaches involved with young soccer players. In this context, evidence suggests that > 70% soccer players start their professional career between 17 and 19 years old (under 19, U19).39 In this context, strength, and body size (which is related to muscle CSA)4 have been reported as main factor to select young professional soccer players.40 Thus, it is expected that players at this age and stage of development are ready to strength train. Additionally, it is important to examine the responsiveness to strength training throughout the competitive schedule, given the lower sensitivity to training-induced adaptations during the in-season compared to pre- or off-season.11

It is important to underline some limitations inherent to this study. This is a case study limited to 7 subjects per intervention group. Thus, our results should be interpreted with caution when generalizing to the generic U19 soccer player population. Additionally, muscle hypertrophy occurs when muscle protein synthesis exceeds muscle protein breakdown and results in positive net balance in cumulative periods, which can be achieved throughout protein ingestion alongside resistance training.[41] However, it was not possible to control the protein intake. Additionally, no control group was included. Although it could have strengthened the study design, it was not ethically acceptable to benefit some players in detriment of others. Importantly, the two protocols (barbell vs flywheel) were not exactly matched (exercise intensity). Indeed, both power and force are significantly different between the exercises, therefore the two groups did not undergo an accurately comparable intervention. For instance, greater average force has been reported for flywheel training, and this could explain the greater CSA adaptations reported.

Practical applications

Either traditional barbell or flywheel resistance exercise seems to be effective to promote quadriceps' hypertrophy in U19 soccer players during the in-season three times per week, as complementary to regular field-based soccer practice and competition within a short range of time (6 weeks). Specifically, barbell squat seems to be more effective for VM hypertrophy whereas flywheel squat for RF and VL hypertrophy. Notwithstanding, these CSA gains were only observed in the dominant leg. Thus, further studies are warranted to explore the interference of field-based practice and competition on changes in muscles' CSA. Despite of the same time under tension, flywheel training allows to produce greater force output than barbell / free weights training, which can be considered also from either strength or reconditioning perspective based on the relevance of the quadriceps muscles for soccer players.

References

1. Palucci Vieira LH, Carling C, Barbieri FA, Aquino R, Santiago PRP. Match Running Performance in Young Soccer Players: A Systematic Review. *Sports Med.* 2019;49(2):289-318.
2. Beato M, Maroto-Izquierdo S, Turner AN, Bishop C. Implementing Strength Training Strategies for Injury Prevention in Soccer: Scientific Rationale and Methodological Recommendations. *Int J Sports Physiol Perform.* 2021;16(3):456-461.
3. Ekstrand J, Hagglund M, Walden M. Epidemiology of muscle injuries in professional football (soccer). *The American journal of sports medicine.* 2011;39(6):1226-1232.
4. Gabriel DA, Kamen G, Frost G. Neural adaptations to resistive exercise: mechanisms and recommendations for training practices. *Sports Med.* 2006;36(2):133-149.
5. Jones EJ, Bishop PA, Woods AK, Green JM. Cross-sectional area and muscular strength: a brief review. *Sports Med.* 2008;38(12):987-994.
6. Shibata K, Takizawa K, Nosaka K, Mizuno M. Effects of Prolonging Eccentric Phase Duration in Parallel Back-Squat Training to Momentary Failure on Muscle Cross-Sectional Area, Squat One Repetition Maximum, and Performance Tests in University Soccer Players. *J Strength Cond Res.* 2021;35(3):668-674.
7. Krzysztofik M, Wilk M, Wojdała G, Gołaś A. Maximizing Muscle Hypertrophy: A Systematic Review of Advanced Resistance Training Techniques and Methods. *Int J Environ Res Public Health.* 2019;16(24).
8. Mendez-Villanueva A, Suarez-Arrones L, Rodas G, et al. MRI-Based Regional Muscle Use during Hamstring Strengthening Exercises in Elite Soccer Players. *PloS one.* 2016;11(9):e0161356.
9. Wakahara T, Fukutani A, Kawakami Y, Yanai T. Nonuniform muscle hypertrophy: its relation to muscle activation in training session. *Med Sci Sports Exerc.* 2013;45(11):2158-2165.
10. Hedayatpour N, Falla D. Non-uniform muscle adaptations to eccentric exercise and the implications for training and sport. *Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology.* 2012;22(3):329-333.
11. Silva JR, Nassis GP, Rebelo A. Strength training in soccer with a specific focus on highly trained players. *Sports medicine - open.* 2015;1(1):17.
12. Allen WJC, De Keijzer KL, Raya-González J, Castillo D, Coratella G, Beato M. Chronic effects of flywheel training on physical capacities in soccer players: a systematic review. *Research in sports medicine (Print).* 2021:1-21.
13. Vicens-Bordas J, Esteve E, Fort-Vanmeerhaeghe A, Bandholm T, Thorborg K. Is inertial flywheel resistance training superior to gravity-dependent resistance training in improving muscle strength? A systematic review with meta-analyses. *Journal of science and medicine in sport.* 2018;21(1):75-83.
14. Beato M, Dello Iacono A. Implementing Flywheel (Isoinertial) Exercise in Strength Training: Current Evidence, Practical Recommendations, and Future Directions. *Frontiers in physiology.* 2020;11:569-569.

15. Carling C, Gall FL, Reilly TP. Effects of physical efforts on injury in elite soccer. *Int J Sports Med.* 2010;31(3):180-185.

16. Maroto-Izquierdo S, García-López D, Fernandez-Gonzalo R, Moreira OC, González-Gallego J, de Paz JA. Skeletal muscle functional and structural adaptations after eccentric overload flywheel resistance training: a systematic review and meta-analysis. *Journal of science and medicine in sport.* 2017;20(10):943-951.

17. Lundberg TR, García-Gutiérrez MT, Mandić M, Lilja M, Fernandez-Gonzalo R. Regional and muscle-specific adaptations in knee extensor hypertrophy using flywheel versus conventional weight-stack resistance exercise. *Applied physiology, nutrition, and metabolism = Physiologie appliquee, nutrition et metabolisme.* 2019;44(8):827-833.

18. Schoenfeld BJ, Ogborn DI, Krieger JW. Effect of repetition duration during resistance training on muscle hypertrophy: a systematic review and meta-analysis. *Sports Med.* 2015;45(4):577-585.

19. Coratella G, Beato M, Cè E, et al. Effects of in-season enhanced negative work-based vs traditional weight training on change of direction and hamstrings-to-quadriceps ratio in soccer players. *Biology of sport.* 2019;36(3):241-248.

20. Winter EM, Maughan RJ. Requirements for ethics approvals. *J Sports Sci.* 2009;27(10):985.

21. Fernandez-Gonzalo R, Tesch PA, Linnehan RM, et al. Individual Muscle use in Hamstring Exercises by Soccer Players Assessed using Functional MRI. *Int J Sports Med.* 2016;37(7):559-564.

22. Sheppard J, Triplett N. Program Design for Resistance Training. In: Haff GG, Triplett N, eds. *Essentials of strength training and conditioning.* Champaign, Illinois: Human Kinetics; 2015.

23. ACSM. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc.* 2009;41(3):687-708.

24. Wilk M, Zajac A, Tufano JJ. The Influence of Movement Tempo During Resistance Training on Muscular Strength and Hypertrophy Responses: A Review. *Sports Med.* 2021;51(8):1629-1650.

25. Stojanović MDM, Mikić M, Drid P, et al. Greater Power but Not Strength Gains Using Flywheel Versus Equivolumed Traditional Strength Training in Junior Basketball Players. *International Journal of Environmental Research and Public Health.* 2021;18(3).

26. Sañudo B, Rueda D, Pozo-Cruz BD, de Hoyo M, Carrasco L. Validation of a Video Analysis Software Package for Quantifying Movement Velocity in Resistance Exercises. *J Strength Cond Res.* 2016;30(10):2934-2941.

27. Annino G, Romagnoli C, Zanela A, et al. Kinematic Analysis of Water Polo Player in the Vertical Thrust Performance to Determine the Force-Velocity and Power-Velocity Relationships in Water: A Preliminary Study. *International Journal of Environmental Research and Public Health.* 2021;18(5):2587.

28. Lakens D. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in psychology.* 2013;4:863.

29. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc.* 2009;41(1):3-13.

30. Lloyd RS, Oliver JL. The Youth Physical Development Model: A New Approach to Long-Term Athletic Development. *Strength & Conditioning Journal.* 2012;34(3).

31. Norrbrand L, Tous-Fajardo J, Vargas R, Tesch PA. Quadriceps muscle use in the flywheel and barbell squat. *Aviat Space Environ Med.* 2011;82(1):13-19.

32. Norrbrand L, Pozzo M, Tesch PA. Flywheel resistance training calls for greater eccentric muscle activation than weight training. *Eur J Appl Physiol.* 2010;110(5):997-1005.

33. Norrbrand L, Fluckey JD, Pozzo M, Tesch PA. Resistance training using eccentric overload induces early adaptations in skeletal muscle size. *Eur J Appl Physiol.* 2008;102(3):271-281.

34. Tesch PA, Ekberg A, Lindquist DM, Trieschmann JT. Muscle hypertrophy following 5-week resistance training using a non-gravity-dependent exercise system. *Acta Physiol Scand.* 2004;180(1):89-98.

35. de Hoyo M, Pozzo M, Sañudo B, et al. Effects of a 10-week in-season eccentric-overload training program on muscle-injury prevention and performance in junior elite soccer players. *Int J Sports Physiol Perform.* 2015;10(1):46-52.

36. Suarez-Arrones L, Saez de Villarreal E, Núñez FJ, et al. In-season eccentric-overload training in elite soccer players: Effects on body composition, strength and sprint performance. *PloS one.* 2018;13(10):e0205332.

37. Miranda C, Rago V, Silva JR, Rebelo A. Effects of traditional vs. complex strength training added to regular football training on physical capacities in U19 football players: a team study. *Sport Sciences for Health.* 2021.

38. Sagelv EH, Pedersen S, Nilsen LPR, et al. Flywheel squats versus free weight high load squats for improving high velocity movements in football. A randomized controlled trial. *BMC sports science, medicine & rehabilitation.* 2020;12:61.

39. Rebelo A, Brito J, Maia J, et al. Anthropometric characteristics, physical fitness and technical performance of under-19 soccer players by competitive level and field position. *Int J Sports Med.* 2013;34(4):312-317.

40. Nughes E, Rago V, Aquino R, Ermidis G, Randers MB, Ardigò LP. Anthropometric and Functional Profile of Selected vs. Non-Selected 13-to-17-Year-Old Soccer Players. *Sports.* 2020;8(8).

41. Damas F, Libardi CA, Ugrinowitsch C. The development of skeletal muscle hypertrophy through resistance training: the role of muscle damage and muscle protein synthesis. *Eur J Appl Physiol.* 2018;118(3):485-500.

Tables

Table 1. Progression of a 6-week in-season traditional barbell or flywheel squat in an under-19 professional soccer team.

	Familiarization		Intervention					
Week	1st	2nd	1st	2nd	3rd	4th	5th	6th
MRI assessment		↓						↓
Training frequency (sessions)	3	3	3	3	3	3	3	1
Squat training intensity								
Barbell free weight (%1RM)	70	70	80		85		90	
Flywheel ($Kg·m^2$)	0.006	0.006	0.0611 to 0.0811	0.0611 to 0.0811	0.0611 to 0.0811	0.0611 to 0.0811	0.0611 to 0.0811	0.0611 to 0.0811

1RM, one-maximum repetition; MRI, magnetic resonance imagery

Table 2. In-season weekly training program for the under-19 professional soccer team involved in a 6-week in-season traditional barbell or flywheel squat.

Day	Intervention	Field practice
Monday		Off
Tuesday	↓	Starters (≥ 60 min): foam roller, upper body and biking (~45 min);
		Non-starters (< 60 min): warm-up, SSGs, aerobic training, upper body (~60 min).
Wednesday	↓	Warm-up (~15 min), agility and quickness (~10 min), tactical (~30 min), SSGs (~20 min) and high-intensity aerobic training (~15 min)
Thursday		Warm-up (~15 min), tactical (~20 min), set pieces (~15 min) and SSGs (~30 min)
Friday	↓	Warm-up (~15 min), set pieces (~15 min), Tactical (~15 min), SSGs (~10 min) and shooting (~10 min).
Saturday		Off
Sunday		Match at 11 AM

SSGs, small-sided games

Table 3. Thigh cross-sectional area before and after a 6-week in-season barbell or flywheel squat in an under-19 professional soccer team.

Variable	Barbell squat (*n* = 7)				Flywheel squat (*n* = 7)			
	Before	After	*P*	*d* (95% CIs)	Before	After	*P*	*d* (95% CIs)
Right leg								
RF_{PROX}	22.5 (19.4; 25.6)	23.5 (20.4; 26.6)	0.268	-0.46 (-1.35; 0.43)	24.9 (21.3; 28.5)	22.7 (18.5; 26.8)	0.192	0.55 (-0.34; 1.45)
RF_{MID}	24.8 (21.2; 28.3)	26.4 (23.7; 29.0)	0.351	-0.38 (-1.27; 0.51)	21.4 (18.4; 24.5)	23.7 (20.2; 27.2)	0.037	-1.01 (-1.94; -0.08)
RF_{DIST}	12.9 (10.6; 15.3)	15.6 (13.7; 17.5)	0.159	-0.61 (-1.51; 0.29)	13.4 (9.8; 16.9)	14.7 (11.4; 17.9)	0.087	-0.77 (-1.68; 0.14)
VM_{PROX}	22.7 (18.8; 26.5)	25.7 (22.9; 28.6)	0.085	-0.78 (-1.69; 0.14)	22.5 (18.5; 26.5)	23.3 (19.3; 27.2)	0.690	-0.16 (-1.04; 0.72)
VM_{MID}	28.3 (26.3; 30.3)	32.2 (28.3; 36.0)	0.040	-0.99 (-1.92; -0.06)	26.4 (24.4; 28.5)	28.6 (26.7; 30.4)	0.063	-0.86 (-1.78; 0.06)
VM_{DIST}	31.4 (26.4; 36.4)	31.7 (27.3; 36.2)	0.923	-0.04 (-0.92; 0.84)	27.4 (24.8; 29.9)	27.3 (21.4; 33.3)	0.992	0.00 (-0.88; 0.88)
VL_{PROX}	36.3 (31.8; 40.9)	33.7 (28.9; 38.4)	0.347	0.39 (-0.5; 1.28)	30.8 (26.4; 35.3)	33.7 (28.3; 39.1)	0.038	-1.00 (-1.93; -0.07)
VL_{MID}	29.7 (24.0; 35.5)	32.5 (30.4; 34.5)	0.387	-0.35 (-1.24; 0.54)	26.2 (22.1; 30.5)	32.3 (26.6; 37.9)	0.003	-1.84 (-2.83; -0.84)
VL_{DIST}	14.0 (10.0; 18.0)	18.2 (13.7; 22.6)	0.041	-0.98 (-1.91; -0.05)	15.1 (12.4; 18.2)	18.3 (15.6; 21.0)	0.091	-0.76 (-1.67; 0.15)
Left leg								
RF_{PROX}	23.8 (20.8; 26.8)	26.2 (22.4; 30.0)	0.169	-0.59 (-1.49; 0.31)	22.3 (19.5; 25.2)	22.6 (19.9; 25.3)	0.855	-0.07 (-0.95; 0.81)
RF_{MID}	26.4 (23.3; 29.5)	25.9 (23.9; 27.9)	0.750	0.13 (-0.76; 1.01)	21.8 (20.2; 23.5)	23.1 (21.0; 25.2)	0.315	-0.41 (-1.31; 0.48)
RF_{DIST}	15.8 (11.4; 20.3)	17.2 (14.6; 19.7)	0.368	-0.37 (-1.26; 0.52)	12.7 (10.6; 14.9)	14.8 (12.1; 17.5)	0.208	-0.53 (-1.43; 0.36)
VM_{PROX}	24.3 (21.5; 27.1)	23.3 (20.9; 25.7)	0.268	0.46 (-0.43; 1.36)	23.2 (19.5; 26.9)	23.5 (21.1; 25.8)	0.888	-0.06 (-0.94; 0.83)
VM_{MID}	28.3 (24.6; 31.9)	28.7 (24.5; 32.9)	0.795	-0.10 (-0.98; 0.78)	24.8 (22.4; 27.1)	25.6 (22.5; 28.8)	0.371	-0.37 (-1.25; 0.52)
VM_{DIST}	32.8 (27.5; 38.1)	30.1 (26.6; 33.7)	0.205	0.54 (-0.36; 1.44)	28.8 (24.3; 33.3)	26.0 (21.2; 30.8)	0.140	0.64 (-0.26; 1.55)
VL_{PROX}	35.0 (30.0; 40.0)	39.6 (34.8; 44.5)	0.200	-0.54 (-1.44; 0.35)	31.5 (27.0; 36.0)	35.9 (28.8; 43.0)	0.159	-0.61 (-1.51; 0.3)
VL_{MID}	30.5 (26.2; 34.8)	36.7 (30.5; 42.9)	0.058	-0.88 (-1.80; 0.04)	28.6 (24.6; 32.6)	32.2 (29.2; 35.2)	0.074	-0.82 (-1.73; 0.10)
VL_{DIST}	22.3 (14.9; 29.8)	24.9 (18.3; 31.5)	0.250	-0.48 (-1.37; 0.40)	21.7 (16.4; 27.0)	24.0 (20.1; 27.9)	0.115	-0.70 (-1.60; 0.21)

CIs, confidence intervals; RF, rectus femoris; VL, vastus lateralis; VM, vastus medialis; PROX, proximal portion; MID, medial portion; DIST, distal portion.

Figures' caption and legend

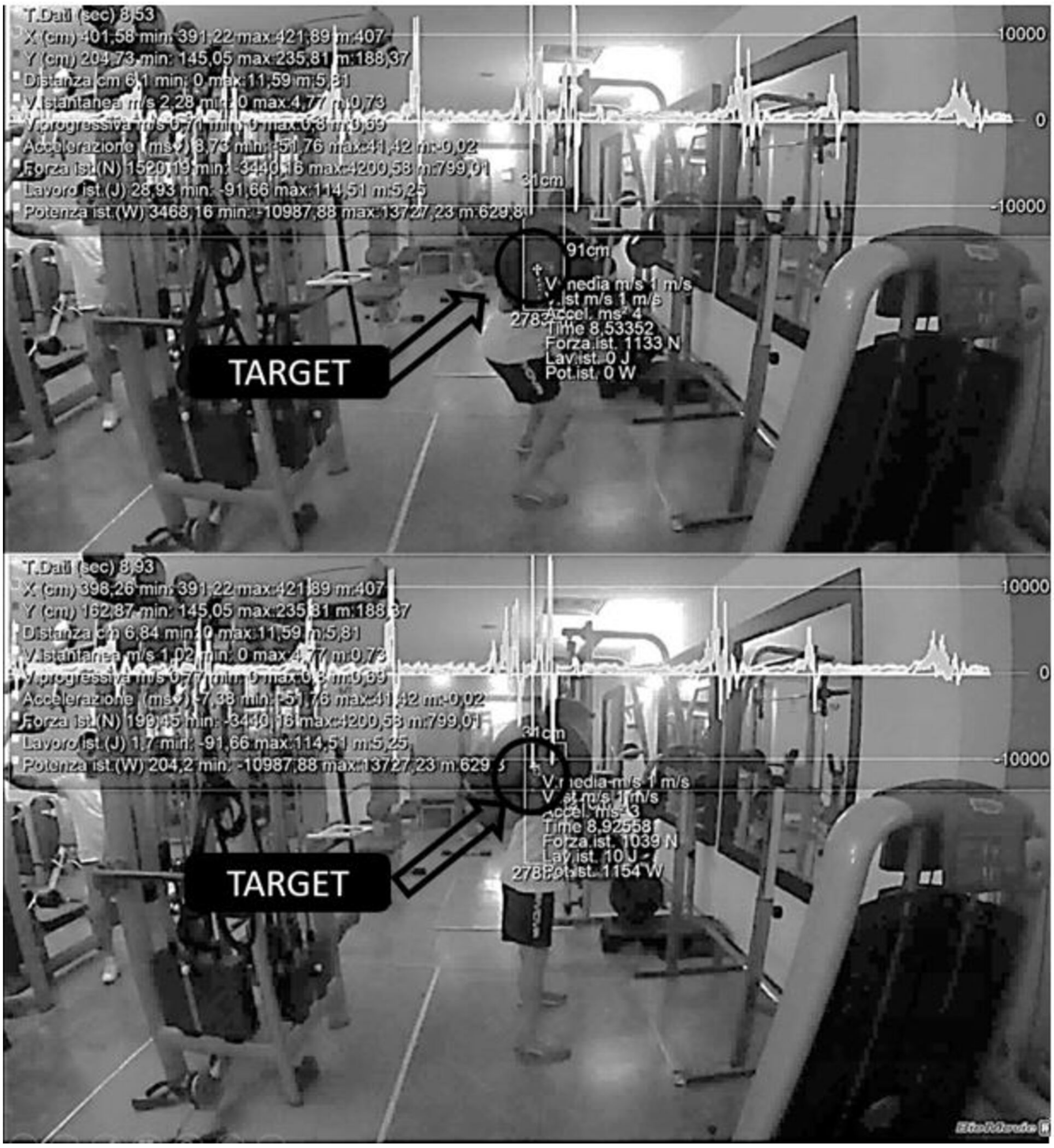
Figure 1. Sample kinetic data collection during the barbell squat.

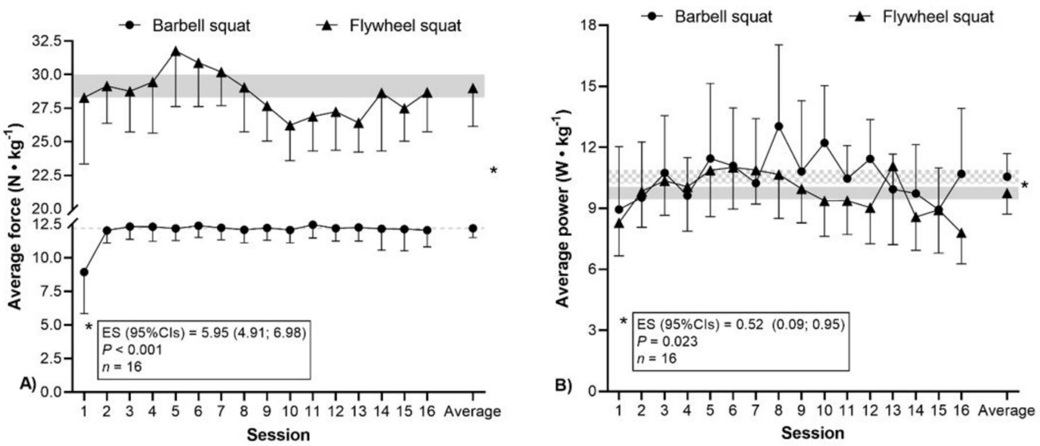
Figure 2. Force (a) and power (b) produced throughout a 6-week in-season traditional barbell or flywheel squat in an under-19 professional soccer team.

The dotted-filled area is the smallest worthwhile change for the barbell squat group, whereas the grey-filled area is the smallest worthwhile change for the flywheel group; *, significant between-group differences ($P < 0.05$); CIs, confidence intervals.

Authors' statement of contribution.

CR designed the study and collected the data. BR and VR conducted the statistical analyses. CR and VR wrote the manuscript. IL organized and assisted with data collection. MP, AC and CM retrieved the data. CR and VR conceptualized the manuscript. All authors read and approved the final version of the manuscript


T.Dati (sec) 8,53
10000
0
-10000
91cm
TARGET
T.Dati (sec) 8,93
TARGET


Barbell squat
Flywheel squat
Average force (N • kg-1)
ES (95%CIs) = 5.95 (4.91; 6.98)
P < 0.001
n = 16
A)
Session
Average
Average power (W • kg-1)
ES (95%CIs) = 0.52 (0.09; 0.95)
P = 0.023
n = 16
B)

© 2021 EDIZIONI MINERVA MEDICA
Online version at https://www.minervamedica.it

The Journal of Sports Medicine and Physical Fitness 2022 June;62(6):838-45
DOI: 10.23736/S0022-4707.21.12768-9

ORIGINAL ARTICLE
EPIDEMIOLOGY AND CLINICAL MEDICINE

Exploring the age of taekwondo athletes in the Olympic Games: an analysis from Sydney 2000 to Rio 2016

Gennaro APOLLARO [1] *, Bruno RUSCELLO [1, 2, 3, 4]

[1]School of Sport Sciences and Exercise, Faculty of Medicine and Surgery, Tor Vergata University, Rome, Italy; [2]School of Sports and Exercise Sciences, San Raffaele University, Rome, Italy; [3]Department of Industrial Engineering, Faculty of Engineering, Tor Vergata University, Rome, Italy; [4] LUISS SportLab – LUISS University, Rome, Italy

*Corresponding author: Gennaro Apollaro, School of Sport Sciences and Exercise, Faculty of Medicine and Surgery, Tor Vergata University, Via Montpellier 1, 00133 Rome, Italy. E-mail: gen.2012.ita@hotmail.com

ABSTRACT

BACKGROUND: The aim of this study was to quantify the age at which taekwondo athletes competed in the Olympic Games and to provide initial insights into weight category changes over time.

METHODS: For the first analysis, the study included all 611 taekwondo athletes who competed in the Olympics between 2000 and 2016; for each sex, a three-way ANOVA (edition of Olympic Games, competitive achievement, weight category) was performed to detect differences in the age of athletes. For the second analysis, we considered all 109 taekwondo athletes who took part in more than one edition of the Olympics between 2000 and 2016; chi-squared goodness of fit tests were performed to study the number of participations and changes in weight category of these athletes.

RESULTS: Female athletes, with a mean age of 23.8±4.1 years, are significantly younger (P=0.001) than their male counterparts, with a mean age of 25.1±3.9 years. In weight category, lighter athletes being younger than heavier ones in both females (22.7±3.7 *vs.* 24.5±4.2 years, P=0.04) and males (23.6±3.8 *vs.* 26.7±3.8 years, P=0.001; 24.2±3.5 *vs.* 26.7±3.8 years, P=0.001). When an athlete reaches Olympic competition several times, he/she generally competes in the same weight category (P=0.001) and takes part in two consecutive editions (P=0.001). Heavier athletes have greater longevity at Olympic level than lighter athletes (P=0.002).

CONCLUSIONS: The current data provides important information for national federations engaged in the selection of athletes for Olympic competitions.

(*Cite this article as*: Apollaro G, Ruscello B. Exploring the age of taekwondo athletes in the Olympic Games: an analysis from Sydney 2000 to Rio 2016. J Sports Med Phys Fitness 2022;62:838-45. DOI: 10.23736/S0022-4707.21.12768-9)

KEY WORDS: Athletic performance; Age groups; Martial arts.

The age of peak competitive performance may vary between athletes in different sports and events, depending on the specific skills and attributes required for success in a particular event.[1] In sports such as track and field, the age of peak performance is determined by personal record performances where performance measurement is based on centimeters or seconds.[1-3] On the contrary, as recently highlighted,[4] in combat sports the World Championships and Olympic Games are considered the two most important indicators of professional success for athletes, since there is no measurement used to establish world record performances.

Combat sports account for an important part of the medals awarded at the Summer Olympics. The current schedule of the Olympic Games includes fencing, boxing, taekwondo, karate, judo, Greco-Roman wrestling and freestyle wrestling. However, the inclusion of these sports in the Olympic programs has followed different paths over time; fencing and wrestling were already present in the program of the 1896 Olympic Games while karate was introduced at the 2020 Olympic Games.[5] In this context, a broad knowledge about the characteristics of combat sports athletes of different ages and performance levels is crucial[6] to provide, to the coaches and the national federations, important information to optimize long-term development and decision-making processes when selecting athletes for major competitions.[7-9]

After participating in the 1988 Seoul Olympic Games and the 1992 Barcelona Olympic Games as a demonstration sport, taekwondo became an official Olympic sport at the 2000 Sydney Olympic Games. Under the leadership of World Taekwondo, which regulates Olympic competitions and World Championships, taekwondo has gained popularity over time and confirmation as one of the 25 core sports for the Tokyo 2020 Olympic Games.[10, 11] Combat sports, such as taekwondo, involve an oppositional relationship between two athletes striving to win the match;[12] consequently, many aspects are considered important to achieve successful competitive performance in taekwondo, including a high degree of technical-tactical competence supported by physiological, psychological[13-16] and sport context-specific components such as periodization strategies[17, 18] and nutritional preparation.[19, 20] The various rule changes that have taken place over the last decade,[21-23] impacting on the kinematic and physiological profile of the fight,[24, 25] have made taekwondo an even more dynamic sport.

Although some studies have investigated the profiles[26-29] and the effect of relative age[30, 31] of Olympic taekwondo athletes, no previous study has investigated the age at which taekwondo athletes competed in the Olympic Games, considering all editions of participation, competitive achievement and weight category. In judo, Franchini *et al.*[4] explored the age at which athletes participated in World Championships and Olympic Games, over a 25-year interval, taking into account achievement performance and weight category in the analysis. The authors reported that generally female athletes, with a mean age of 24.9±3.9 years, were significantly younger than their male counterparts, with a mean age of 25.4±3.8 years.

In line with the above, the objectives of the present study were 1) to examine the age at which taekwondo athletes competed in the Olympic Games; 2) to compare the age of taekwondo athletes who won medals, placed 5th/7th and were defeated in the eliminatory phases; 3) to compare the age of taekwondo athletes in different weight categories; 4) to monitor taekwondo athletes who have taken ;part in multiple editions of the Olympic Games for changes in weight category over time; and 5) to examine whether there was a change in the age category distribution over the period of taekwondo's participation in the Olympic Games.

Materials and methods

Participants and data collection

The present study included all 611 taekwondo athletes (females =300; males =311) who competed in the 5 Olympics between 2000 and 2016. Birth dates, competitive achievements and weight categories were collected from publicly available online sources (www.olympic.org and www.olympiandatabase.com). The use of data from open access sites has been previously described in other studies[4, 30, 32] and there are no ethical issues involved in the analysis and interpretation of the data used as these were obtained in a secondary form and not from direct experimentation.

Procedures

Taekwondo athletes were divided by gender (female and male), edition of the Olympic Games (Sydney 2000, Athens 2004, Beijing 2008, London 2012, Rio 2016), competitive achievement (1st-3rd placers, *i.e.* one gold, one silver and one or two bronze medal winners; 5th and 7th placers, *i.e.* defeated in the repechage and bronze medal matches; 9th placers and below, *i.e.* defeated in the eliminatory phases), weight category (flyweight, featherweight, middleweight and heavyweight) and age category (<20 years, 20-25 years, 25-30 years and >30 years).

Statistical analysis

Data were tabulated and organized in a Microsoft Excel worksheet and then reported and analyzed using IBM SPSS 25 software (SPSS Inc., Chicago, IL, USA). Based on previous studies[30, 31] that did not find the relative age effect in the Olympic taekwondo population (from Sydney 2000 to Rio 2016), the age of each athlete was calculated as follows: year of the Olympic edition-year of birth of the athlete = age of athlete. For each variable, the normality of the data distribution was examined using a Shapiro-Wilk Test. Descriptive statistics (mean±standard deviation [95% confidence intervals]) were used to summarize the collected data and were presented when considered relevant. A Student's *t*-test for independent samples was used to compare male and female athletes. The Effect Size (ES) was determined, and the threshold values for Cohen's ES statistics were classified as trivial (0.0-0.19), small (0.2-0.59), moderate (0.6-1.1), large (1.2-1.9) and very large (>2.0).[33] As this analysis revealed age differences between the sexes, each group was analyzed separately.[4] Thus, for each sex, a three-way ANOVA (edition of Olympic Games, competitive achievement and weight category) was performed with Tukey's *post-hoc* tests, when appropriate, to detect significant differences in the age of athletes from different groups; ES in ANOVA was computed as partial η^2, with partial $\eta^2<0.01$, $0.01<$partial $\eta^2<0.06$, $0.06<$partial $\eta^2<0.14$ and partial $\eta^2>0.14$, as trivial, small, moderate, and large ES, respectively.[34] χ^2 goodness of fit tests and odds ratio (95% confidence intervals) were performed to study the athletes who took part in more than one edition of the Olympic Games; χ^2 tests of independence were performed to identify the association between edition of the Olympic Games and the age categories. For these analyzes, ES was reported using Cramer's V as small (0.06-0.17), medium (0.18-0.29) and large (>0.30).[35] Statistical significance was accepted at P<0.05.

Results

Female taekwondo athletes were younger (23.8±4.1 years) than male taekwondo athletes (25.1±3.9 years) (t=4.01, P=0.001, d=0.33, small, confidence interval of the differences =0.67; 1.95).

For female taekwondo athletes, no main effects were found for edition of the Olympic Games ($F_{2,240}$ =0.96; P=0.43, η^2_{P}=0.02, small) and competitive achievement ($F_{2,240}$ = 0.99; P=0.37, η^2_{P}=0.01, small). However, main effects were found by weight category ($F_{3,240}$ = 2.9; P=0.04, η^2_{P}=0.03, small) (Table I).

Female taekwondo athletes in the flyweight category were younger (P=0.04) than those in the heavyweight category (Table I).

Table I.—*Descriptive statistics (m±SD [95% CI]) of the chronological age (years) of female taekwondo athletes according to Olympic edition, competitive achievement and weight category (N.=300).*

Parameters	Values
Olympic edition	
Sydney 2000	24.4±4.5 y [23.1-25.7]
Athens 2004	23.5±4 y [22.5-24.5]
Beijing 2008	23.1±4.2 y [22.1-24.2]
London 2012	23.6±3.8 y [22.6-24.5]
Rio 2016	24.5±4.1 y [23.5-25.5]
Competition achievement	
1st-3rd	23.3±3.2 y [22.6-24.1]
5th/7th	24.3±4.6 y [23.3-25.3]
≥9th	23.8±4.3 y [23.1-24.5]
Weight category	
-49 kg "Fly"	22.7±3.7 y [a] [21.9-23.6]
-57 kg "Feather"	23.6±3.8 y [22.7-24.5]
-67 kg "Middle"	24.4±4.5 y [23.3-25.4]
+67 kg "Heavy"	24.5±4.2 y [23.6-25.5]

1st-3rd: one gold, one silver and one or two bronze medal winners, 5th / 7th: defeated in the repechage and bronze medal matches, ≥ 9th: defeated in the eliminatory phases.
aSignificantly younger (P=0.04) when compared to heavyweight category.

Table II.—*Descriptive statistics (m±SD [95% CI]) of the chronological age (years) of male taekwondo athletes according to Olympic edition, competitive achievement and weight category (N.=311).*

Parameters	Values
Olympic edition	
Sydney 2000	25±4 y [23.9-26.1]
Athens 2004	25.2±3.5 y [24.3-26.1]
Beijing 2008	25.3±4.1 y [24.2-26.3]
London 2012	25.4±3.9 y [24.5-26.4]
Rio 2016	24.7±4.3 y [23.6-25.7]
Competition achievement	
1st-3rd	24.4±3.3 y [23.7-25.2]
5th/7th	25.7±4.1 y [24.8-26.5]
≥9th	25.1±4.1 y [24.5-25.8]
Weight category	
-58 kg "Fly"	23.6±3.8 y [a] [22.7-24.4]
-68 kg "Feather"	24.2±3.5 y [b] [23.4-25]
-80 kg "Middle"	26±3.9 y [25.1-26.9]
+80 kg "Heavy"	26.7±3.8 y [25.9-27.6]

1st-3rd: one gold, one silver and one or two bronze medal winners, 5th / 7th: defeated in the repechage and bronze medal matches, ≥ 9th: defeated in the eliminatory phases.
aSignificantly younger when compared to middleweight (P=0.001) and heavyweight (P=0.001) categories; bsignificantly younger when compared to middleweight (P=0.02) and heavyweight (P=0.001) categories.

For male taekwondo athletes, there was no main effect by edition of the Olympic games ($F_{4,251}$ = 0.37; P=0.85, η^2_{P}=0.01, small) and by competitive achievement ($F_{2,251}$ = 1.75; P=0.16, η^2_{P}=0.01, small). However, main effects by weight category were also found for male taekwondo athletes ($F_{3,251}$ = 9.11; P=0.001, η^2_{P}=0.1, moderate) (Table II).

Male taekwondo athletes in the flyweight category were younger than those in the middleweight (P=0.001) and heavyweight (P=0.001) categories. Athletes in the featherweight category were younger than those in the middleweight (P=0.02) and heavyweight (P=0.001) categories (Table II).

Considering the main effects found for the weight category, we then considered all the athletes who took part in more than one edition of the Olympic Games for further analysis. This study included 109 athletes for a total of 242 participations out of 611 Olympic passes (39.61%).

For the first analysis: 1) we compared athletes who took part in more than one edition of the Olympic Games keeping the same weight category over time with athletes who took part in more than one edition of the Olympic Games changing weight category over time; and 2) we compared athletes who took part in 2 consecutive editions (*i.e.*, one four-year period) with athletes who took part in 2 non-consecutive or in ≥ 3 consecutive editions (*i.e.*, two or more

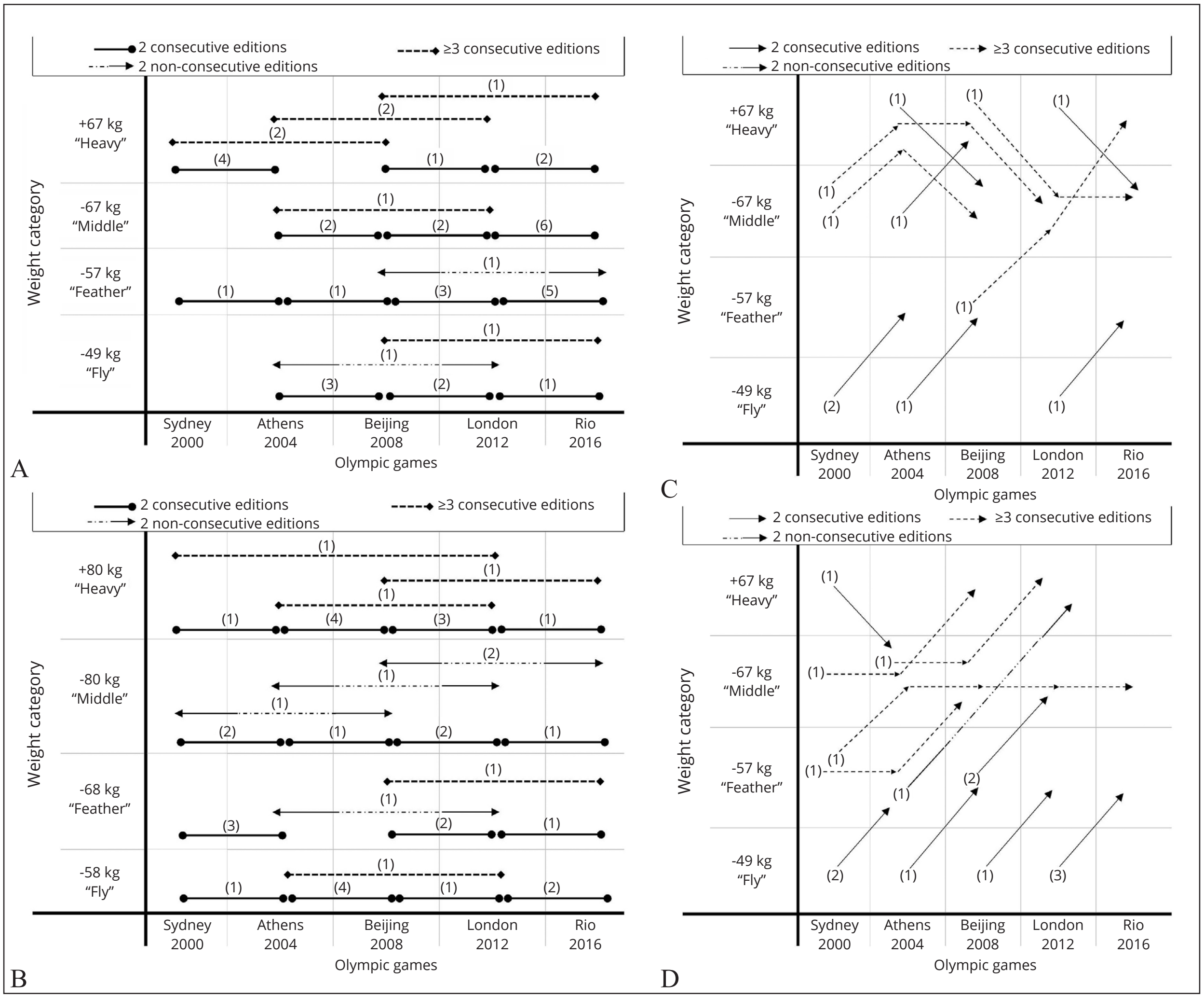


Figure 1.—A) Female taekwondo athletes (N.=44); and B) male taekwondo athletes (N.=39) who have taken part in several editions of the Olympic Games while maintaining the same weight category over time; C) female taekwondo athletes (N.=11); and D) male taekwondo athletes (N.=15) who took part in more than one edition of the Olympic Games changing weight category over time.
In Figure 1C, D, the arrow pointing upwards to the right indicates that the athlete participated in a higher weight category in his/her successive edition, the arrow pointing downwards to the right indicates that the athlete participated in a lower weight category in his/her successive edition, the arrow pointing to the right indicates that the athlete kept the same weight category in his/her successive edition.

four-year periods) (the details of the athletes are shown in Figure 1).

A difference was observed between athletes who took part in several editions of the Olympic Games keeping the same weight category over time and athletes who took part in several editions of the Olympic Games changing weight category over time (76.15% *vs.* 23.85%; $\chi^2_{(1)}$ =29.807; P=0.001; V=0.52, large; OR=3.19, 95% CI: 1.79-5.69); at the same time a difference was observed between athletes who took part in 2 consecutive editions and athletes who took part in 2 non-consecutive editions or in ≥3 consecutive editions (74.31% *vs.* 25.69%; $\chi^2_{(1)}$ = 25.771; P=0.001; V=0.49, large; OR=2.89, 95% CI: 1.63-5.12).

In the second analysis, 1) considering the athletes who took part in 2 consecutive editions, we compared the athletes of the lighter categories (fly and feather) with the athletes of the heavier categories (middle and heavy) and 2) considering the athletes who took part in 2 non-consecutive or in ≥ 3 consecutive editions, we compared the athletes of the lighter categories (fly and feather) with the athletes of the heavier categories (middle and heavy). For this analysis, the athletes were divided into two groups (light and heavy) on the basis of the main effects found for the weight category and the athletes who changed category over time were placed in a group taking into consideration their last participation (the details of the athletes are shown in Figure 1).

No difference was reported between the athletes of the lighter and heavier categories considering the athletes who took part in 2 consecutive editions (50.62% *vs.* 49.38%; $\chi^2_{(1)}$ =0.012; P=0.912; V=0.01, small; OR=1.03, 95% CI: 0.55-1.90); on the contrary, a difference was reported between the athletes of the lighter categories and the athletes of the heavier categories considering the athletes who took part in 2 non-consecutive editions or in ≥3 consecutive editions (21.43% *vs.* 78.57%; $\chi^2_{(1)}$ =9.143; P=0.002; V=0.57, large; OR=3.67, 95% CI: 1.14-11.79).

No association was shown between edition of the Olympic Games and age category for both females ($\chi^2_{(12)}$ =14.181; P=0.289; V=0.13, small) (Figure 2A and males ($\chi^2_{(12)}$ =7.666; P=0.811; V=0.09, small) (Figure 2B).

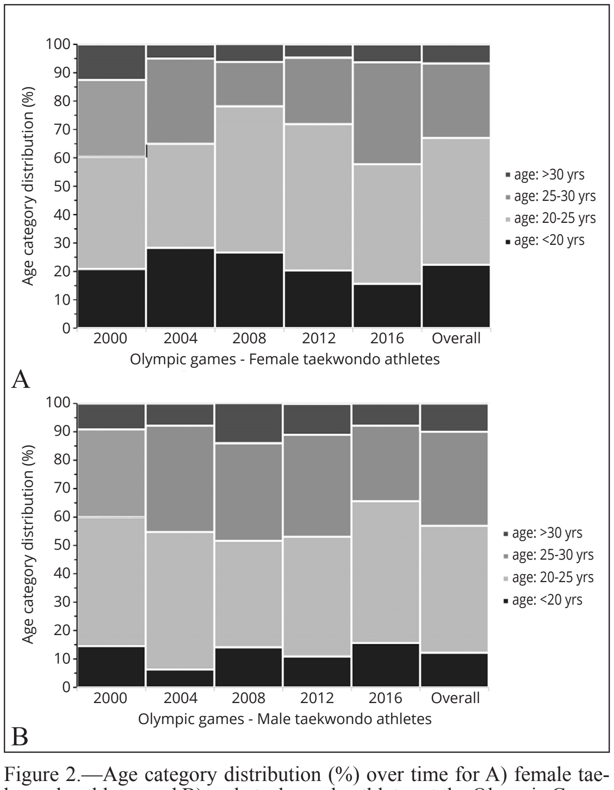


Figure 2.—Age category distribution (%) over time for A) female taekwondo athletes and B) male taekwondo athletes at the Olympic Games (2000-2016).

Discussion

To our knowledge, this is the first study that has analyzed the age at which taekwondo athletes competed in the Olympic Games considering all editions of taekwondo participation in the Olympic Games, competitive achievement and weight category. The main findings concerned the weight category where, regardless of gender, lighter athletes are younger than heavier ones. No difference in age was found between all editions of participation and in final classification for both female and male athletes. Overall, taekwondo athletes are most represented in the 20-25 age category with the same percentage in both sexes; in females the <20 age category has a similar value to the 25-30 age category, while in males the <20 age category has a similar value to the >30 age category.

Franchini *et al.*,[4] exploring the age at which judo athletes participated in the World Championships and Olympic Games between 1993 and 2018, involved the last six Olympic Games participations in the analysis by considering the same variables used in our study, thus allowing a direct comparison between these two Olympic combat sports.

Specifically, no age difference was found when comparing all editions of taekwondo participation in the Olympic Games in both sexes. In judo, only the female athletes who took part in the London 2012 and Rio 2016 Olympics were significantly older than the female athletes who participated in the Atlanta 1996 Olympics, while no significant difference emerged for their male counterparts. These results appear to be in line as in both judo and taekwondo, compared since the Sydney 2000 Olympics when taekwondo became an Olympic sport, no age difference was found between the editions.

Our data did not reveal any age difference regarding the competitive achievement in both sexes. In judo (considering both the World Championships and the Olympic Games), only significantly younger female athletes performed worse in the preliminary rounds, whereas no significant difference emerged for their male counterparts. According to the authors, this could be the consequence of the important selectivity of these events in terms of participation where probably only athletes who are successful in high-level preparatory competitions manage to reach such important competitions. Taekwondo also uses a highly selective qualification system for the Olympic Games, which until the London 2012 Olympic Games was based on world and continental qualification competitions, while since the Rio 2016 Olympic Games on world ranking and continental qualification competitions.[36, 37] In judo, the world ranking-based qualification system for the Olympic Games was first used at the 2012 London Olympics.[38] Franchini and Julio[32] studied how long-term and short-term performance in competitions valid to gain world ranking points predict performance for the Olympic Games. The authors identified that 24% and 26% of judo performances at the London 2012 Olympic Games, for females and males respectively, could be predicted by variables derived from world ranking. In contrast, in taekwondo, no studies have investigated how point and qualifying competitions influence selectivity and success in the Olympic Games, and future studies should investigate this aspect to justify the absence of age differences in the final classification of the Olympic Games.

With regard to weight category, it is important to note that our data is in line with what emerged in judo (considering both the World Championships and the Olympic Games) where lighter athletes are generally younger than heavier athletes in both sexes. A first hypothesis discussed by the researchers, which attempts to explain the age differences in the weight category, revolves around the process of rapid weight loss in the precompetition period where it would appear that elite judo athletes use more aggressive methods particularly at the beginning of their careers.[39] In taekwondo it would also appear that elite athletes begin to lose weight at younger ages in order to compete at the highest level, confirming evidence from judo that competition at high levels is associated with worsened weight management behaviours.[19, 39]

A second hypothesis in judo is that athletes change their weight category as they age. Although this is a common observation and recently highlighted in taekwondo, where older athletes tend to abandon the passive model in favour of not losing weight at all,[20] no previous study has shown this change in weight categories in combat sports. In this regard, another objective of the present study was to monitor taekwondo athletes who took part in multiple editions of the Olympic Games for changes in weight category over time.

The most important results show that, generally, when a taekwondo athlete reaches the Olympic competition more than once in his career, he competes in the same weight category and takes part in two consecutive editions. Secondly, athletes in the lighter categories seem to have more difficulty in reaching Olympic competition more than twice in their career. In this regard, considering that taekwondo athletes at the Olympic level compete in four weight categories while in other international competitions (such as World Championships and ranking competitions) in eight weight categories, the hypothesis is that athletes, when unable to maintain the Olympic weight category of their first participation, will compete in adjacent weight categories during the four-year period,[23, 37] and then return to the same Olympic weight category in their next participation and retain a likely competitive advantage. The possible difficulties resulting from similar long-term weight management and the greater competitiveness in term of participants in the selection process of the lighter categories could represent a barrier for these athletes and result in shorter Olympic careers. In contrast, double participation in two Olympic four-year terms and three or more consecutive participations seem to be more characteristic of athletes competing in the heavier categories. The hypothesis is that heavier athletes have greater longevity at Olympic level than lighter athletes, probably due to less competitiveness in these categories and easier weight management. Another important hypothesis to consider could stem from the differences found in technical-tactical behaviors in taekwondo athletes of different weight categories who participated in the 2012 London Olympics.[40] This study found that both male and female athletes in the lighter categories (fly and feather) performed more anticipated, posterior and linear actions at both impact zones (head and trunk) with the left and front leg than those in the heavier categories (middle and heavy). Specifically, lighter female athletes performed more indirect actions, anticipated and posterior counterattacks, linear actions, to the head and trunk, with the left leg and open guard than heavier athletes. Conversely, heavier female athletes performed more defensive actions (blocks and cuts) than lighter ones because these defensive actions do not require a global move to perform them. Lighter male athletes performed more actions (direct, indirect, back, circular, spin, at the head and trunk, left and right leg, front and back and closed guard) than heavier athletes. This tendency of the heavier male and female athletes in performing fewer actions has also been reported at other competitive levels[41, 42] and has been attributed to the higher energy demands in heavier athletes to perform kicks and punches, due to the greater mass in the arms and legs, resulting in a lower fight pace and longer recovery times compared to the lighter athletes.[43, 44] These differences found in the technical-tactical behaviors, between the athletes of the lighter categories and the athletes of the heavier categories, could have a different impact on the physiological level in the long term and consequently on the duration of the athlete's competitive career, so the relationship between these factors in taekwondo deserves particular attention and further research in the future.

This twofold and divergent aspect in the duration of the Olympic career, found by comparing the lightest and heaviest athletes in our study, may provide more of an explanation for the fact that lighter athletes are generally younger than heavier athletes in the Olympic taekwondo population, rather than the common observation that athletes change their weight category as they age. However, it seems relevant to highlight that the possible reasons for age differences in weight category may be unique to the context analyzed. Judo athletes, for example, compete in seven weight categories in both Olympic and world competition, unlike taekwondo. Therefore, weight management during the four-year period may be influenced by the specific regulations of each discipline and, to this end, future studies are encouraged to investigate this aspect in different combat sports and competitive levels.

Finally, our data showed no significant change in the different age categories in either gender. In judo, only for female athletes there was a significant increase in the 25-30 years category and a significant decrease in the 20-25 years category from the Atlanta 1996 Olympics to the Rio 2016 Olympics, in parallel with a significant and progressive decrease in the <20 years category. These progressive increases in the age of female athletes were justified by the authors as a potential increase in competitiveness over time as women's judo was introduced to the Olympic Games 20 years after men's judo.[5] Therefore, considering that taekwondo is a younger Olympic sport than judo and most Olympic combat sports and that it was introduced to the Olympic Games in parallel for both sexes, the absence of changes in the different age categories will have to be interpreted in the long term, also taking into consideration future participations of taekwondo in the Olympic Games.

Conclusions

The present study is the first to investigate the age at which taekwondo athletes competed in the Olympic Games and the first to provide initial insights into weight category changes over time. Female taekwondo athletes, with a mean age of 23.8±4.1 years, are significantly younger than their male counterparts, with a mean age of 25.1±3.9 years. Regardless of gender, no difference in age was found between all editions of participation, in the final classification and no significant change occurred in the different age categories. The main results concerned the weight category where, generally, lighter athletes are younger than heavier ones. When a taekwondo athlete reaches the Olympic competition several times in his career, he/she generally competes in the same weight category and takes part in two consecutive editions. Athletes in the lighter categories seem to have more difficulty in reaching Olympic competition more than twice in their career. In contrast, double participation in two Olympic four-year terms and three or more consecutive participations seem to be more characteristic of athletes competing in the heavier categories. This twofold aspect could provide more justification for the fact that lighter athletes are generally younger than heavier athletes in the Olympic taekwondo population. The current data derived from the study of all taekwondo participations in the Olympic Games not only provides additional knowledge about this increasingly popular combat sport, but also important information for national federations engaged at the highest level in the selection of athletes and long-term development processes for Olympic competitions.

References

1. Allen SV, Hopkins WG. Age of Peak Competitive Performance of Elite Athletes: A Systematic Review. Sports Med 2015;45:1431–41.

2. Longo AF, Siffredi CR, Cardey ML, Aquilino GD, Lentini NA. Age of peak performance in Olympic sports: a comparative research among disciplines. J Hum Sport Exerc 2016;11:31–41.

3. Haugen TA, Solberg PA, Foster C, Morán-Navarro R, Breitschädel F, Hopkins WG. Peak Age and Performance Progression in World-Class Track-and-Field Athletes. Int J Sports Physiol Perform 2018;13:1122–9.

4. Franchini E, Fukuda DH, Lopes-Silva JP. Tracking 25 years of judo results from the World Championships and Olympic Games: age and competitive achievement. J Sports Sci 2020;38:1531–8.

5. International Olympic Committee [Internet]. Sports: summer sports/winter sports; 2021 [Internet]. Available from: https://www.olympic.org/sports [cited 2021, Mar 1].

6. Norjali Wazir MR, Van Hiel M, Mostaert M, Deconinck FJ, Pion J, Lenoir M. Identification of elite performance characteristics in a small sample of taekwondo athletes. PLoS One 2019;14:e0217358.

7. Vaeyens R, Güllich A, Warr CR, Philippaerts R. Talent identification and promotion programmes of Olympic athletes. J Sports Sci 2009;27:1367–80.

8. Ford P, De Ste Croix M, Lloyd R, Meyers R, Moosavi M, Oliver J, *et al.* The long-term athlete development model: physiological evidence and application. J Sports Sci 2011;29:389–402.

9. Rees T, Hardy L, Güllich A, Abernethy B, Côté J, Woodman T, *et al.* The Great British Medalists Project: A Review of Current Knowledge on the Development of the World's Best Sporting Talent. Sports Med 2016;46:1041–58.

10. International Olympic Committee [Internet]. TAEKWONDO: History of Taekwondo at the Olympic Games; 2015 [Internet]. Available from:

https://stillmed.olympic.org/AssetsDocs/OSC%20Section/pdf/QR_sports_summer/Sports_Olympiques_taekwondo_eng.pdf [cited 2021, Mar 1].

11. Taekwondo W. Vision, Mission, Strategy; 2021 [Internet]. Available from: http://www.worldtaekwondo.org/about-wt/about.html [cited 2021, Mar 1].

12. Menescardi C, Ruiz L, Estevan I, Falcó C. An update of sparring taekwondo's internal logic. Movimento 2020;26:e26038.

13. Bridge CA, Ferreira da Silva Santos J, Chaabène H, Pieter W, Franchini E. Physical and physiological profiles of taekwondo athletes. Sports Med 2014;44:713–33.

14. Chaabene H, Negra Y, Bouguezzi R, Capranica L, Franchini E, Prieske O, *et al.* Tests for the Assessment of Sport-Specific Performance in Olympic Combat Sports: A Systematic Review With Practical Recommendations. Front Physiol 2018;9:386.

15. Franchini E, Cormack S, Takito MY. Effects of High-Intensity Interval Training on Olympic Combat Sports Athletes' Performance and Physiological Adaptation: A Systematic Review. J Strength Cond Res 2019;33:242–52.

16. da Silva Santos JF, Dias Wilson V, Herrera-Valenzuela T, Sander Mansur Machado F. Time-Motion Analysis and Physiological Responses to Taekwondo Combat in Juvenile and Adult Athletes: A Systematic Review. Strength Condit J 2020;42:103–21.

17. Ball N, Nolan E, Wheeler K. Anthropometrical, physiological, and tracked power profiles of elite taekwondo athletes 9 weeks before the Olympic competition phase. J Strength Cond Res 2011;25:2752–63.

18. Carazo-Vargas P, González-Ravé J, Newton R, Moncada-Jiménez J. Periodization Model for Costa Rican Taekwondo Athletes. Strength Condit J 2015;37:74–83.

19. da Silva Santos JF, Takito MY, Artioli GG, Franchini E. Weight loss practices in Taekwondo athletes of different competitive levels. J Exerc Rehabil 2016;12:202–8.

20. Janiszewska K, Przybyłowicz KE. Pre-Competition Weight Loss Models in Taekwondo: Identification, Characteristics and Risk of Dehydration. Nutrients 2020;12:2793.

21. Moenig U, Cho S, Song H. The Modifications of Protective Gear, Rules and Regulations During Taekwondo's Evolution – From its Obscure Origins to the Olympics. Int J Hist Sport 2012;29:1363–81.

22. Moenig U. Rule and Equipment Modification Issues in World Taekwondo Federation (WTF) Competition. Ido Mov Culture. J Martial Arts Anthrop. 2015;15:3–12.

23. Taekwondo W. Competition Rules and Interpretation; 2021 [Internet]. Available from: http://www.worldtaekwondo.org/rules-wt/rules.html [cited 2021, Mar 1].

24. Janowski M, Zieliński J, Kusy K. Exercise Response to Real Combat in Elite Taekwondo Athletes Before and After Competition Rule Changes. J Strength Cond Res 2021;35:2222–9.

25. Janowski M, Zieliński J, Ciekot-Sołtysiak M, Schneider A, Kusy K. The Effect of Sports Rules Amendments on Exercise Intensity during Taekwondo-Specific Workouts. Int J Environ Res Public Health 2020;17:6779.

26. Kazemi M, Waalen J, Morgan C, White AR. A profile of olympic taekwondo competitors. J Sports Sci Med 2006;5(CSSI):114–21.

27. Kazemi M, Casella C, Perri G. 2004 olympic tae kwon do athlete profile. J Can Chiropr Assoc 2009;53:144–52.

28. Kazemi M, Perri G, Soave D. A profile of 2008 Olympic Taekwondo competitors. J Can Chiropr Assoc 2010;54:243–9.

29. Kazemi M, Ong M, Pacis A, Tseng K. A profile of 2012 Olympic games taekwondo athletes. J Int Assoc Taekwondo Res. 2014;1:12–8.

30. Albuquerque MR, Lage GM, da Costa VT, Ferreira RM, Penna EM, Moraes LC, *et al.* Relative age effect in Olympic Taekwondo athletes. Percept Mot Skills 2012;114:461–8.

31. Campideli TS, Ferreira RM, Coelho EF, Penna EM, Panza PS, Werneck FZ. Relative age effect in Olympic combat sports athletes/ Efeito da idade relativa em atletas olimpicos de esportes de combate. Motricidade 2018;14:279–86.

32. Franchini E, Julio UF. The Judo World Ranking List and the Performances in the 2012 London Olympics. Asian J Sports Med 2015;6:e24045.

33. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 2009;41:3–13.

34. Cohen J. Statistical Power Anaylsis for the Behavioural Science. Second edition. Mahwah, NJ: L. Erlbaum Associates; 1988.

35. Cramer H. Mathematical Methods of Statistics (PMS-9), Volume 9. Princeton, NJ: Princeton University Press; 2016.

36. Taekwondo W. Qualification System – Games of the XXXII Olympiad – Tokyo 2020; 2020 [Internet]. Available from: http://www.worldtaekwondo.org/wp-content/uploads/2017/09/FINAL-2020-01-06-Tokyo-2020-Qualification-System-Taekwondo-eng.pdf [cited 2021, Mar 1].

37. Taekwondo W. WT Ranking Bylaw; 2021 [Internet]. Available from: http://www.worldtaekwondo.org/rules-wt/rules.html [cited 2021, Mar 1].

38. Ferreira Julio U, Panissa VL, Miarka B, Takito MY, Franchini E. Home advantage in judo: a study of the world ranking list. J Sports Sci 2013;31:212–8.

39. Artioli GG, Gualano B, Franchini E, Scagliusi FB, Takesian M, Fuchs M, *et al.* Prevalence, magnitude, and methods of rapid weight loss among judo competitors. Med Sci Sports Exerc 2010;42:436–42.

40. Menescardi C, Liébana E, Falcó C. Why do female and male taekwondo athletes win the bout? An analysis based on the Olympic weight category and the result of the bout. RAMA 2019;14:67–82.

41. Falco C, Landeo R, Menescardi C, Bermejo JL, Estevan I. Match analysis in a university taekwondo championship. Adv Phys Educ 2012;2:28–31.

42. Mavi Var S. Technical analysis of 2007 and 2017 World Taekwondo Women and Men championship finals. Turk J Sport Exe. 2018;20:256–62.

43. Santos VG, Franchini E, Lima-Silva AE. Relationship between attack and skipping in Taekwondo contests. J Strength Cond Res 2011;25:1743–51.

44. Menescardi C, Moya I, Ros C, Estevan I. Análisis del tiempo de lucha y no lucha en taekwondistas cadetes. Sportis Sci J. 2016;2:164–76.

Conflicts of interest.—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions.—Gennaro Apollaro revised the manuscript critically. Both authors read and approved the final version of the manuscript.

History.—Article first published online: November 25, 2021. - Manuscript accepted: October 11, 2021. - Manuscript revised: September 28, 2021. – Manuscript received: April 26, 2021.

Science and Medicine in Football

Routledge
Taylor & Francis Group

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rsmf20

Relative age effects and the youth-to-senior transition in Italian soccer: the underdog hypothesis versus knock-on effects of relative age

Gabriele Morganti, Adam L. Kelly, Gennaro Apollaro, Laura Pantanella, Mario Esposito, Alberto Grossi & Bruno Ruscello

To cite this article: Gabriele Morganti, Adam L. Kelly, Gennaro Apollaro, Laura Pantanella, Mario Esposito, Alberto Grossi & Bruno Ruscello (2022): Relative age effects and the youth-to-senior transition in Italian soccer: the underdog hypothesis versus knock-on effects of relative age, Science and Medicine in Football, DOI: 10.1080/24733938.2022.2125170

To link to this article: https://doi.org/10.1080/24733938.2022.2125170

Published online: 20 Sep 2022.

SCIENCE AND MEDICINE IN FOOTBALL
https://doi.org/10.1080/24733938.2022.2125170

ORIGINAL INVESTIGATION

Relative age effects and the youth-to-senior transition in Italian soccer: the underdog hypothesis versus knock-on effects of relative age

Gabriele Morganti[a], Adam L. Kelly[b], Gennaro Apollaro[a], Laura Pantanella[a], Mario Esposito[a], Alberto Grossi[a] and Bruno Ruscello[a,c,d,e]

[a]National TalentObservatory, School of Sports and Exercise Sciences, Faculty of Medicine and Surgery, "Tor Vergata" University, Rome, Italy; [b]Centre for Life and Sport Sciences (CLaSS), Faculty of Health, Education and Life Sciences, Birmingham City University, Birmingham, UK; [c]School of Sports and Exercise Sciences, "San Raffaele" University, Rome, Italy; [d]Department of Industrial Engineering, Faculty of Engineering, "Tor Vergata" University, Rome, Italy; [e]LUISS SportLab, LUISS University, Rome, Italy

ABSTRACT

Relative Age Effects (RAEs) appear largely throughout youth soccer. However, little is known about how RAEs at youth levels can impact transition at senior levels. Accordingly, this study aimed to : (a) provide further test of RAEs by exploring the birth quarter (BQ) distribution of 2,030 Italian players born from 1975 to 2001 who have played in any of the Youth National Italian Soccer Teams ; and (b) investigate how RAEs influence future career outcomes, by exploring the BQ distribution of players who completed the transition from youth squads to the Senior National Team (n = 182) Chi-square statistics revealed significantly skewed BQ distributions for all Youth squads (*P* values <0.0001), and for the cohort of players who completed the transition (*P* = 0.003). In contrast, results from the Odds Ratios highlighted how BQ4s were more likely to transition from youth-to-senior compared to BQ1s . Results showed BQ1s remained overrepresented at senior level due to a residual bias effect. Whereas BQ4s who were able to overcome selection processes at youth levels recorded the highest likelihood of competing at senior levels. Involving players' career trajectories in RAEs studies is needed to understand how RAEs impacts career outcomes of early selected players.

ARTICLE HISTORY
Accepted 10 September 2022

KEYWORDS
Talent identification; talent selection; relative age effect; expertise; youth soccer; athlete development

Introduction

To provide every child with an equal opportunity to develop, youth sport organisations adopt a strategy that follows a cut-off criterion whereby players are grouped based on their birthdate (Gil et al. 2020). During this age-based system, those who are born near the beginning of the annual selection year (e.g., January 1st in Italy) can be almost one year older than those who are born near the end of the selection year (e.g., December 31st in Italy). As a result of the timing of one's birth within a given (bi)annual-age group, an individual can be relatively older or younger in comparison to their peers (Musch and Grondin 2001). Research has shown how from a very young age relatively older athletes have increased selection opportunities into Talent Identification Development Systems (TIDS) due to relative age advantages (Till and Baker 2020). This selection bias is labelled Relative Age Effect (RAE), which is a well-known phenomenon, having been observed in various individual and team sports across the globe (e.g., Costa et al. 2013; Yagüe et al. 2018; Pérez-González et al. 2021).

Generally, it was assumed that relatively older players tend to be more biologically mature than their younger counterpart and thus favoured by their physical and athletic advantages (Cobley et al. 2009). However, recent findings in this research area have suggested how relative age and maturation are two different constructs which need to be separated (see Towlson et al. 2021 for a detailed discussion). Sport systems tend to select children based on their current level of performance as young as aged 9 years (Baker et al. 2018), and it seems obvious that when selecting athletes this early in the course of their development, any age-related difference is well marked (Doyle et al. 2017). An 11-month difference in age represents almost a year of experiences and opportunities to practice (Aune et al. 2018), which in relative terms means that a 10-year-old child born in January, has 10% more time to practice, and develop, compared to their younger peers born instead in December. This highlights how higher performance standards at the beginning of the developmental process, often attributed to innate ability, are more likely due to chronological age (Doyle et al. 2017).

Further theoretical support for the explanation of RAEs was given by Kelly et al. (2022), who used the Personal Assets Framework to explain the immediate (i.e., personal engagement in activities, appropriate settings and organisational structures, and quality social dynamics), short-term (i.e., competence, confidence, connection, and character), and long-term (i.e., performance, participation, and personal development) developmental outcomes due to RAEs. For example, athletes born at the begin of the competition year are provided with greater openings to elite developmental programs due to their age, and consequently experiment longer developmental advantages, thus benefit from the increased exposure to sport-specific motor experiences, to quality coaches and facilities,

CONTACT Gabriele Morganti gabriele.morganti@libero.it School of Sport and Exercise Sciences, Faculty of Medicine and Surgery, University "Tor Vergata", Rome, Italy

and from the regular involvement in higher competition levels from a young age (Ibàñez et al. 2018). This creates differences in opportunity for growth, as early born athletes have more time and possibility to develop and fulfil their true potential, suggesting how they may enhance their sport-specific skills faster than their younger peers (Doncaster et al. 2020). This rise in sporting competence leads them to increase their performance standards and to experiment early successes, that in turn result in higher levels of confidence and motivation (Aune et al. 2018; Kelly et al. 2022), that eventually rise to further improvement of performance.

The higher developmental opportunities experimented by the relatively older athletes could augment their likelihood of becoming the better athletes in the long term. Research has shown how RAEs affect the early phase of senior career in team sports (Lupo et al. 2019) and influence the likelihood of achieving world class performance in individual sport (Brustio et al. 2019). Some studies use the overrepresentation of relatively older athletes at senior level to indicate that they remain to be considered the most "talented", proving the long-term effects of relative age (e.g., Tribolet et al. 2019; Kelly et al. 2022). As an example, recently in Italian soccer, Brustio et al. (2018) found a skewed birthdate distribution favouring relatively older players in all playing categories at youth and senior levels (U15, U16, U17; Primavera [U20], and Serie A [i.e., Italian Premier League]). In detail, examination of the BQ distribution across all youth Italian soccer categories showed how only 5%, 6%, 11% and 10% of players who played at U15, U16, U17 and Primavera level were born in the last quartile, respectively. These low percentages indicate most relatively younger players, who may have the potential to excel in adulthood, are overlooked by youth sport organisations, being underrepresented across all elite age-group categories. This causes a smaller pool of talented later born players to select from at senior levels (Kelly et al. 2022). In other words, when Italian soccer clubs will select players, from the youth leagues, for their senior teams, the likelihood of selecting a player born in January, rather than one born instead in December will be much higher. Players are selected from a pool of players already affected by the relative age effect, indicating the existence of a residual bias labelled "knock-on effect" of relative age phenomenon (Mujika et al. 2009; Lovell et al. 2015).

In line with these observations, literature has found that despite the presence of RAEs both at youth and senior levels, relatively younger players able to enter the system at an earlier age are the ones who possess the greater likelihood of achieving the professional status. More specifically, research conducted in rugby union (Kelly et al. 2021a), cricket (Kelly et al. 2022); basketball (Kelly et al. 2021b), and soccer (Kelly et al. 2020a) has shown how later born players are less likely to be selected by academy systems but are more likely to transition into senior squads once selected. These findings are explained using the "underdog hypothesis" (Gibbs et al. 2012), whereby it has been suggested that relatively younger players may hold the greatest potential for success at the adult level, due to being required to develop superior technical, tactical, physical, psychological, and social skills in order to compete with their relatively older and more advanced peers (Schorer et al. 2009; Gibbs et al. 2012; McCarthy et al. 2016). This body of research shows it is important to capture players' career trajectories to better understand how age group structures can impact senior opportunities for young players who enter talent pathways at youth levels.

Accordingly, this study aimed to explore the complex relationship between the date of birth, the likelihood of being selected by talent identification and development system, and the opportunity to complete the transition and compete at senior level. For this reason, this study was divided into two parts: Part 1 explored the BQ distribution of 2,030 Italian players born from 1975 to 2001 (both years included) who have played in any of the Youth National Italian Soccer Teams (i.e., U15, U16, U17, U18, U19, U20, and U21); Part 2 recorded career trajectories of these players to investigate how RAEs influence future career outcomes, by exploring the BQ distribution of players who completed the transition from youth levels to the Senior National Team (n = 182) and those who eventually achieved the Super International Achievers (SIA) status (i.e., playing at a senior level in a UEFA European Champions and/or FIFA World Championship; n = 58). For Part 1 of the study, it was hypothesised RAEs were largely present at youth levels due to the immediate and short-term effects of relative age. For Part 2 of the study, it was hypothesised RAEs remain present in the cohort of players who completed the transition, and their presence rather that because of the long-term effects of relative age, whereby relatively older players remain to be considered the most "talented" even at senior level, was expected only due to a residual bias labelled "knock-on effect" of relative age, whereby, in contrast, are the relatively younger players the ones with the greatest likelihood to complete the transition due to the effects of the "underdog hypothesis".

Methods

Subjects

In Part 1 of this study, a total sample of 2,030 male Italian soccer players were included. To be eligible for inclusion, a player must have been born from 1975 to 2001 (both years included) and must have been selected at least once during their career to play for any Youth National Italian Soccer Team (U15: n = 431; U16: n = 722; U17: n = 736; U18: n = 855; U19: n = 708; U20: n = 671; U21: n = 511). One player could have been registered in more than one youth team, depending on how many times they were selected for (i.e., a player during their youth career could have been selected to play for the U15 team and for the U16 team).

For Part 2 of this study, players who made the successful transition from the Youth National Teams to the Senior National Team (n = 182), as well as players who went on to play a UEFA European Championship or a FIFA World Championship with the Senior National Team (i.e., players who achieved SIA status; n = 58) were included. Because all data were freely available from the internet, no approval by an Ethical Committee was required.

Procedures

The data for this study (i.e., players' birthdates and selections) were obtained from the official data centre of the Italian Soccer Federation (Federazione Italiana Giuoco Calcio; FIGC), which were allocated on the FIGC website (https://www.figc.it). The birth month of each player was used to define the BQ, which was then allocated into one of the four quartiles: (a) BQ1 = January, February, and March, (b) BQ2 = April, May, and June, (c) BQ3 = July, August, and September, and (d) BQ4 = October, November, and December. The observed birthdate distribution of the Youth National Teams was calculated for each BQ and compared to the expected distribution of an assumed equal number of players in each BQ (Schorer et al. 2009). Subsequently, the observed birthdate distribution of the players who successfully made the transition to the Senior National Team, and of the players who achieved the SIA Status, was also calculated. Moreover, in order to gain a full understanding of any bias effects, the Senior National Team and SIA were compared to both the uniform distribution and to the U15 player BQ distribution.

Statistical analysis

In Part 1 of this study, the observed Youth National Teams BQ distributions were compared against the expected BQ distribution based on the assumption that the BQs were equally distributed (Schorer et al. 2013). In Part 2 of this study, to explore the youth-to-senior transition, the BQ distribution of players who successfully progressed to play for the Senior National Team as well as the BQ distribution of players who then achieved SIA status were compared both to the uniform distribution (i.e., assumed equal BQs distribution) and to the expected distribution (i.e., U15 BQ distribution) (Kelly et al. 2020b). A chi-square (x^2) goodness-of-fit test was used to compare the observed and expected BQ distributions. As the chi-square does not reveal the magnitude of difference between quartile distributions for significant chi-square outputs, effect sizes (Cramer's V), was also used. The Cramer's V was interpreted as follows: a value of 0.06 or more indicated a small effect size, 0.17 or more indicated a medium effect size, and 0.29 or more indicated a large effect size (Cohen 1998). Odds Ratios (ORs) and 95% Confidence Intervals (CIs) were used to compare BQs for achievement of youth and senior status, with the youngest group used as reference (BQ4), as previously conducted in other relative age studies (Brustio et al. 2018). The ORs were calculated and interpreted following the procedures outlined by Szumilas (2010), with CIs including 1 (i.e., 95% CI 0.90–1.10) marked no association. Results were considered significant for $P < 0.05$.

Results

The frequency and percentage of the Youth National Teams distributions from each BQ, the results from the chi-square tests, and the results from the ORs are shown in Table 1. The observed BQ distribution for the U15, U16, U17, U18, U19, U20, and U21 were significantly skewed when compared to the expected BQ distribution (all $P < 0.0001$; effect sizes ranged from medium to large; BQ1 range from 34.4% to 46.7%, BQ2 from 24.8% to 29.4%, BQ3 from 18.1% to 22.7%, and BQ4 from 7.2% to 15.2%; overall mean: BQ1 = 41.4%, BQ2 = 27.2%, BQ3 = 20.5%, and BQ4 = 10.8%). The ORs showed an increased likelihood of relatively older players being selected for every Youth National Teams (i.e., from U15 to U21), with the highest ORs recorded between BQ1 and BQ4 (ranging from 2.4 [U20] to 6.5 [U15]).

The observed BQ distribution of the senior cohorts (i.e., Senior National Team and SIA), as well as the uniform and the expected distributions, are separately displayed in Figure 1. When comparing both senior cohorts to the uniform distribution, results show RAEs remain present in the Senior National Team cohort, as relatively older players are overrepresented (x^2 (3) = 13.956, $P = 0.003$, Cramer's V =

Table 1. Birthdate distribution of the International Youth Italian football players compared to the uniform distribution. The uniform distribution was of 25% for each birth quarter.

National team	BQ1 (expected)	BQ2 (expected)	BQ3 (expected)	BQ4 (expected)	X^2	P	V	Effect	BQ4 vs. BQ1 OR (95% CI)
U21	177 (128.3)	150 (128.3)	117 (128.3)	69 (128.3)	50.579	**<0.0001**	0.18	Medium	**2.57 (1.77–3.72)**
%	34.5	29.2	22.8	13.5					
U20	243 (168)	179 (168)	148 (168)	102 (168)	62.512	**<0.0001**	0.18	Medium	**2.40 (1.75–3.28)**
%	36.2	26.6	22	15.2					
U19	284 (179)	201 (179)	146 (179)	85 (179)	119.743	**<0.0001**	0.24	Medium	**3.34 (2.43–4.60)**
%	39.7	28	20.4	11.9					
U18	370 (224)	239 (224)	186 (224)	101 (224)	170.152	**<0.0001**	0.25	Medium	**3.66 (2.75–4.88)**
%	41	26.7	20.8	11.5					
U17	357 (200.5)	224 (200.5)	147 (200.5)	74 (200.5)	218.998	**<0.0001**	0.3	Large	**4.82 (3.51–6.63)**
%	44.5	27.9	18.3	9.3					
U16	396 (211.3)	219 (211.3)	163 (211.3)	67 (211.3)	271.379	**<0.0001**	0.33	Large	**5.91 (4-29-8.15)**
%	46.9	25.9	19.3	7.9					
U15	266 (136.5)	134 (136.5)	110 (136.5)	35 (136.5)	203.895	**<0.0001**	0.35	Large	**7.60 (4.97–11.62)**
%	48.8	24.6	20.2	6.4					

Bold = statistically significant at $P < 0.05$.

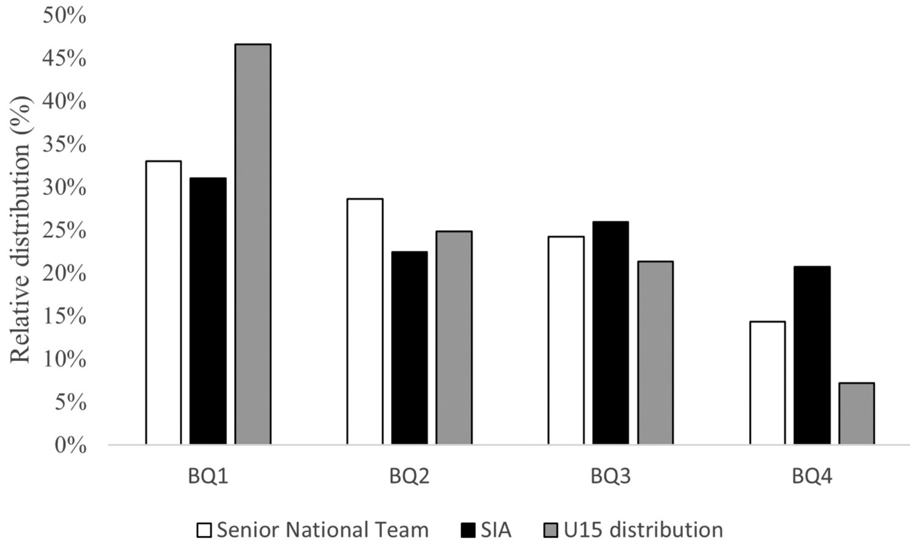


Figure 1. Birth date distribution of the international Italian soccer players who successfully completed the transition from youth-to-senior. The uniform distribution was of 25% for each birth quarter.

0.16; BQ1 = 33% vs. BQ4 = 14.2%), although this was not statistically significant for the SIA Status cohort (χ^2 (3) = 1.448, $P = 0.694$, Cramer's V = 0.08; BQ1 = 31% vs. BQ4 = 20.7%). In contrast, relatively younger players recorded significantly higher conversion rates, whereby BQ4s had the largest proportion of players who successfully transitioned out of the Youth National Teams to play for the Senior National Team (BQ1 = 7.2% vs. BQ4 = 11.1%) and achieve SIA status (BQ1 = 2.2% vs. BQ4 = 5.1%; see Figure 2). Indeed, statistical analysis showed how the BQ distributions of both senior cohorts were significantly skewed when compared to the U15 BQ distribution (Senior National Team: X^2 (3) = 21.681, $P < 0.0001$, Cramer's V = 0.20; SIA: X^2 (3) = 18.328, $P < 0.001$, Cramer's V = 0.32), which favoured relatively younger players. Furthermore, the ORs showed an increased likelihood of relatively younger players to successfully make the transition youth-to-senior (Senior National Team: BQ4 vs. BQ1 = 2.81, 95% CI = 1.34–5.89; SIA: BQ4 vs. BQ1 = 4.31, 95% CI = 1.22–15.24).

Discussion

This is the first study that has provided an overview of the selection processes into and transition out of the Italian national soccer talent pathway. Results from Part 1 of the study showed that RAEs were strongly present across every Youth National Team from U15 to U21. This indicates how relatively older players are more likely to being considered as "talented" at youth level. Results from Part 2 of the study showed how BQ4s recorded the largest proportion of players who successfully made the youth-to-senior transition, thus highlighting the overrepresentation of early born players at senior level is probably due to a residual bias effect, which will be further discussed later.

Findings from Part 1 which showed strong RAEs presence at youth levels are in line with the functional perspective of the society, whereby people, social systems, and all aspects of society are evaluated according to its functionality and on their ability to meet their goals. In the context of soccer, any

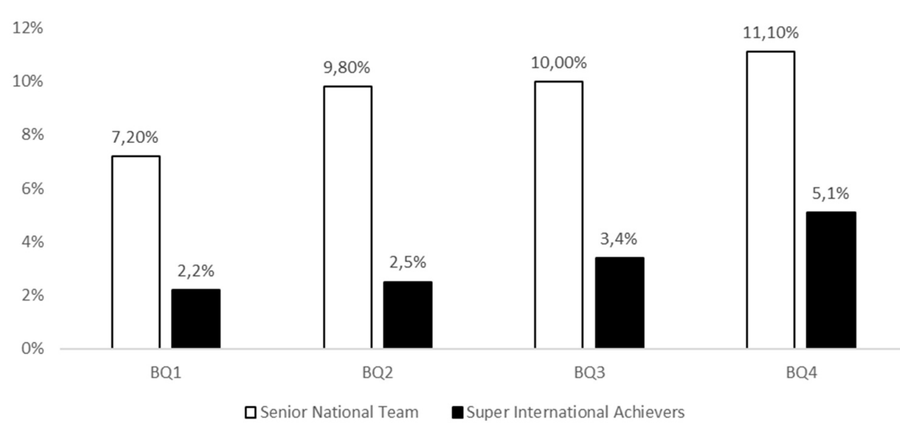


Figure 2. Conversion of talent for each BQ.

performance that yields a victory is functional and preferred over a defeat (Delaney 2015). Applying this functional perspective to the talent identification system when selecting players, head coaches would ask themselves whether that player would be a good fit for the team, answering questions like: "Who will perform best in a relatively short timeframe?" (Baker et al. 2018). In this perspective, head coaches select players for short-term goals (i.e., next tournament, next game), concerned in trying to find the best age group player, informing their decision-making independently of players' birthdate, nor potential, but rather by current performance evaluations (i.e., the ends justify the means; Delaney 2015).

When selecting players based on their current level of performance, for most relatively younger athletes, the probability of being selected is lower than for relatively older athletes (Bjørndal et al. 2018). Athletes born earlier in the year have more motor experiences in the sport context, whereby they are able to attain higher performance standards, which ensure them greater openings to talent pathways. This can in turn exacerbate the inequalities, providing relatively older athletes even more opportunities for sport-specific growth (Helsen et al. 1998). BQ1 players are therefore favoured at the beginning of the selection process due to relative age advantages which provide them more opportunity to be selected by talent development organisations (Doyle et al. 2017; Aune et al. 2018), and continue to be favoured in the next developmental stages due to advantages derived by being included from an early age in talent development programmes.

The findings from Part 2 of this study showed how, even though relatively older players remained overrepresented in the cohort of players who transitioned to the Senior National Team, BQ4 had the largest proportion of players who completed the pathway from entry to expertise (i.e., "underdog hypothesis"). Thus, the presence of RAEs at senior level is probably due to a residual bias effect (i.e., "knock-on effect"). More specifically, in our study population of 2,030 Italian soccer players who played for any of the Youth Italian National Soccer teams, more than the 40% of them were born in the first quartile, while instead only the 10% were born in the last quartile. Consequently, when we examined players' future career outcomes, early born players remained overrepresented in the cohort of players who completed the transition from youth-to-senior only because they were much more represented at youth level. Therefore, our study highlighted how RAEs at senior level are perhaps consequential of RAEs at youth levels (Mujika et al. 2009; Lovell et al. 2015), highlighting how contrary to expectations, and despite the longer developmental advantages, most relatively older players may fail to make the transition. This shows the importance of studying RAEs at more than one timepoint by involving players' career trajectories to understand how age group structures impact career outcomes of players who enter the sport system at youth level.

Based on the results of our study, relatively younger players who enter the national system at a younger age are more likely to experience soccer success at senior level, compared to the relatively older players who enter the system at the same age. Relatively younger players may be challenged by older peers (Schorer et al. 2009) and have to develop certain technical proficiencies and/or tactical awareness to counteract with them (Schorer et al. 2009; Gibbs et al. 2012; McCarthy et al. 2016). It has been suggested that since BQ4 players have to face greater challenges in order to have the opportunity to fulfil their potential, in that they are less likely to be selected by talent development organisations, they develop a more robust coping mechanism (Roberts and Stott 2015), learning to "work harder", which then results in facilitate resilience and improved motivation (Schorer et al. 2009), which can in turn help them building the required character to successfully complete the youth-to-senior transition (Kelly et al. 2022). It is also plausible to suggest that relatively younger players who, despite the longer developmental advantages and advanced psychosocial skills of their relatively older peers, can overcome selection processes, may be the ones more accurately selected by head coaches (Gil et al. 2020).

These late advantages for the relatively younger players are experimented only by the few of them who were able to enter the system at a younger age, and who have therefore had the opportunity to develop in high-quality environment. While the vast majority of them, being overshadowed by their older peers, will soon lose interest in sporting activities, and may experiment early drop-out from sport (Kelly et al. 2022). On the other side of the same coin, our study highlighted many relatively older players that win at youth level, are not prepared for the next step at senior level and may fail to make the transition (Abbott and Collins 2004). Therefore, these findings revealed how in adopting a functional approach to talent identification (i.e., Who is the most functional player for the team?), sport systems put an overemphasis on players' current level of performance and are losing talent at both spectrum of the developmental stage (i.e., initial de-selection of relatively younger players and later de-selection of relatively older players). Considering youth players performance is the result of developmental advantages (e.g., hours of training, psychosocial skills), which may be also exacerbated by the relative age, a functional approach to talent identification may be thus required only if sport systems' aim is to win at youth level and are valued on their ability to produce the few who eventually make it. In contrast, a functional approach to talent development (i.e., What is needed to be the next most functional player?) may be more appropriated to nurture players for senior-level successes, as in turn this will cause sport systems to be judged on their impact on the many.

Study limitations

When interpreting the findings from this study, it is also important to consider its limitations. First, playing positions were not included as a variable in this study. Recent research has shown that goalkeeper and forwards are more affected by RAEs in comparison to defenders and midfielders (Pérez-González et al. 2021). Including playing positions when studying RAEs in sport is important to better understand who is more vulnerable to this selection bias. Second, only one appearance with any of the Youth National Italian Football Teams was required to be included in this study, whereas some players could have played in considerably more games. Therefore, career durations should be a variable included to better study RAEs' long-term development outcomes. Finally, this study did not make a distinction between playing a friendly match or an official match. In considering the different requirements needed for players to play internationally during a major tournament and to play in a friendly match, a more appropriate data analysis would have included this variable of diversification, even if the authors would highlight when young players are selected to play at the international level, both in a friendly or in an official match, they face in both cases, a strict process of selection policy.

Practical implications and future directions

RAEs are an unintended form of age discrimination and talent wastage (e.g., Doyle et al. 2017; Romann et al. 2021). Thus, it is important to consider possible solutions to eradicate RAEs from sports, avoiding loss of talent, and offering directions for future research. Avoiding early selection and early de-selection are two possible and viable solutions to prevent the loss of talent (i.e., RAEs) (Tribolet et al. 2019; Romann et al. 2020). Moreover, Kelly et al. (2020b) proposed to have a more flexible chronological approach, whereby early birth quartiles (i.e., BQ1s) and late birth quartiles (i.e., BQ4) should be offered the opportunity to "play-up" (e.g., Kelly et al. 2021c) and "play-down". Additionally, in an attempt to remove particular selection time points and specific chronological age groups, Kelly et al. (2020a) introduced the birthday-banding, whereby athletes move up to their next age group based on their birthday.

Recently, Hancock (2021) has conducted a qualitative research, based upon the social agent's model (Hancock et al. 2013), studying RAE in an elite Canadian youth ice-hockey team. This is a different approach to the study of RAEs, whereby they are investigated through the lens of social agent point of view (i.e., athletes, coaches, and parents). For this reason, considering the cohesion between athlete and environment, athlete and socio-cultural constraints (e.g., Hancock et al. 2013), a further key to the interpretation of RAEs presence in sport may be to investigate the athletes' perceptions of the youth sport development environment through the administration of the Talent Development Environment Questionnaire (i.e., TDEQ-5, 45) (e.g., Gangsø et al. 2021; Apollaro et al. 2022).

Conclusion

This was the first study to investigate the influence of the relative age on the selection into and successful transition out of a national talent pathway in soccer. Results from Part 1 of the study showed how the selection processes of the Youth Italian National Teams are highly influenced by RAEs, with relatively older players overrepresented across every Youth squad, due to immediate and short-term effects of relative age. Results from Part 2 showed BQ1 players remain overrepresented in the cohort of players who completed the transition to the Senior National Team, but only due to a residual bias (i.e., "knock-on effect"), as statistical analyses have highlighted relatively younger players, selected for Italy at youth levels, are the ones more likely to complete the transition from entry to expertise (i.e., "underdog hypothesis). This study showed how inequalities of opportunities for development characterise youth soccer in Italy. It highlighted how most relatively younger players, who may have the potential to succeed, are overshadowed by their older peers, causing a loss of talent at the begin of the developmental process; and how most relatively older players that were considered ready for youth sport, are not able to complete the transition to senior sport, causing a loss of talent at the end of the developmental process. Moving forward, as youth performance appears as the result of developmental advantages in an attempt to avoid the loss of talent at both spectrum of the developmental process, a cultural Change is needed, one that will guarantee a passage from a functional approach to talent *identification* to a functional approach to talent *development*.

Acknowledgments

The authors acknowledge Daniele Petrone from the "Department of Infectious Diseases - Istituto Superiore di Sanità – Rome, Italy" for his help with the statistical part of the article.

Disclosure statement

No potential conflict of interest was reported by the authors.

Author Contributions

GM, AK, GA and BR have given substantial contributions to the conception and design of the manuscript to acquisition, analysis and interpretation of the data. GM, AK, GA and BR have participated to drafting the manusript. All authors revised it critically. All authors read and approved the final version of the manuscript.

Funding

The authors reported there is no funding associated with the work featured in this article.

ORCID

Gabriele Morganti http://orcid.org/0000-0001-9448-3872
Adam L. Kelly http://orcid.org/0000-0003-4929-1067
Gennaro Apollaro http://orcid.org/0000-0002-0427-037X
Bruno Ruscello http://orcid.org/0000-0002-5381-9146

References

Abbott A, Collins D. 2004. Eliminating dichotomy between theory and practice in talent identification and development: considering the role of psychology. J Sports Sci. 22(5):395–408. doi:10.1080/02640410410001675324.

Apollaro G, Pantanella L, Esposito M, Ruscello B. 2022. Talent development environments in elite taekwondo population: a study within an Italian context. J Sports Med Phys Fitness. 62(5):618–625. doi:10.23736/S0022-4707.21.12282-0.

Aune TK, Ingvaldsen RP, Vestheim OP, Bjerkeset O, Dalen T. Relative age effects and gender differences in the national test of numeracy: a population study of Norwegian children. Front Psychol. *9*: 1091. 2018

Baker J, Schorer J, Wattie N. 2018. Compromising talent: issues in identifying and selecting talent in tport. Quest. 70(1):48–63. doi:10.1080/00336297.2017.1333438.

Bjørndal CT, Luteberget LS, Till K, Holm S. 2018. The relative age effect in selection to international team matches in Norwegian handball. Plos One. 13(12):e0209288. doi:10.1371/journal.pone.0209288.

Brustio PR, Kearney PE, Lupo C, Ungureanu AN, Mulasso A, Rainoldi A, Boccia G. 2019. Relative age influences performance of world-class track and field athletes even in the adulthood. Front Psychol. 10:1395. doi:10.3389/fpsyg.2019.01395.

Brustio PR, Lupo C, Ungureanu AN, Frati R, Rainoldi A, Boccia G. 2018. The relative age effect is larger in Italian soccer top-level youth categories and smaller in Serie a. Plos One. 13(4):e0196253. doi:10.1371/journal.pone.0196253.

Cobley S, Baker J, Wattie N, McKenna J. 2009. Annual age-grouping and athlete development: a meta-analytical review of relative age effects in sport. Sports Med. 39(3):235–256. doi:10.2165/00007256-200939030-00005.

Cohen J. 1998. Statistical power analysis for the behavioral sciences. Hillsdale (NJ): L. Erlbaum Associates.

Costa AM, Marques MC, Louro H, Ferreira SS, Marinho DA. 2013. The relative age effect among elite youth competitive swimmers. Eur J Sport Sci. 13 (5):437–444. doi:10.1080/17461391.2012.742571.

Delaney T. 2015. The functionalist perspective on sport. In: Giulianotti R, editor. Routledge handbook of the sociology of sport. London: Routledge; pp. 18–29.

Doncaster G, Medina D, Drobnic F, Gómez-Díaz AJ, Unnithan V. 2020. Appreciating factors beyond the physical in talent identification and development: insights from the FC Barcelona sporting model. Front Sports Act Living. 2:91. doi:10.3389/fspor.2020.00091.

Doyle JR, Bottomley PA, Angell R. 2017. Tails of the travelling Gaussian model and the relative age effect: tales of age discrimination and wasted talent. Plos One. 12(4):e0176206. doi:10.1371/journal.pone.0176206.

Gangsø K, Aspvik NP, Mehus I, Høigaard R, Sæther SA. 2021. Talent development environments in Football: comparing the top-five and bottom-five-ranked Football Academies in Norway. Int J Environ Res Public Health. 18(3):1321. doi:10.3390/ijerph18031321.

Gibbs BG, Jarvis JA, Dufur MJ. 2012. The rise of the underdog? The relative age effect reversal among Canadian-born NHL hockey players: a reply to Nolan and Howell. Int Rev Sociol Sport. 47(5):644–649. doi:10.1177/1012690211414343.

Gil SM, Bidaurrazaga-Letona I, Martin-Garetxana I, Lekue JA, Larruskain J. 2020. Does birth date influence career attainment in professional soccer?. Sci Med Football. 4(2):119–126. doi:10.1080/24733938.2019.1696471.

Hancock DJ. 2021. Exploring relative age effects in Youth Ice Hockey through a single team case study and composite narratives. Front Sports Act Living. 3:658953. doi:10.3389/fspor.2021.658953.

Hancock DJ, Adler AL, Côté J. 2013. A proposed theoretical model to explain relative age effects in sport. Eur J Sport Sci. 13(6):630–637. doi:10.1080/17461391.2013.775352.

Helsen WF, Starkes JL, Van Winckel J. 1998. The influence of relative age on success and dropout in male soccer players. Am J Hum Biol. 10 (6):791–798. doi:10.1002/(SICI)1520-6300(1998)10:6<791:AID-AJHB10>3.0.CO;2-1.

Ibàñez SJ, Mazo A, Nascimento J, Garcìa-Rubio J. 2018. The relative age effect in under-18 basketball: effects on performance according to playing position. Plos One. 13(7):e0200408. doi:10.1371/journal.pone.0200408.

Kelly AL, Brown T, Reed RC, Côté J, Turnnidge J. 2022. Relative age effects in male cricket: a personal assets approach to explain immediate, short-term, and long-term developmental outcomes. Sports. 10(3):39. doi:10.3390/sports10030039.

Kelly AL, Jackson DT, Taylor JJ, Jeffreys MA, Turnnidge J. 2020a. "Birthday-Banding" as a strategy to moderate the relative age effect: a case study into the England Squash talent pathway. Front Sports Act Living. 2:573890. doi:10.3389/fspor.2020.573890.

Kelly AL, Jiménez Sáiz SL, Lorenzo Calvo A, de la Rubia A, Jackson DT, Jeffreys MA, Ford C, Owen D, Santos SDLD. 2021b. Relative age effects in basketball: exploring the selection into and successful transition out of a national talent pathway. Sports. 9(7):101. doi:10.3390/sports9070101.

Kelly AL, Till K, Jackson D, Barrell D, Burke K, Turnnidge J. 2021a. Talent identification and relative age effects in English male rugby union pathways: from entry to expertise. Front Sports Act Living. 3:640607. doi:10.3389/fspor.2021.640607.

Kelly AL, Wilson M, Gough L, Knapman H, Morgan P, Cole M, Jackson DT, Williams CA. 2020b. A longitudinal investigation into the relative age effect in an English professional football club: exploring the 'underdog hypothesis'. Sci Med Football. 4(2):111–118. doi:10.1080/24733938.2019.1694169.

Kelly AL, Wilson M, Jackson DT, Goldman DE, Turnnidge J, Côté J, Williams CA. 2021c. A multidisciplinary investigation into "playing-up" in academy football according to age phase. J Sports Sci. 39(8):854–864. doi:10.1080/02640414.2020.1848117.

Lovell R, Towlson C, Parkin G, Portas M, Vaeyens R, Cobley S. 2015. Soccer player characteristics in English lower-league development programmes: the relationships between relative age, maturation, anthropometry and physical fitness. Plos One. 10(9):e0137238. doi:10.1371/journal.pone.0137238.

Lupo C, Boccia G, Ungureanu AN, Frati R, Marocco R, Brustio PR. 2019. The beginning of senior career in team sport is affected by relative age effect. Front Psychol. 10:1465. doi:10.3389/fpsyg.2019.01465.

McCarthy N, Collins D, Court D. 2016. Start hard, finish better: further evidence for the reversal of the RAE advantage. J Sports Sci. 34 (15):1461–1465. doi:10.1080/02640414.2015.1119297.

Mujika I, Vaeyens R, Matthys SP, Santisteban J, Goiriena J, Philippaerts R. 2009. The relative age effect in a professional football club setting. J Sports Sci. 27(11):1153–1158. doi:10.1080/02640410903220328.

Musch J, Grondin S. 2001. Unequal competition as an impediment to personal development: a review of the relative age effect in sport. Dev Rev. 21(2):147–167. doi:10.1006/drev.2000.0516.

Pérez-González B, León-Quismondo J, Bonal J, Burillo P, Fernández-Luna Á. 2021. The new generation of professional Soccer talent is born under the bias of the RAE: relative age effect in International Male Youth Soccer Championships. Children. 8(12):1117. doi:10.3390/children8121117.

Roberts SJ, Stott TA. 2015. A new factor in UK students' university attainment: the relative age effect reversal? Qual Assur Educ. 23(3):295–305. doi:10.1108/QAE-01-2013-0008.

Romann M, Javet M, Cobley S, Born DP. 2021. How relative age effects associate with Football players' market values: indicators of losing talent and wasting money. Sports. 9(7):99. doi:10.3390/sports9070099.

Romann M, Rüeger E, Hintermann M, Kern R, Faude O. 2020. Origins of relative age effects in youth football—a nationwide analysis. Front Sports Act Living. 2:1–7. doi:10.3389/fspor.2020.591072.

Rosenthal R, Jacobson L. 1968. Pygmalion in the classroom: teacher expectation and pupil's intellectual development. New York, NY: Holt, Rinehart & Winston.

Schorer J, Cobley S, Busch D, Brautigam H, Baker J. 2009. Influences of competition level, gender, player nationality, career stage and playing position on relative age effects. Scand J Med Sci Sports. 19(5):720–730. doi:10.1111/j.1600-0838.2008.00838.x.

Schorer J, Wattie N, Baker JR. 2013. A new dimension to relative age effects: constant year effects in German youth handball. Plos One. 8(4):e60336. doi:10.1371/journal.pone.0060336.

Szumilas M. 2010. Explaining odds ratios [published correction appears in J Can Acad Child Adolesc Psychiatry 24(1): 58], 2015. J Can Acad Child Adolesc Psychiatry. 19(3):227–229.

Till K, Baker J. 2020. Challenges and [Possible] solutions to optimizing talent identification and development in sport. Front Psychol. 11:664. doi:10.3389/fpsyg.2020.00664.

Towlson C, MacMaster C, Parr J, Cumming S. 2021. One of these things is not like the other: time to differentiate between relative age and biological maturity selection biases in soccer? Sci Med Football. doi:10.1080/24733938.2021.1946133.

Tribolet R, Watsford ML, Coutts AJ, Smith C, Fransen J. 2019. From entry to elite: the relative age effect in the Australian football talent pathway. J Scie Med Sport. 22(6):741–745. doi:10.1016/j.jsams.2018.12.014.

Yagüe JM, de la Rubia A, Sánchez-Molina J, Maroto-Izquierdo S, Molinero O. 2018. The relative age effect in the 10 best leagues of male professional Football of the Union of European Football Associations (UEFA). J Sports Sci Med. 17(3):409–416.

© 2022 EDIZIONI MINERVA MEDICA
Online version at https://www.minervamedica.it

The Journal of Sports Medicine and Physical Fitness 2023 January;63(1):136-43
DOI: 10.23736/S0022-4707.22.13663-7

ORIGINAL ARTICLE
EPIDEMIOLOGY AND CLINICAL MEDICINE

Relative age effect in Italian soccer: a cultural issue in talent management?

Bruno RUSCELLO [1, 2, 3, 4] *, Gabriele MORGANTI [1], Gennaro APOLLARO [1], Antonio SAPONARA [1], Mario ESPOSITO [1], Lorenzo MARCELLI [1, 3], Cristoforo FILETTI [5], Marco PORTA [2], Alberto GROSSI [1], Laura PANTANELLA [1]

[1]School of Sports Sciences and Exercise, Faculty of Medicine and Surgery, Tor Vergata University, Rome, Italy; [2]School of Sports and Exercise Sciences, San Raffaele University, Rome, Italy; [3]Department of Industrial Engineering, Faculty of Engineering, Tor Vergata University, Rome, Italy; [4]LUISS SportLab, LUISS University, Rome, Italy; [5]Paris Saint Germain Football Club, Paris, France

*Corresponding author: Bruno Ruscello, School of Sports Sciences and Exercise, Faculty of Medicine and Surgery, Tor Vergata University, via Montpellier 1, 00133 Rome, Italy. E-mail: bruno.ruscello@uniroma2.it

ABSTRACT

BACKGROUND: Relative age effect (RAE) is a well-known phenomenon among those involved in youth sports, especially when the sport being investigated is widespread and involves early selection for participation in national and international competitions.
METHODS: The purpose of this study was to verify whether the Italian youth soccer ecosystem has adapted to this issue over the years, comparing players born in 1995 and in 2005 and been playing in Under 16 teams in the appropriate years. The sample included 13 professional Italian soccer teams. The number of players analysed was 260 (1995) and 344 boys (2005), respectively, making a total of 604 players enrolled in this study.
RESULTS: Relative age effects were detected by χ^2 goodness of fit tests both in players born in 1995 (P<0.000;V=0.40) and in 2005 (P<0.0001;V=0.39). χ^2 test of independence showed no significant difference between the two groups of players (P=0.986;V=0.02), confirming a substantial parity of the phenomenon over the two investigated birth years.
CONCLUSIONS: Ten years of research and dissemination of RAE did not change the selection policies adopted by coaches and/or scouts, who favor relatively older players during the selection processes. Therefore, RAE appears as the result of the Talent Identification and Development Structures, characterized by early selection and early specialization, and which consider performance as the pre-requisite for gaining access to the next developmental stages. Sport organizations should be aware of this issue and counteract accordingly, since it is important to mitigate the presence of RAE, as it causes inequality of opportunity.

(*Cite this article as:* Ruscello B, Morganti G, Apollaro G, Saponara A, Esposito M, Marcelli L, *et al.* Relative age effect in Italian soccer: a cultural issue in talent management? J Sports Med Phys Fitness 2023;63:136-43. DOI: 10.23736/S0022-4707.22.13663-7)

KEY WORDS: Youth sports; Soccer; Age factors.

Modern sport exhibits a high quest for elite performance, as a result of the increased competitiveness, between athletes, nations and professional clubs, caused by the high financial and commercial rewards of winning sporting competitions or avoid relegations.[1-3] Most sport organizations opt to identify early talented athletes and develop them in an optimal environment (*e.g.*, 1; 3; 4), following what has been called by Bailey and Collins[4] the Standard Model of Talent Development (SMTD), which is indeed based on early identification from current level of performance or psychological and/or anthropometrical measures, and on the removing of the not eligible athletes in the progression to the next developmental stages. Therefore, the idea behind talent identification (TID) is to select the most "promising" young players from the general population to give them the chance to raise as elite players in a Talent Development Program (TDP), in which selected players are supported throughout a system of practice and competitions.[1] Soccer is by far the most popular sport globally and continue to flourish in terms of participation rates and commercial growth.[5] This means that in soccer the competitive[6] and financial gains,[7] associated to the early recruitment of talented youngsters, are even higher. Therefore, the identification and development of young soccer players have become increasingly professionalized, involving now significant amounts of resources (*e.g.*, personnel, financial and time; 6). Youth soccer is certainly the largest youth sporting movement in Italy, with over one million members [8] in various age groups, who compete in several provincial, regional, and national competitions, organized based on the year of birth (under 15, under 16, etc.).

In Italy, to be able to coach at any level, including children, one must attend training courses, organized by the Italian Football Federation (FIGC)[9] which entitles a coaching license.

The main types of coaching licenses are:

- UEFA PRO;
- UEFA A;
- UEFA B;
- UEFA “GRASSROOTS” LICENSE C;
- LICENSE D (Amateur Football Coaching License).

The Amateur Football Coaching License (License D) is needed to coach in the Amateur leagues (*i.e.*, from the “*Eccellenza*”, the 5th level of football in Italy, to the “*Terza Categoria*”, the 9th and lowest level of football in Italy); and is also required for children’s football not involved in professional soccer clubs. The UEFA Grassroots Young Player Course (License C) is the level of qualification needed to coach in youth soccer, in professional level clubs. While UEFA B, UEFA A, and UEFA PRO licenses represent the level of qualification needed to coach at the higher professional level (“Serie C”, “Serie B”, “Serie A”).

The Italian Football Federation, as most other sports organizations, guarantees athlete participation and development during the youth years, providing talent development pathway, based on the SMTD,[4] having an organizational strategy which follows a cutoff criterion, thus grouping players based on their birthdate (from January 1st to December 31st), in trying to provide every child an equal chance to succeed.[10] However, in this grouping approach, players born at the begin of the cut-off date are 12 months older than players born at the end of the cut-off year, thus based on the timing of one’s birth within a given cohort, an individual can be relatively older or younger in comparison to their peers.[10]

In youth sport, relatively older athletes are favored in terms of talent identification, selection and development opportunities, compared to the relatively younger ones;[11, 12] indeed when observing the birth dates of young athletes selected for an elite youth team (*i.e.*, professional club, national selections) one notices a highly skewed distribution of birth periods with relatively older players being overrepresented,[1] almost as if to signify that talent - in our case soccer talent - is born in a precise period of the year. This selection bias is labelled as relative age effect (RAE) and it is a well-known phenomenon among those involved in youth sports, especially when the sport being investigated is widespread and involves early selection for participation in national and international competitions.[2-5, 13]

From a theoretical point of view RAEs are the results of multiple interactions involving individual (*i.e.*, individual’s birth date, sex, physical maturation and size), task (*i.e.*, sport type and level of competitive play), and environmental constraints (*i.e.*, cultural popularity of a sport in a particular country or region, different policies and developmental systems of sport, a sport’s maturity level and family influences).[14] Relatively older athletes are generally assumed to be more biologically mature compared to their younger counterparts,[15] but the presence of RAE also before puberty signifies that this is not a solely maturity-associated selection bias, and therefore is connected also to longer developmental advantages, greater time for practice and advanced psychosocial skills.[16, 17]

In both youth and professional soccer, RAE has been a research topic since the early nineties.[18, 19] Indeed, soccer is probably the most researched sport throughout the RAEs literature, as research has been done across a broad range of countries and level of competition.[20-24] It has been showed that higher levels of popularity, competition and selection processes focused on the short-term success are all features which can exacerbate the presence of RAE. Indeed, RAEs are more prevalent in youth academies and clubs classified with a higher level of certification.[20, 23] Moreover, RAEs are present even at a senior level,[22, 25-27] and recent RAEs literature highlighted how relative age influences future career outcome,[28] whereby in professional soccer relatively older players earn more money, compared to the relatively younger ones,[29] and have the greatest market values.[30] Furthermore, it has been hypothesized that RAE can very likely decrease the pool of available talents that nations can select from[31] as it can lead to an increase in drop-out rate from sports,[32, 33] and thus it is considered as an unintended form of age discrimination and talent wastage,[34, 35] which can clearly indicates how the “talent identification is not done on a level playing field”[13].

Italian soccer seems to be prone to RAE.[22, 28] Brustio *et al.*,[22] found a skewed birthdate distribution in all Italian elite playing categories (both youth and senior), but no studies are still available, investigating this phenomenon over time. Therefore, our main aim was to examine the birth composition of elite Italian youth soccer teams over two seasons of a decade apart (*i.e.*, 2010-11 and 2020-21), to investigate whether the magnitude or the presence of this bias has changed over time. We hypothesize two kind of results: 1) the decreasing of RAE in the last decade, due the increased practitioners' awareness of this bias, as RAE is a major topic in formal training courses held by the Italian Universities – Sport Sciences degrees – and the Italian Football Federation; and 2) no decreasing in RAE trends in the last decade, as a recent study have highlighted how the most important youth soccer competitions around the world are characterized by the presence of RAE, leading the authors to state that: "The new generation of professional soccer talent is born under the bias of RAE."[36]

Materials and methods

Participants and data collection

The study included 260 players for the 1995 class and 344 boys for the 2005 class, respectively, making a total of 604 players, representing a sample of about 18% of the entire considered population of young players engaged at this level of qualification, over the two investigated classes. This sample was recruited from 13 Italian professional soccer teams: A.C. Milan, A.C.F. Fiorentina, A.S. Roma, Benevento Calcio, F.C. Empoli, F.C. Internazionale, F.C. Juventus, Parma Calcio, Pordenone Calcio, S.S. Lazio, U.C. Sampdoria, Udinese Calcio, Vicenza Calcio. Birth dates were collected from publicly available online sources (https://www.transfermarkt.it/ and https://www.figc.it/it/home/). The use of data from open access sites has been previously described in other studies[22, 25] and there are no ethical issues involved in the analysis and interpretation of the data used as these were obtained in a secondary form and not from direct experimentation.

Procedures

After collecting the dates of birth of the players involved in this study, these were allocated to the four quarters considered – birth quarter (BQ) – for each year of birth analysed in this study (1995, 2005). This collection is representing the variable of interest of our study.

Birth Quarters considered in this study

- First quarter (BQ1) from January 1st to March 31st.
- Second quarter (BQ2) running from April 1st to June 30th.
- Third quarter (BQ3) running from July 1st to September 30th.
- Fourth quarter (BQ4) running from October 1st to December 31st.

Statistical analysis

Data were tabulated and organized in a Microsoft Excel worksheet and then reported and analysed using IBM SPSS Statistics for Windows, version 26.0 (IBM Corp., Armonk, NY, USA). For the first part of the study, χ^2 goodness of fit tests were used to compare the observed U16 players BQ distributions (for each year of birth considered) against the expected BQ distributions. Similar to other studies,[22, 37] the sample consisted of multinational players (*i.e.*, coming from different world countries) so the expected BQ distributions were calculated on the basis of the assumption of an even distribution of births throughout each quarter of the year, because it has been showed that the births are not evenly distributed in the year and they are affected by environmental zones and cultural factors.[38] Effect sizes (ES) (Cramer's V), odds ratios (ORs), and 95% confidence intervals (CIs) were calculated. The Cramer's V was interpreted as follows: a value of 0.06 or more indicated a small effect size, 0.17 or more indicated a medium effect size, and 0.29 or more indicated a large effect size.[39] The ORs and 95% CIs were calculated for the quartiles (BQ1, BQ2, and BQ3) with the youngest group used as reference (BQ4), as previously conducted in other relative age studies.[25, 40] For the second part of the study, χ^2 test of independence was used to compare the BQs distributions of the selected years. For this analysis, ES was reported using Cramer's *V*. The value of statistical significance was accepted with $P<0.05$.

A flow-chart diagram summarizing the study protocol is provided in Figure 1.

Results

Results for the first part of this study (*i.e.*, verifying RAEs in the investigated years of the study) are shown in Table I, Figure 2. Relative age effects were detected by χ^2 goodness of fit tests, confirming significant differences in BQ distributions of the players born in 1995 (considered U16 in 2010-11 season) and in 2005 (considered U16 in 2020-21 season). In both cohorts, the ORs showed an increased likelihood of relatively older footballers of playing with the U16 elite talent clubs (U16–1995: BQ2 *vs.* BQ4: OR=3.63, 95% CI=1.97-6.71; BQ3 *vs.* BQ4: OR=1.84, 95% CI=0.96-3.55; U16–2005: BQ2 *vs.* BQ4:

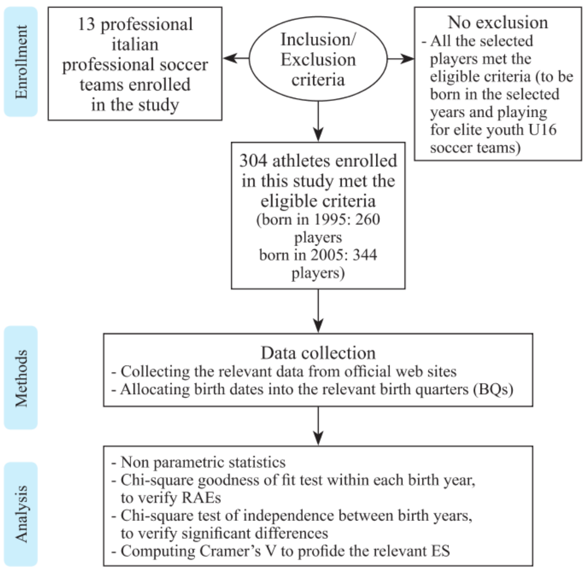


Figure 1.—Flow-diagram describing enrollment, methodological investigation and analysis of the young soccer players undergone this research project.

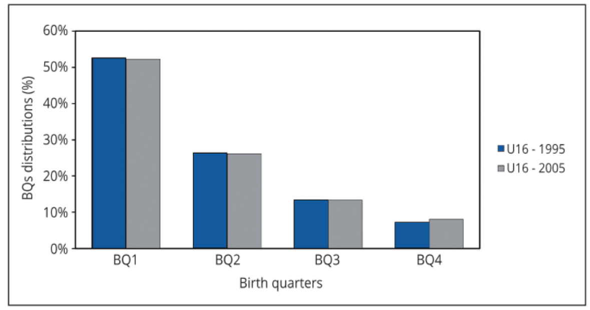


Figure 2.—Observed and expected relative (%) BQs distributions of U16 players (born in 1995 and in 2005).

OR=3.21, 95% CI=1.91-5.40; BQ3 *vs.* BQ4: OR=1.64, 95% CI=0.94-2.87).

Regarding the results for the second part of the study (*i.e.*, comparing the BQ distributions between players born in different years: 1995 *vs.* 2005), performing a χ^2 test of independence we found no significant differences between the distributions of the two groups of players ($\chi^2_{(3)}$=0.14; P=0.986; V=0.02, small).

Discussion

Prior works have already documented the presence of RAE in Italian soccer,[22, 28] but no studies are available investigating this phenomenon over time, to explore RAEs trends. Therefore, to the best of our knowledge this was the first study, which investigated RAEs' trends over a decade, considering the BQ distributions of two different cohorts of soccer players (born in 1995 and in 2005) and then acting as Under 16 players in the seasons 2010-11 and 2020-21, respectively.

Results showed that the BQ distributions of both cohorts are characterized by the presence of RAE, indicating how selection into elite Italian youth soccer club are influenced by players' relative ages. This study highlighted how ten years of research and dissemination of RAE, in both the academic and Italian Football Federation environments, did not change the selection mechanisms, whereby RAE was present ten years ago, and it is still present nowadays, with the same magnitude of a decade ago, indicating how youth Italian elite clubs are still favoring relatively older players. These findings are in line with other studies which tried to depict RAEs trends over time in soccer,[41-43] and ice-hockey,[44] and which showed a historical no decrease of this issue. In one of the most relevant studies of RAE in soccer, Helsen *et al.* in 1998[45] found a skewed birthdate distribution in Belgian youth players selected by first division teams, but not in players who played in regular youth leagues. More recently, in England Jackson & Comber[46] found a more pronounced RAE at academy level, compared to the grassroots level. Similar results were found in Portuguese and Scottish soccer.[20, 40] Perez-Gonzalez *et al.*[36] found RAEs in four major male junior championships (*i.e.*, FIFA U20 World Cup, UEFA U19-U21 European Championship and Conmebol U20) and concluded

Table I.—*Birthdate distribution of the U16 players (born in 1995 and in 2005) compared to the uniform distribution.*

	BQ1 (expected)	BQ2 (expected)	BQ3 (expected)	BQ4 (expected)	χ^2 (df)	P	V (effect)	BQ1 *vs.* BQ4 OR (95% CI)
U16 – 1995	137 (65)	69 (65)	35 (65)	19 (65)	126.40 (3)	[a]0.0001	0.40 (large)	7.21 (4.00-13.01)
%	52.7	26.5	13.5	7.3				
U16 – 2015	180 (86)	90 (86)	46 (86)	28 (86)	160.65 (3)	[b]0.0001	0.39 (large)	6.43 (3.91-10.58)
%	52.3	26.2	13.4	8.1				

[a, b]Significantly skewed when compared to the expected distribution (N.).

affirming that the new generation of soccer talent is born under the bias of RAE. Therefore, these findings taken together suggest how RAE is a global phenomenon, resulting from the strict selection-based policy, associated with competitive pressures, which characterizes most sport organizations' talent identification and development programs across the world, which striving with the limited availability of positions inform their decision-making analyzing players' current level of performance.[47] When selecting players based on their current performance level, relatively older players have the greatest likelihood of being selected, as they are usually taller, heavier and able to perform best at physical fitness test compared to their younger peers,[48] which is the possible cause of birthdate asymmetry found in both our cohorts.

The Italian Football Federation, in an attempt to mitigate the presence of RAE, decided to follow the recommendations delineated by Grossman and Lames,[49] and opted to include the relative age phenomena into coach and practitioner education, with the aim of enhancing knowledge and understanding of RAEs. Despite this, talent detection and selection decision-making showed no changes, as results from this study clearly highlighted how selection procedures done by Italian coaches and/or scouts, are still influenced by players' relative age. Indeed, past research has already shown that coaches' knowledge of RAE and awareness of its impacts, do not eliminate or reduce the presence of this bias.[50, 51] Therefore coaches, yet knowing full well the RAE-related issue, decide to ignore it, by simply respond adequately and practically to the functionally perspective of the society, whereby every aspect of society (*i.e.*, people, social institutions, social systems) is evaluated based on its ability to meet its goal (*i.e.*, *"is it functional?"*), meaning that in a sport context any sport performance that yields a victory is functional and preferred over a defeat:[52] as coaches' perceptions and evaluations are defined by their ability to satisfy the "need" of producing "winning" age group,[53] their main focus will be that of achieving short-term success, because only by achieving it they will be able to retain their employment,[13] and bring some reputational capital.[54] For this reason, rather than providing players good long term developmental experiences,[53] they will tend to select the actual most proficient players (*i.e.*, the most functional player which can best help the team winning games), in terms of maturity and fitness performances (*i.e.*, the relatively older athletes, who are physically and functionally superior compared to their younger peers; 49), in order to win matches and leagues – right here, right now. Indeed, it has been showed by Augste & Lames[21] that selecting early born athletes is an important aspect for succeeding in youth soccer.

This is a big issue in every talent development pathway, which often are assessed by their ability to produce the few who eventually "make it", rather than against the impact they have on the many (*i.e.*, the many who don't "make it").[55] Whereby coaches have a strong influence on athletes but are not the one who directly influence the settings in which coaching happens, other actors and stakeholders are responsible for it, as coaches are often required to balance contradictory concerns, such as the one of fulfilling short-term success and long-term development.[56] Coaching therefore can be understood as the results of intertwined goals, interests and relationships which happens in this context.[57] Coaches may thus fall into the trap of sport systems which see victory, "right here, right now" as the pre-requisite for future sport success, and which value age-group coaches by their "win or loss records"[13], whose consequently start to be concerned in trying to find the best current player, rather than finding the best player for the future.[58]

Concluding thoughts, in trying to answer the question we posed on the title: "Is RAE a cultural issue in talent management?", the findings from our study suggest that RAE is the resultant of the Talent Identification and Development Systems' structures, which facing with selective and competitive pressures, are mostly focused on early identification (based on current level of performance/early ability or psychological and/or anthropometrical measures) and early specialization, practices both based on the concept of deliberate practice.[3, 4, 13, 59-61] Therefore, RAE derives from a structural issue, but that is influenced and dependent on a specific cultural approach to youth sport, whereby STDM are rooted in the 10,000 hours theory;[62] it is centered on the quest of youth performance, as players in order to advance to the next developmental stage are required to attain certain performance level; and often see players as a form of capital,[63] which should benefit the clubs' both financial resources and field results. Thereby, sports organizations should start trying to ask themselves: 1) "what is youth sport for?"; and 2) "what achievement are they working for?" (*i.e.*, performance, participation or personal development).

Practical applications

To move the RAE debate forward in this last section of the paper we will try to delineate some of the best practices utilized by some country to effectively counteract this issue. Lidor *et al.*,[64] described the "open door" policy which characterizes sports in Israel, whereby children who are selected by a talent development program are encouraged to continue their sporting experience, even though they do not demonstrate the physical attributes required to achieve elite performances, so that even the late bloomers have the opportunity to train in high quality sporting environment, thus continuing to participate in sport.

Mann and Van Ginneken[65] proposed an age-ordered shirt numbering, whereby the numbers on player's shirts corresponded to their relative age. The Belgium Soccer Federation provides a system based on semester of birth rather than considering the year of birth, so limiting the effects of maturation status on the selection processes.[66] To remove particular selection times and fixed chronological age groups, Kelly *et al.*[67] introduced the birthday-banding whereby young athletes move up to their next birthdate group on their birthday. Lawrence *et al.*,[68] proposed the Average Team Age (ATA) method and found that youth teams with an average age closer to the beginning of the cut-off date experienced competitive advantages. Based on this mathematical model, it has been recently proposed to set the average age of a team to a predetermined maximum.[69] Furthermore, using repeated procedures of selection and deselection through childhood and youth, to avoid early deselection and long-term continuous nurture[70] is a possible and viable solution with the aim of reducing the loss of talent.

Conclusions

This survey allows us to confirm that RAE is still a problem that characterizes the management of soccer talent in Italy, whereby ten years of research and dissemination of RAE, in both the academic and Italian Football Federation environments, did not change the selection policy associated with elite youth Italian football teams. The detrimental effects of this phenomenon are clearly evident: relatively younger players are less likely to develop in high quality training environment, compared to their relatively older peers, and this is cause of inequality. Based on the results from our study, to respond adequately to the expectations posed on them of building successful age-group teams, coaches follow the functionalist perspective of the society, and inform their decision-making searching for the best possible player, which can best help the team winning games, independently of his birthdate. Therefore, RAE appears as the result of the standard model of talent development's structure, characterized by early identification and early specialization, influenced culturally by the concept of deliberate practice and which puts an overemphasis on the quest of youth performance, as it is the pre-requisite for gaining access to the next developmental stages. We thereby suggest that sport organization should ask themselves what their main aim is (*i.e.*, performance, participation and/or personal development). In the last section of the paper, we tried to suggest some practical applications, taken from previous research done on this field, which could help sport organizations and practitioners in trying to mitigate RAE presence in youth sport, and as a consequence in senior sport too.

References

1. Güllich A, Cobley S. On the efficacy of Talent Identification and Development Programmes. In: Baker J, Cobley S, Schörer J, Wattie J, editors. Routledge Handbook of Talent Identification and Development in Sport. London: Routledge; 2017.

2. Till K, Emmonds S, Jones B. Talent identification. In: Lloyd R, Oliver J, editors. Strength & Conditioning for Youth Athletes. Science and Practical Applications. Second Edition. London: Routledge; 2019.

3. Till K, Baker J. Challenges and [Possible] Solutions to Optimizing Talent Identification and Development in Sport. Front Psychol 2020;11:664.

4. Bailey R, Collins D. The standard model of talent development and its discontents. Kinesiol Rev (Champaign) 2013;2:248–59.

5. Williams AM, Ford PR, Drust B. Talent identification and development in soccer since the millennium. J Sports Sci 2020;38:1199–210.

6. Vaeyens R, Lenoir M, Williams AM, Philippaerts RM. Talent identification and development programmes in sport : current models and future directions. Sports Med 2008;38:703–14.

7. Reilly T, Bangsbo J, Franks A. Anthropometric and physiological predispositions for elite soccer. J Sports Sci 2000;18:669–83.

8. Federazione Italiana Giuoco Calcio. I numeri del calcio italiano; 2021 [Internet]. Available from: https://www.figc.it/it/federazione/mission-e-governance/i-numeri-del-calcio-italiano/ [cited 2021, Oct 1].

9. Federazione IG. Regolamento del Settore Tecnico; 2018. [Internet]. Available from: https://www.figc.it/media/105223/regolamento-st_parte-2.pdf [cited 2021, Oct 1].

10. Musch J, Grondin S. Unequal competition as an impediment to personal development: A review of the relative age effect in sport. Dev Rev 2001;21:147–67.

11. Till K, Cobley S, Wattie N, O'Hara J, Cooke C, Chapman C. The prevalence, influential factors and mechanisms of relative age effects in UK Rugby League. Scand J Med Sci Sports 2010;20:320–9.

12. Mujika I, Vaeyens R, Matthys SP, Santisteban J, Goiriena J, Philippaerts R. The relative age effect in a professional football club setting. J Sports Sci 2009;27:1153–8.

13. Baker J, Schorer J, Wattie N. Compromising Talent: Issues in Identifying and Selecting Talent in Sport. Quest 2018;70:48–63.

14. Wattie N, Schorer J, Baker J. The relative age effect in sport: a developmental systems model. Sports Med 2015;45:83–94.

15. Cobley S, Baker J, Wattie N, McKenna J. Annual age-grouping and athlete development: a meta-analytical review of relative age effects in sport. Sports Med 2009;39:235–56.

16. Doncaster G, Medina D, Drobnic F, Gómez-Díaz AJ, Unnithan V. Appreciating Factors Beyond the Physical in Talent Identification and Development: Insights From the FC Barcelona Sporting Model. Front Sports Act Living 2020;2:91.

17. Harter S. Effectance motivation reconsidered: toward a developmental model. Hum Development 1978;21:34–64.

18. Verhulst J. Seasonal birth distribution of west European soccer players: a possible explanation. Med Hypotheses 1992;38:346–8.

19. Dudink A. Birth date and sporting success. Nature 1994;368:592.

20. Figueiredo P, Seabra A, Brito M, Galvão M, Brito J. Are Soccer and Futsal Affected by the Relative Age Effect? The Portuguese Football Association Case. Front Psychol 2021;12:679476.

21. Augste C, Lames M. The relative age effect and success in German elite U-17 soccer teams. J Sports Sci 2011;29:983–7.

22. Brustio PR, Lupo C, Ungureanu AN, Frati R, Rainoldi A, Boccia G. The relative age effect is larger in Italian soccer top-level youth categories and smaller in Serie A. PLoS One 2018;13:e0196253.

23. Bezuglov EN, Nikolaidis PT, Khaitin V, Usmanova E, Luibushkina A, Repetiuk A, *et al.* Prevalence of Relative Age Effect in Russian Soccer: The Role of Chronological Age and Performance. Int J Environ Res Public Health 2019;16:4055.

24. Söderström T, Brusvik P, Lund S. Factors underlying competitive success in youth football. A study of the Swedish national U15 football talent system. Scand Sport Stud Forum 2019;10:139–62.

25. Götze M, Hoppe MW. Relative Age Effect in Elite German Soccer: Influence of Gender and Competition Level. Front Psychol 2021;11:587023.

26. Gutierrez Diaz Del Campo D, Pastor Vicedo JC, Gonzalez Villora S, Contreras Jordan OR. The relative age effect in youth soccer players from Spain. J Sports Sci Med 2010;9:190–8.

27. Yagüe JM, de la Rubia A, Sánchez-Molina J, Maroto-Izquierdo S, Molinero O. The Relative Age Effect in the 10 Best Leagues of Male Professional Football of the Union of European Football Associations (UEFA). J Sports Sci Med 2018;17:409–16.

28. Lupo C, Boccia G, Ungureanu AN, Frati R, Marocco R, Brustio PR. The beginning of senior career in team sport is affected by relative age effect. Front Psychol 2019;10:1465.

29. Fumarco L, Rossi G. The relative age effect on labour market outcomes – evidence from Italian football. Eur Sport Manag Q 2018;18:501–16.

30. Gyimesi A, Kehl D. Relative age effect on the market value of elite European football players: a balanced sample approach. Eur Sport Manag Q 2021. [Epub ahead of print]

31. Helsen WF, Thomis M, Starkes JL, Vrijens S, Ooms G, MacMaster C, *et al.* Leveling the Playing Field: A New Proposed Method to Address Relative Age- and Maturity-Related Bias in Soccer. Front Sports Act Living 2021;3:635379.

32. Jiménez IP, Pain MT. Relative age effect in Spanish association football: its extent and implications for wasted potential. J Sports Sci 2008;26:995–1003.

33. Vaeyens R, Philippaerts RM, Malina RM. The relative age effect in soccer: a match-related perspective. J Sports Sci 2005;23:747–56.

34. Doyle JR, Bottomley PA, Angell R. Tails of the Travelling Gaussian model and the relative age effect: tales of age discrimination and wasted talent. PLoS One 2017;12:e0176206.

35. Romann M, Javet M, Cobley S, Born DP. How Relative Age Effects Associate with Football Players' Market Values: Indicators of Losing Talent and Wasting Money. Sports (Basel) 2021;9:99.

36. Pérez-González B, León-Quismondo J, Bonal J, Burillo P, Fernández-Luna Á. The New Generation of Professional Soccer Talent Is Born under the Bias of the RAE: Relative Age Effect in International Male Youth Soccer Championships. Children (Basel) 2021;8:1117.

37. Williams JH. Relative age effect in youth soccer: analysis of the FIFA U17 World Cup competition. Scand J Med Sci Sports 2010;20:502–8.

38. Condon RG, Scaglion R. The ecology of human birth seasonality. Hum Ecol 1982;10:495–511.

39. Cohen J. Statistical Power Anaylsis for the Behavioural Science. Second Edition. L. Erlbaum Associates; 1988.

40. Dugdale JH, McRobert AP, Unnithan VB. "He's Just a Wee Laddie": The Relative Age Effect in Male Scottish Soccer. Front Psychol 2021;12:633469.

41. Helsen WF, Baker J, Michiels S, Schorer J, Van Winckel J, Williams AM. The relative age effect in European professional soccer: did ten years of research make any difference? J Sports Sci 2012;30:1665–71.

42. Cobley SP, Schorer J, Baker J. Relative age effects in professional German soccer: a historical analysis. J Sports Sci 2008;26:1531–8.

43. Da Costa IT, Albuquerque RM, Garganta J. Relative age effect in Brazilian soccer players: a historical analysis. Int J Perform Anal Sport 2012;12:3.

44. Wattie N, Cobley S, Macpherson A, Howard A, Montelpare WJ, Baker J. Relative age and injuries in youth ice-hockey. Pediatrics 2007;120:140–8.

45. Helsen WF, Starkes JL, Van Winckel J. The influence of relative age on success and dropout in male soccer players. Am J Hum Biol 1998;10:791–8.

46. Jackson RC, Comber G. Hill on a mountaintop: A longitudinal and cross-sectional analysis of the relative age effect in competitive youth football. J Sports Sci 2020;38:1352–8.

47. Bjørndal CT, Luteberget LS, Till K, Holm S. The relative age effect in selection to international team matches in Norwegian handball. PLoS One 2018;13:e0209288.

48. Figueiredo AJ, Gonçalves CE, Coelho E Silva MJ, Malina RM. Characteristics of youth soccer players who drop out, persist or move up. J Sports Sci 2009;27:883–91.

49. Grossmann B, Lames M. Relative age effect (RAE) in football talents—the role of youth academies in transition to professional status in Germany. Int J Perform Anal Sport 2013;13:120–34.

50. Hill B, Sotiriadou P. Coach decision-making and the relative age effect on talent selection in football. Eur Sport Manag Q 2016;16:292–315.

51. Lund S, Söderström T. To See or Not to See: Talent Identification in the Swedish Football Association. Sociol Sport J 2017;34:1–27.

52. Delaney T. The Functionalist Perspective on Sport. In: Giulianotti R. (editor). Routledge Handbook of the Sociology of Sport. London: Routledge; 2015.

53. Martindale RJ, Collins C, Daubney J. Talent Development: A Guide for Practice and Research Within Sport. Quest 2005;57:353–75.

54. Collins D, MacNamara A, Cruickshank A. Research and Practice in Talent Identification and DevelopmentSome Thoughts on the State of Play. J Appl Sport Psychol 2019;31:340–51.

55. Rongen F, McKenna J, Cobley S, Till K. Are youth sport talent identification and development systems necessary and healthy? Sports Med Open 2018;4:18.

56. Bjørndal CT, Ronglan LT. Engaging with uncertainty in athlete development – orchestrating talent development through incremental leadership. Sport Educ Soc 2021;26:104–16.

57. Jones RL, Wallace M. Another bad day at the training ground: coping with ambiguity in the coaching context. Sport Educ Soc 2005;10:119–34.

58. Ford PR, Bordonau JL, Bonanno D, Tavares J, Groenendijk C, Fink C, *et al.* A survey of talent identification and development processes in the youth academies of professional soccer clubs from around the world. J Sports Sci 2020;38:1269–78.

59. Côté J, Hancock DJ. Evidence-based policies for youth sport programmes. International Journal of Sport Policy and Politics. 2016;8:51–65.

60. Bjørndal CT, Ronglan LT, Andersen SS. Talent development as an ecology of games: a case study of Norwegian handball. Sport Educ Soc 2017;22:864–77.

61. Lascu A, Spratford W, Pyne D, Etxebarria N. Practical application of ecological dynamics for talent development in cricket. Int J Sports Sci Coaching 2020;15:227–38.

62. Ericsson KA, Krampe RT, Tesch-Roemer C. The role of deliberate practice in the acquisition of expert performance. Psychol Rev 1993;100:363–406.

63. Ojala AL. Nurturing and sidelining capitalism in discourses of player potentiality in Finnish ice hockey. Sport Soc 2021;24:1574–89.

64. Lidor R, Côté J, Arnon M, Zeev A, Cohen-Maoz S. Relative age and birthplace effects in Division 1 players—do they exist in a small country? Talent Dev Excell. 2010;2:181–92.

65. Mann DL, van Ginneken PJ. Age-ordered shirt numbering reduces the selection bias associated with the relative age effect. J Sports Sci 2017;35:784–90.

66. Royal Belgian Football Association [Internet]. Available from: https://www.rbfa.be/en [cited 2021, Oct 1].

67. Kelly AL, Jackson DT, Taylor JJ, Jeffreys MA, Turnnidge J. "Birthday-Banding" as a Strategy to Moderate the Relative Age Effect: A Case Study Into the England Squash Talent Pathway. Front Sports Act Living 2020;2:573890.

68. Lawrence S, Jonker L, Verbeek J. The age advantage in youth football. In: Karlis D, Ntzoufras I, Drikos S, editors. Proceedings of the MathSport International Congress. Athens: Propobos Publications; 2019.

69. Verbeek J, Lawrence S, van der Breggen J, Kelly AL, Jonker L. The average team age method and its potential to reduce relative age effects. In: A.L. Kelly, J. Coté, M. Jeffreys & J. Turnnidge (editors). Birth Advantages and Relative Age Effects in Sport. New York, NY: Routledge; 2021.

70. Güllich A. Selection, de-selection and progression in German football talent promotion. Eur J Sport Sci 2014;14:530–7.

Conflicts of interest.—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions.—Bruno Ruscello, Antonio Saponara, Alberto Grossi, Gabriele Morganti and Laura Pantanella have given substantial contributions to the conception or the design of the manuscript to acquisition, analysis and interpretation of the data. All authors have participated to drafting the manuscript revised it critically. All authors read and approved the final version of the manuscript.

Acknowledgements.—The authors wish to thank for their precious help all the players participating to the study.

History.—Article first published online: April 19, 2022. - Manuscript accepted: April 12, 2022. - Manuscript revised: March 30, 2022. - Manuscript received: December 8, 2021.

Online version at https://www.minervamedica.it

The Journal of Sports Medicine and Physical Fitness 2023 January;63(1):60-8
DOI: 10.23736/S0022-4707.22.13793-X

ORIGINAL ARTICLE

EXERCISE PHYSIOLOGY AND BIOMECHANICS

Hypertrophic adaptations to a 6-week in-season barbell *vs*. flywheel squat added to regular soccer training

Cristoforo FILETTI [1, 2, 3, 4], Bruno RUSCELLO [1, 2, 5, 6], Italo LEO [3, 7, 8], Marco PORTA [2], Aldo CHIARI [9], Carlos MIRANDA [10], Vincenzo RAGO [11] *

[1]School of Sports and Exercise Sciences, Faculty of Medicine and Surgery, Tor Vergata University, Rome, Italy; [2]School of Sports and Exercise Sciences, Vita-Salute San Raffaele University, Rome, Italy; [3]Unione Sportiva Salernitana 1919, Salerno, Italy; [4]Performance Department, FC Paris Saint Germain, Paris, France; [5]Department of Industrial Engineering, Faculty of Engineering, Tor Vergata University, Rome, Italy; [6]LUISS SportLab, LUISS University, Rome, Italy; [7]Department of Human, Philosophical and Educational Sciences, University of Salerno, Salerno, Italy; [8]Department of Sport Rehab, San Giovanni di Dio e Ruggi d'Aragona University Hospital, Salerno, Italy; [9]Parthenope Sant'Antimo Basket, Naples, Italy; [10]Querétaro Fútbol Club, Santiago de Querétaro, Mexico; [11]Faculty of Health and Sports Sciences, European University of Lisbon, Lisbon, Portugal

*Corresponding author: Vincenzo Rago, Faculty of Health and Sports Sciences, European University of Lisbon, Lisbon, Portugal.
E-mail: vincenzo.rago@live.com

ABSTRACT

BACKGROUND: The aim of this study was to compare the hypertrophic adaptations to barbell or flywheel squat exercise added to regular in-season soccer training.

METHODS: Quadriceps' (rectus femoris [RF], vastus medialis [VM] and vastus lateralis [VL]) cross-sectional area (CSA) in its portions (proximal [PROX], middle [MID], and distal [DIST]) was measured on both legs before and after a 6-week barbell (80 to 90% one-maximum repetition; N.=7) or flywheel (0.0611 to 0.0811 kg·m^2; N.=7) in an U19 professional soccer team using a 3T magnetic resonance imaging. Both groups underwent 5 sets × 6 reps per session of squat separated by 3-min rest, while controlling the time under tension (within 0.5 and 0.8 s).

RESULTS: The barbell squat group experienced moderate CSA increments in the VM_{MID} and the VL_{DIST} of the right leg (*d*=0.98-0.99). Additionally, the flywheel group experience large CSA increments in the RF_{MID}, VL_{PROX} and VL_{MID} of the right leg (*d*=1.00-1.84). On average, flywheel squat training largely produced greater force during exercise compared to the barbell squat training (29.2 *vs*. 12.2 N·kg^{-1}; *d*=5.95), whereas the barbell squat training produced moderately greater power output (10.5 *vs*. 9.7; *d*=0.52).

CONCLUSIONS: Barbell squat training seems to be more effective for VM hypertrophy whereas flywheel squat triggers greater RF and VL hypertrophy as complementary to regular field-based soccer practice and competition within a short range of time (6 weeks) during the in-season. These findings can be considered also from either strength or reconditioning perspective based on the increase in the quadriceps muscles' CSA as mechanism underlying strength/power adaptations.

(*Cite this article as:* Filetti C, Ruscello B, Leo I, Porta M, Chiari A, Miranda C, *et al.* Hypertrophic adaptations to a 6-week in-season barbell *vs*. flywheel squat added to regular soccer training. J Sports Med Phys Fitness 2023;63:60-8. DOI: 10.23736/S0022-4707.22.13793-X)

KEY WORDS: Exercise; Athletes; Sports; Hypertrophy.

Young soccer players cover 7000-10,000 m and change activity approximately every 4 s during an official match.[1] To cope with these physical demands, players need adequate levels of muscle strength to achieve successful physical outcomes[2] and reduce the risk of non-contact musculoskeletal injuries.[2] Particularly, thigh (hamstring or quadriceps) muscle tears are the most common muscle injuries in male soccer players and are associated with significant time loss and high financial costs for the player and clubs.[3] It is therefore paramount that strength and conditioning coaches identify and optimize methods that can efficiently enhance muscle strength capacity of professional soccer players.[2]

The mechanisms underlying strength/power adaptations are largely associated with increases in the cross-sectional area (CSA) of the muscle (hypertrophy methods) among other factors (neural mechanisms).[4, 5] Collegiate-level soccer player exhibited similar CSA adaptations to a 6-week back squat program (3 sets of 75% one-repetition maximum [1RM]) of two different eccentric durations (2 *vs*. 4 s).[6] Changes in morphology (*i.e.*, anatomical CSA, muscle thickness) and architecture (*i.e.*, fascicle length, pennation angles) in response to resistance training have been widely described in non-athletic populations,[7] but available information in soccer players is currently limited to one study.[6] However, the aforementioned study quantified the total thigh CSA using MRI, without considering the specific muscle regions.[6] This could be of importance as a recent study in professional soccer players showed that different region-specific responses can be observed throughout MRI during different strength exercises.[8] Additionally, CSA adaptations following resistance training have been attributed to the region-specific muscle activation assessed by the magnetic resonance imaging (MRI) during the training session.[9, 10] Thus, considering that specific muscle areas might be selectively activated during different strength exercises, it would be of interest to examine changes in specific muscle CSA after resistance training interventions.

A diverse range of either traditional resistance, plyometric[11] or flywheel[12] training interventions can effectively improve muscle strength, power, jump, and change of direction measures in male soccer players of varying competitive standards. Traditional resistance training programs involving free weights and weight stack machines based on the use of gravity-dependent loads have shown to achieve desirable structural and neural adaptions in athletes.[13] Nonetheless, these training modalities are limited by the load lifted in the concentric phase and typically significantly underload the eccentric component of the exercise task.[14] This is of importance given that the occurrence of thigh muscle strains in soccer is generally believed to be related with the presence of repetitive high force eccentric actions in soccer, such as the ones observed during high-speed running, where the lengthening demands placed on the muscle could exceed the mechanical limits of the tissue.[15] To date, studies comparing the effectiveness of traditional barbell *vs*. flywheel training have been conducted in non-athletic populations, showing that flywheel training may lead to superior[16] or similar[13, 17] gains in muscle mass. Additionally, intervention studies comparing the effectiveness of barbell *vs*. flywheel training in soccer players have been conducted on field or laboratory-based performance test, without information available on skeletal muscles' structural adaptations.[11, 12] Thus, it would be of interest to examine changes in muscles' CSA after either barbell or flywheel training in soccer players.

Based on the aforementioned information, the aim of this study was to compare the CSA effects of barbell or flywheel squat exercise added to regular in-season soccer training. A secondary aim was to compare the kinetic (force and power) responses during the squat exercise throughout the intervention.

Materials and methods

Experimental approach to the problem

A randomized controlled design was adopted to compare the short-term (6 weeks) effects of the two different training protocols (barbell *vs*. flywheel) squat on the quadriceps' CSA during the in-season (April-May 2019). The training intervention consisted of 5 sets × 6 reps per session of squat separated by 3-min rest, while controlling the time under tension (within 0.5 and 0.8 s).[18] Quadriceps' (rectus femoris [RF], vastus medialis [VM] and vastus lateralis [VL]) cross-sectional area (CSA) in its portions (proximal [PROX], middle [MID], and distal [DIST]) was measured on both legs before and after a 6-week barbell or flywheel using a 3T MRI. Specifically, both groups underwent a baseline testing to assess the individual one-maximum repetition (1RM), then 6 familiarization sessions over a two-week period, preintervention MRI assessment, then the intervention which consisted of 16 sessions (3 sessions for the first 5 weeks, and one session in the last week), and finally a postintervention MRI. Quadriceps' CSA was tested in the week before the commencement of the study, and in the last week of the intervention (2 days after the last session). A detailed description of the training intervention is reported in Table I.

During the intervention period, the participants were not involved in congested fixtures, and the intervention sessions were always performed on the match day plus 2, minus 4 and minus 2, before the players' regular soccer practice on the field (4 practice sessions per week). No further lower body resistance training was performed. A detailed description of the weekly program is reported in Table II. No control group was used since it would have resulted in an unethical and impactable approach, not suitable for the present in-season design.[19]

TABLE I.—*Progression of a 6-week in-season traditional barbell or flywheel squat in an under-19 professional soccer team.*

Parameters	Familiar-ization		Intervention					
Week	1st	2nd	1st	2nd	3rd	4th	5th	6th
MRI assessment		↓						↓
Training frequency (sessions)	3	3	3	3	3	3	3	1
Squat training intensity								
Barbell free weight (%1RM)	70	70	80		85		90	
Flywheel (kg·m²)	0.006	0.006	0.0611 to 0.0811	0.0611 to 0.0811	0.0611 to 0.0811	0.0611 to 0.0811	0.0611 to 0.0811	0.0611 to 0.0811

1RM: one-maximum repetition; MRI: magnetic resonance imaging.

TABLE II.—*In-season weekly training program for the under-19 professional soccer team involved in a 6-week in-season traditional barbell or flywheel squat.*

Day	Intervention	Field practice
Monday		Off
Tuesday	↓	Starters (≥60 min): foam roller, upper body and biking (~45 min) Non-starters (<60 min): warm-up, SSGs, aerobic training, upper body (~60 min)
Wednesday	↓	Warm-up (~15 min), agility and quickness (~10 min), tactical (~30 min), SSGs (~20 min) and high-intensity aerobic training (~15 min)
Thursday		Warm-up (~15 min), tactical (~20 min), set pieces (~15 min) and SSGs (~30 min)
Friday	↓	Warm-up (~15 min), set pieces (~15 min), Tactical (~15 min), SSGs (~10 min) and shooting (~10 min)
Saturday		Off
Sunday		Match at 11 AM

SSGs: small-sided games.

Subjects

Sixteen outfield professional U19 male soccer players from the same team competing in U19 Italian first league (*Campionato Primavera*) voluntarily participated in the present study. After exclusion of two players due to muscle injury throughout the intervention, 14 players (mean±standard deviation [SD]; age =18±1 years old, body mass =76.2±6.9 kg, height 182±6 cm), were randomly assigned to barbell squat group (FW, N.=7) or and flywheel squat group (FD, N.=7). The players trained 4 times per week, for a total training volume of ~8 hours/week of soccer plus ~50 minutes of strength workout in the gym, and one competitive game per week. All the participants were injury-free during the last 8 weeks before the beginning of the study and had a minimum of 7-years professional football background. None of the players were involved with the first team' practice sessions for the whole period of the study. All players had the right foot as dominant.

The Institutional Board of the Faculty of Medicine, Tor Vergara University, Rome (Italy) provided clearance for the procedures before the commencement of this study. Written informed consent was obtained from all the participants after familiarization and explanation of the benefit and risks involved in the procedures of this study. All participants were free to withdraw during the study period at any time without penalty. All procedures were conducted in accordance with ethical standards for sport sciences studies.[20]

Procedures

Magnetic resonance imagery

The CSA of the quadriceps muscles (RF, VM and VL), measurements of the thigh were performed on both legs (right leg was the dominant for all the subjects) using a 3T whole-body imager with surface phased-array coils (Siemens Magnetom Symphony TIM 1.5 T, Gradient 30mT/m, intensity 125 T/m/s slew rate; Siemens Healthineers, Erlangen, Germany) similarly to that described elsewhere.[8, 21] All the scans were performed with the subjects positioned inside the magnet, the thighs of both legs were kept parallel to the MRI table, and a custom-made foot-restrain device was used to standardize and fix limb position and to avoid any compression of thigh muscles. The players were supine on the MR-gurney with thighs covered with one 32- and 2 flexible 4-channel coils, respectively in the proximal and distal segments. 12 cross-sectional images of both thighs were obtained, starting at the distal margin of the ischial tuberosity. Acquisition time of the imaging sequence was 16 s. A parametric image was generated from transverse relaxation time mapping sequence using a workstation. Scout images and anatomical landmarks were obtained to ensure identical and time-efficient positioning in pre- and post-scans. Muscles' transverse relaxation time of the dominant leg (all right) were measured using OSIRIX program for review and display of DICOM images.

The total thickness of each of VM, RM and VL in its portions (PRO, MID and DIST) was assessed. Using the fat-suppressed images to detect any confounding artifact (*i.e.*, vessels, fat), a circular region of interest was selected for individual muscles in each of the transverse relaxation time mapping images where muscles were visible. The vastus intermedius was not considered due to the impossibility to distinguish between vastus lateralis both anatomically and on MRI images, and its weak connection to soccer-specific tasks. All images were independently analyzed by one accredited radiologist, blinded to the origin of any image.

Training intervention

A standardized generic warm-up lasting approximately 20 min were performed by both intervention group. This consisted of approximately 5-min dynamic stretching, and half squat (3 sets of 10 repetitions body weight, separated by 45-s rest). Then, a specific activation was performed according to the specific group (see below). The participants of both groups were instructed to perform the concentric phase (knee and hip extension) and to reach approximately 90° of knee bending during the eccentric phase (knee and hip flexion) within 0.5 to 0.8 s. Environmental temperature was kept to 21±1 °C in the gym. A mirror was placed opposite to the participants to let them visually check their technique.

After the generic warm-up (described above), the barbell squat group performed a specific warm-up based on 70% of 1RM (which was directly determined previously using the procedure outlined by Sheppard *et al.*[22]). During the intervention, training intensity (in kg) ranged from 80 and 90% 1RM throughout the intervention (5% increases every 2 weeks starting at 80%, 85% and 90% in the 1st, 3rd, and 5th week, respectively). Each set was interspersed by 3 min of passive recovery. This training intensity and progression was in line with the American College of Sports Medicine which recommends 3-6 sets of 1-12 repetitions with 70-100% 1RM for advanced individuals.[23] As specific warm-up, the flywheel group performed two sets of 10 repetitions squats on the flywheel device (Desmotec D.11 device; Desmotec, Biella, Italy) with a fixed inertia of 0.006 kg·m^2 separated by 45-s rest between sets. During the intervention, intensity ranged from 0.0611 to 0.0811 kg·m^2, which was within the range of practical recommendations using flywheel exercise in athletes.[14] Rather than using a fixed inertia, we adopted an individualized inertia based on players' capacity. The participants were instructed to perform the concentric phase of the flywheel half squats with maximal velocity, and the eccentric phase until the thighs were parallel to the ground.[2, 14] Each set was interspersed by 3 min of passive recovery. In addition to number of sets, repetitions and rest between sets, to ensure relatively comparable conditions between the two interventions, we standardized the time under tension between 0.5 to 0.8 s. This was based on a meta-analysis which indicated that hypertrophic adaptations occur in this range18 whereby acute exercise stress could vary between intervention group.[24]

Kinetic responses during exercise

Kinetic responses during the flywheel squat were recorded using a miniature compression load cell that measured force through the pull of the strap. Two contact panels were connected to a computer equipped with the dedicated software (D11-Full, Desmotec D-Soft; Desmotec) sampling at 25 Hz. The participant was connected to the device by a strap with one end tied to the device and the other to a waistcoat worn. The strap was tightened not to allow the respondent to move up. During the squat execution, the contact panels measured the force that the participant produces, and which is read on the computer (good test-retest reliability; α=0.889).[25]

For the barbell squat, kinetic responses were recorded using a high-frequency Video Camera (Go Pro Hero 5; Go Pro, San Mateo, CA, USA) sampling at 60 frames per second with a resolution of 1080 pixels. The camera was placed laterally at 1.6 m apart of the center of mass of each subject. Afterwards, the videos were analyzed using the BioMovie Software (Infolabmedia, Turin, Italy). The performance area was calibrated by calculating the pixels' size of the chosen one area, and trajectory of the barbell was automatically tracked by the video analysis software using specific purposeful algorithms based on the spatiotemporal parameters as similarly described by Sañudo *et al.*[26] This allowed to calculate the force produced based on the barbell' acceleration and the weight lifted. Then, power was calculated by multiplying the instantaneous force with the corresponding speed every 0.01 s. The software generated an automated graph that synchronized itself to the video from which the force and power outputs were extrapolated. This system showed excellent levels of reproducibility (coefficient of variation <4.5%).[27] A sample

Figure 1.A, B) Sample kinetic data collection during the barbell squat.

kinetic data collection during the barbell squat was illustrated in Figure 1.

Average power (W·kg-1) and the average force (N·kg-1) produced during the squat execution were scaled by individual body mass and retained as indicators of kinetic responses during exercise. Average values between considering both concentric and eccentric phases were presented.

Statistical analysis

Before the commencement of the study, the hypothesis of no between-group differences in the preintervention CSA was tested (P>0.05). Shapiro-Wilk Test revealed that CSA data were normally distributed within each evaluation moment. A paired-sample *t*-test was used to compare muscle' CSA before and after the intervention (within groups), whereas an independent sample *t*-test to compare acute kinetic responses during exercise (between groups). The magnitude of differences (*d*) and associated 95% confidence intervals (95% CIs) were computed on *t* statistic and degrees of freedom,[28] and interpreted according to Rhea's recommendation for strength training interventions of highly-trained individuals: trivial (*d*<0.25), small (*d*=0.25-0.50), moderate (*d*=0.50-1.00), large (*d*>1.0). When 95% confidence intervals overlapped positive and negative values, the effect was deemed to be unclear. To provide practical indications about changes in force and power output during the squat exercise, the smallest worthwhile change (SWC) was calculated by multiplying 0.3 by the between-subjects' CV.[29]

Data were presented as mean and 95% CI unless otherwise stated. Data analyses were performed in R software (R-4.1.1 for Windows; R Foundation for Statistical Computing, Vienna, Austria).

Results

The barbell squat group experienced moderate CSA increments in the VM_{MID} and the VL_{DIST} of the right leg (*d* [95% CIs]=-0.99 [-1.92; -0.06] and -0.98 [-1.91; -0.05], respectively; P<0.05) whereas no significant changes were observed in the left leg (P>0.05). Additionally, the flywheel group experience large CSA increments in the RF_{MID}, VL_{PROX} and VL_{MID} (*d* [95% CIs]=-1.01 [-1.94; -0.08], -1.00 [-1.93; -0.07] and -1.84 [-2.83; -0.84], respectively; P<0.05). A detailed description of CSA adaptations to barbell and flywheel squat training is reported in Table III.

For force output, the SWC was 0.34 and 0.86 $N \cdot kg^{-1}$, whereas for power output was 0.34 and 0.31 $W \cdot kg^{-1}$, for the barbell and flywheel squat respectively (Figure 2). On average, flywheel squat training largely produced greater force during exercise compared to the barbell squat training (29.2±1.5 *vs*. 12.2±0.1 $N \cdot kg^{-1}$; *d* [95% CIs]=5.95 [4.91; 6.98]; P<0.001) (Figure 2A). However, traditional barbell squat training produced moderately greater power output during exercise compared to flywheel squat training (10.5±0.6 *vs*. 9.7±0.5; *d*=0.52 [0.09; 0.95]; P=0.023) (Figure 2B).

Discussion

This is the first study to examine CSA adaptations following traditional resistance (*i.e.*, barbell) or flywheel squat training during the competitive period in professional young soccer players. Muscle hypertrophy is considered one important goal to be achieved in youth sport as a foundation for further improvements in strength and power.[5, 30] In this randomized controlled trial, we observed that U19 professional soccer players can benefit from either barbell and flywheel squat exercise added to regular training and competitive schedule three times per week. Both training interventions seem to promote meaningful CSA increments of dominant leg. Specifically, barbell squat seems to be more effective for VM hypertrophy whereas flywheel

TABLE III.—*Thigh cross-sectional area before and after a 6-week in-season barbell or flywheel squat in an under-19 professional soccer team.*

Variable	Barbell squat (N.=7)				Flywheel squat (N.=7)			
	Before	After	P	*d* (95% CIs)	Before	After	P	*d* (95% CIs)
Right leg								
RF_{PROX}	22.5 (19.4; 25.6)	23.5 (20.4; 26.6)	0.268	-0.46 (-1.35; 0.43)	24.9 (21.3; 28.5)	22.7 (18.5; 26.8)	0.192	0.55 (-0.34; 1.45)
RF_{MID}	24.8 (21.2; 28.3)	26.4 (23.7; 29.0)	0.351	-0.38 (-1.27; 0.51)	21.4 (18.4; 24.5)	23.7 (20.2; 27.2)	0.037	-1.01 (-1.94; -0.08)
RF_{DIST}	12.9 (10.6; 15.3)	15.6 (13.7; 17.5)	0.159	-0.61 (-1.51; 0.29)	13.4 (9.8; 16.9)	14.7 (11.4; 17.9)	0.087	-0.77 (-1.68; 0.14)
VM_{PROX}	22.7 (18.8; 26.5)	25.7 (22.9; 28.6)	0.085	-0.78 (-1.69; 0.14)	22.5 (18.5; 26.5)	23.3 (19.3; 27.2)	0.690	-0.16 (-1.04; 0.72)
VM_{MID}	28.3 (26.3; 30.3)	32.2 (28.3; 36.0)	0.040	-0.99 (-1.92; -0.06)	26.4 (24.4; 28.5)	28.6 (26.7; 30.4)	0.063	-0.86 (-1.78; 0.06)
VM_{DIST}	31.4 (26.4; 36.4)	31.7 (27.3; 36.2)	0.923	-0.04 (-0.92; 0.84)	27.4 (24.8; 29.9)	27.3 (21.4; 33.3)	0.992	0.00 (-0.88; 0.88)
VL_{PROX}	36.3 (31.8; 40.9)	33.7 (28.9; 38.4)	0.347	0.39 (-0.5; 1.28)	30.8 (26.4; 35.3)	33.7 (28.3; 39.1)	0.038	-1.00 (-1.93; -0.07)
VL_{MID}	29.7 (24.0; 35.5)	32.5 (30.4; 34.5)	0.387	-0.35 (-1.24; 0.54)	26.2 (22.1; 30.5)	32.3 (26.6; 37.9)	0.003	-1.84 (-2.83; -0.84)
VL_{DIST}	14.0 (10.0; 18.0)	18.2 (13.7; 22.6)	0.041	-0.98 (-1.91; -0.05)	15.1 (12.4; 18.2)	18.3 (15.6; 21.0)	0.091	-0.76 (-1.67; 0.15)
Left leg								
RF_{PROX}	23.8 (20.8; 26.8)	26.2 (22.4; 30.0)	0.169	-0.59 (-1.49; 0.31)	22.3 (19.5; 25.2)	22.6 (19.9; 25.3)	0.855	-0.07 (-0.95; 0.81)
RF_{MID}	26.4 (23.3; 29.5)	25.9 (23.9; 27.9)	0.750	0.13 (-0.76; 1.01)	21.8 (20.2; 23.5)	23.1 (21.0; 25.2)	0.315	-0.41 (-1.31; 0.48)
RF_{DIST}	15.8 (11.4; 20.3)	17.2 (14.6; 19.7)	0.368	-0.37 (-1.26; 0.52)	12.7 (10.6; 14.9)	14.8 (12.1; 17.5)	0.208	-0.53 (-1.43; 0.36)
VM_{PROX}	24.3 (21.5; 27.1)	23.3 (20.9; 25.7)	0.268	0.46 (-0.43; 1.36)	23.2 (19.5; 26.9)	23.5 (21.1; 25.8)	0.888	-0.06 (-0.94; 0.83)
VM_{MID}	28.3 (24.6; 31.9)	28.7 (24.5; 32.9)	0.795	-0.10 (-0.98; 0.78)	24.8 (22.4; 27.1)	25.6 (22.5; 28.8)	0.371	-0.37 (-1.25; 0.52)
VM_{DIST}	32.8 (27.5; 38.1)	30.1 (26.6; 33.7)	0.205	0.54 (-0.36; 1.44)	28.8 (24.3; 33.3)	26.0 (21.2; 30.8)	0.140	0.64 (-0.26; 1.55)
VL_{PROX}	35.0 (30.0; 40.0)	39.6 (34.8; 44.5)	0.200	-0.54 (-1.44; 0.35)	31.5 (27.0; 36.0)	35.9 (28.8; 43.0)	0.159	-0.61 (-1.51; 0.3)
VL_{MID}	30.5 (26.2; 34.8)	36.7 (30.5; 42.9)	0.058	-0.88 (-1.80; 0.04)	28.6 (24.6; 32.6)	32.2 (29.2; 35.2)	0.074	-0.82 (-1.73; 0.10)
VL_{DIST}	22.3 (14.9; 29.8)	24.9 (18.3; 31.5)	0.250	-0.48 (-1.37; 0.40)	21.7 (16.4; 27.0)	24.0 (20.1; 27.9)	0.115	-0.70 (-1.60; 0.21)

CIs: confidence intervals; RF: rectus femoris; VL: vastus lateralis; VM: vastus medialis; PROX: proximal portion; MID: medial portion; DIST: distal portion.

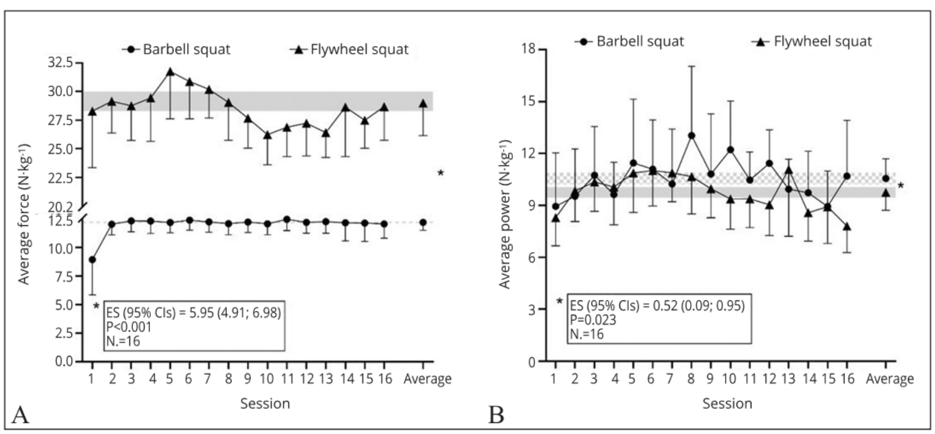


Figure 2.A) Force; and B) power produced throughout a 6-week in-season traditional barbell or flywheel squat in an under-19 professional soccer team.
The dotted-filled area is the smallest worthwhile change for the barbell squat group, whereas the grey-filled area is the smallest worthwhile change for the flywheel group.
*Significant between-group differences (P<0.05).
Cis: confidence intervals.

squat for RF and VL hypertrophy. These findings can be considered also from either strength or reconditioning perspective based on the increase in the quadriceps muscles' CSA as mechanism underlying strength/power adaptations.

The RF_{MID} adaptations of the right leg after flywheel squat training compared to the non-significant changes in RF muscle after barbell squat training might be explained by the greater RF use during flywheel compared to barbell squat.[31] On the other hand, the barbell squat group experienced moderate increments in the CSA of the right VM_{MID}, whereas no significant VM adaptations were observed in the flywheel group. This seems to be in contrast to extensive studies reporting greater muscle use collected throughout MRI31 and activation throughout electromyography.[32] Thus, further research is warranted to clarify greater increases in VM following barbell (isotonic) squat compared to flywheel squat. In this context, it is clear that regular soccer practice characterized by frequent kicking and associated stimulation of VM muscles, may have interfered with the training intervention. The flywheel group experience moderate increments in the CSA of the VL_{PROX} and VL_{MID}, whereas the barbell squat group increased the CSA of the VL_{DIST}. Our observed greater VL growth following flywheel training than barbell squat might be supported by the greater VL activation, and the resulting mechanical stress promoting hypertrophy.[32-34] However, the aforementioned studies have been conducted in non-athletic populations underling the need of further research in soccer players or other athletic populations to better understand physiological factors leading to muscle hypertrophy.

It is not possible to directly compare free weights *vs*. iso-inertial exercise due their different inherent unit of measure to calibrate intensity (weight in kg *vs*. inertia in kg·m^2). Thus, to ensure relatively comparable conditions between the two interventions, we adopted a quasi-identical time under tension (0.5 to 0.8 s) with same number of sets, repetitions and rest between sets. This is of importance as different time under tension could positively (if longer) or negatively (if shorter) mediate intracellular anabolic signaling, promoting different hypertrophic responses.[18]

Based on the well-established association between strength-/power-based capacities and muscles' CSA, our findings might be comparable to other ones examining the effectiveness of barbell squat training in young soccer players during the in-season throughout 8 to 12 weeks as complementary of regular soccer training.[11] In general, our findings are supported by extensive evidence supporting the usefulness of flywheel training to promote skeletal muscle adaptations in various healthy and athletic population.[16] Specifically, significant increases in quadriceps muscle volume have been observed in healthy men aged 39 years old following a 5-week flywheel squat training (4 sets of 7 reps/session)[33] as well as in 30-53 year men and women following 5-week unilateral leg extension flywheel training.[34] Whereas a wide range of studies has proven the beneficial effects of squat-based flywheel training in soccer players,[12] no information was available regarding changes in muscle size. Thus, it is challenging to compare our findings with the available published research in this area. Nonetheless, based on the well-established association between strength-/power-based capacities and muscles' CSA, our findings might be comparable to other ones examining the effectiveness of squat-based flywheel training in soccer players during the in-season. For example, improved isokinetic strength of the thigh muscles, change of direction capacity,[19] jumping and linear sprinting ability, injury incidence and severity[35] as well as body composition[36] have been observed following flywheel training based on squat or leg curl exercise in soccer players.

The lack of significant changes in the non-dominant (left) leg could be explained by the fact that players were involved in an-season intervention, being less sensitive to resistance training compared to the preseason or off-season.[11] Additionally, the whole week load (including field training) could have resulted in load differences between players. Consequently, performance adaptations to a given training intervention could be mediated by the physiological demands imposed by field practice as recently revealed in an U19 professional soccer team.[37]

When directly comparing resistance training according to the eccentric emphasis, one study have examined changes in CSA following barbell squat training, demonstrating positive effects on CSA irrespective of the eccentric duration (2 *vs*. 4 s).[6] Additionally, a recent study showed that either barbell or flywheel squat training were equally effective in improving sprint time and jump height in amateur soccer players, whereas barbell squat promoted a more than two-fold larger increase in 1RM maximal partial squat strength than flywheel.[38] Taken, together with our findings, this may suggest that both traditional resistance and eccentric training may promote similar performance and structural adaptations. However, further research is warranted to support our findings.

On average, flywheel squat training largely produced greater force during exercise compared to the barbell squat training, which could be attributed to higher electromyographic activity noted during the eccentric phase, which also result in greater mechanical stress and associated hypertrophic responses.[32] Indeed, muscle activation during free weight exercise is far from maximal throughout the range of motion, except for the last repetition at the point of failure to raise the weight. In contrast, the inertia of flywheel offers unrestrained resistance in each action, evoking maximal or near-maximal activation throughout the set, with force progressively decreasing with fatigue.[32] On the other hand, traditional barbell squat training produced moderately greater power output during exercise compared to flywheel squat training, which could be attributed to the movement speed during the concentric phase of the squat. Despite of the moderate-to-large effect sizes, our comparison in acute kinetic responses during exercise should interpreted with caution based on the different methodologies adopted to collect force and power data. Indeed, ergometer (flywheel) and 2D video-analysis (barbell) possess different measurement error, and thus data quality might be skewed by the different data collection methods employed. Thus, it is important that future studies adopt the same motion analysis system to compare acute kinetic/kinematic responses during exercise.

To our knowledge, this is the first randomized controlled trial to compare traditional barbell to flywheel squat added to regular soccer training. Such information is applicable for strength and conditioning coaches involved with young soccer players. In this context, evidence suggests that >70% soccer players start their professional career between 17 and 19 years old (under 19, U19).[39] In this context, strength, and body size (which is related to muscle CSA)[4] have been reported as main factor to select young professional soccer players.[40] Thus, it is expected that players at this age and stage of development are ready to strength train. Additionally, it is important to examine the responsiveness to strength training throughout the competitive schedule, given the lower sensitivity to training-induced adaptations during the in-season compared to pre- or off-season.[11]

Limitations of the study

It is important to underline some limitations inherent to this study. This is a case study limited to 7 subjects per intervention group. Thus, our results should be interpreted with caution when generalizing to the generic U19 soccer player population. Additionally, muscle hypertrophy occurs when muscle protein synthesis exceeds muscle protein breakdown and results in positive net balance in cumulative periods, which can be achieved throughout protein ingestion alongside resistance training.[41] However, it was not possible to control the protein intake. Additionally, no control group was included. Although it could have strengthened the study design, it was not ethically acceptable to benefit some players in detriment of others. Importantly, the two protocols (barbell *vs.* flywheel) were not exactly matched (exercise intensity). Indeed, both power and force are significantly different between the exercises, therefore the two groups did not undergo an accurately comparable intervention. For instance, greater average force has been reported for flywheel training, and this could explain the greater CSA adaptations reported.

Conclusions

Either traditional barbell or flywheel resistance exercise seems to be effective to promote quadriceps' hypertrophy in U19 soccer players during the in-season three times per week, as complementary to regular field-based soccer practice and competition within a short range of time (6 weeks). Specifically, barbell squat seems to be more effective for VM hypertrophy whereas flywheel squat for RF and VL hypertrophy. Notwithstanding, these CSA gains were only observed in the dominant leg. Thus, further studies are warranted to explore the interference of field-based practice and competition on changes in muscles' CSA. Despite of the same time under tension, flywheel training allows to produce greater force output than barbell/free weights training, which can be considered also from either strength or reconditioning perspective based on the relevance of the quadriceps muscles for soccer players.

References

1. Palucci Vieira LH, Carling C, Barbieri FA, Aquino R, Santiago PR. Match Running Performance in Young Soccer Players: A Systematic Review. Sports Med 2019;49:289–318.

2. Beato M, Maroto-Izquierdo S, Turner AN, Bishop C. Implementing Strength Training Strategies for Injury Prevention in Soccer: Scientific Rationale and Methodological Recommendations. Int J Sports Physiol Perform 2021;16:456–61.

3. Ekstrand J, Hägglund M, Waldén M. Epidemiology of muscle injuries in professional football (soccer). Am J Sports Med 2011;39:1226–32.

4. Gabriel DA, Kamen G, Frost G. Neural adaptations to resistive exercise: mechanisms and recommendations for training practices. Sports Med 2006;36:133–49.

5. Jones EJ, Bishop PA, Woods AK, Green JM. Cross-sectional area and muscular strength: a brief review. Sports Med 2008;38:987–94.

6. Shibata K, Takizawa K, Nosaka K, Mizuno M. Effects of Prolonging Eccentric Phase Duration in Parallel Back-Squat Training to Momentary Failure on Muscle Cross-Sectional Area, Squat One Repetition Maximum, and Performance Tests in University Soccer Players. J Strength Cond Res 2021;35:668–74.

7. Krzysztofik M, Wilk M, Wojdała G, Gołaś A. Maximizing Muscle Hypertrophy: A Systematic Review of Advanced Resistance Training Techniques and Methods. Int J Environ Res Public Health 2019;16:E4897.

8. Mendez-Villanueva A, Suarez-Arrones L, Rodas G, Fernandez-Gonzalo R, Tesch P, Linnehan R, *et al.* MRI-Based Regional Muscle Use during Hamstring Strengthening Exercises in Elite Soccer Players. PLoS One 2016;11:e0161356.

9. Wakahara T, Fukutani A, Kawakami Y, Yanai T. Nonuniform muscle hypertrophy: its relation to muscle activation in training session. Med Sci Sports Exerc 2013;45:2158–65.

10. Hedayatpour N, Falla D. Non-uniform muscle adaptations to eccentric exercise and the implications for training and sport. J Electromyogr Kinesiol 2012;22:329–33.

11. Silva JR, Nassis GP, Rebelo A. Strength training in soccer with a specific focus on highly trained players. Sports Med Open 2015;1:17.

12. Allen WJ, De Keijzer KL, Raya-González J, Castillo D, Coratella G, Beato M. Chronic effects of flywheel training on physical capacities in soccer players: a systematic review. Res Sports Med 2021;1:1–21.

13. Vicens-Bordas J, Esteve E, Fort-Vanmeerhaeghe A, Bandholm T, Thorborg K. Is inertial flywheel resistance training superior to gravity-dependent resistance training in improving muscle strength? A systematic review with meta-analyses. J Sci Med Sport 2018;21:75–83.

14. Beato M, Dello Iacono A. Implementing Flywheel (Isoinertial) Exercise in Strength Training: Current Evidence, Practical Recommendations, and Future Directions. Front Physiol 2020;11:569–569.

15. Carling C, Gall FL, Reilly TP. Effects of physical efforts on injury in elite soccer. Int J Sports Med 2010;31:180–5.

16. Maroto-Izquierdo S, García-López D, Fernandez-Gonzalo R, Moreira OC, González-Gallego J, de Paz JA. Skeletal muscle functional and structural adaptations after eccentric overload flywheel resistance training: a systematic review and meta-analysis. J Sci Med Sport 2017;20:943–51.

17. Lundberg TR, García-Gutiérrez MT, Mandić M, Lilja M, Fernandez-Gonzalo R. Regional and muscle-specific adaptations in knee extensor hypertrophy using flywheel versus conventional weight-stack resistance exercise. Appl Physiol Nutr Metab 2019;44:827–33.

18. Schoenfeld BJ, Ogborn DI, Krieger JW. Effect of repetition duration during resistance training on muscle hypertrophy: a systematic review and meta-analysis. Sports Med 2015;45:577–85.

19. Coratella G, Beato M, Cè E, Scurati R, Milanese C, Schena F, *et al.* Effects of in-season enhanced negative work-based vs traditional weight training on change of direction and hamstrings-to-quadriceps ratio in soccer players. Biol Sport 2019;36:241–8.

20. Winter EM, Maughan RJ. Requirements for ethics approvals. J Sports Sci 2009;27:985.

21. Fernandez-Gonzalo R, Tesch PA, Linnehan RM, Kreider RB, Di Salvo V, Suarez-Arrones L, *et al.* Individual Muscle use in Hamstring Exercises by Soccer Players Assessed using Functional MRI. Int J Sports Med 2016;37:559–64.

22. Sheppard J, Triplett N. Program design for resistance training. In: Haff GG, Triplett N, editors. Essentials of strength training and conditioning. Champaign, IL: Human Kinetics; 2015.

23. American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc 2009;41:687–708.

24. Wilk M, Zajac A, Tufano JJ. The Influence of Movement Tempo During Resistance Training on Muscular Strength and Hypertrophy Responses: A Review. Sports Med 2021;51:1629–50.

25. Stojanović MD, Mikić M, Drid P, Calleja-González J, Maksimović N, Belegišanin B, *et al.* Greater Power but Not Strength Gains Using Flywheel Versus Equivolumed Traditional Strength Training in Junior Basketball Players. Int J Environ Res Public Health 2021;18:1181.

26. Sañudo B, Rueda D, Pozo-Cruz BD, de Hoyo M, Carrasco L. Validation of a Video Analysis Software Package for Quantifying Movement Velocity in Resistance Exercises. J Strength Cond Res 2016;30:2934–41.

27. Annino G, Romagnoli C, Zanela A, Melchiorri G, Viero V, Padua E, *et al.* Kinematic Analysis of Water Polo Player in the Vertical Thrust Performance to Determine the Force-Velocity and Power-Velocity Relationships in Water: A Preliminary Study. Int J Environ Res Public Health 2021;18:2587.

28. Lakens D. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. Front Psychol 2013;4:863.

29. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 2009;41:3–13.

30. Lloyd RS, Oliver JL. The Youth Physical Development Model: A New Approach to Long-Term Athletic Development. Strength Condit J 2012;34.

31. Norrbrand L, Tous-Fajardo J, Vargas R, Tesch PA. Quadriceps muscle use in the flywheel and barbell squat. Aviat Space Environ Med 2011;82:13–9.

32. Norrbrand L, Pozzo M, Tesch PA. Flywheel resistance training calls for greater eccentric muscle activation than weight training. Eur J Appl Physiol 2010;110:997–1005.

33. Norrbrand L, Fluckey JD, Pozzo M, Tesch PA. Resistance training using eccentric overload induces early adaptations in skeletal muscle size. Eur J Appl Physiol 2008;102:271–81.

34. Tesch PA, Ekberg A, Lindquist DM, Trieschmann JT. Muscle hypertrophy following 5-week resistance training using a non-gravity-dependent exercise system. Acta Physiol Scand 2004;180:89–98.

35. de Hoyo M, Pozzo M, Sañudo B, Carrasco L, Gonzalo-Skok O, Domínguez-Cobo S, *et al.* Effects of a 10-week in-season eccentric-overload training program on muscle-injury prevention and performance in junior elite soccer players. Int J Sports Physiol Perform 2015;10:46–52.

36. Suarez-Arrones L, Saez de Villarreal E, Núñez FJ, Di Salvo V, Petri C, Buccolini A, *et al.* In-season eccentric-overload training in elite soccer players: effects on body composition, strength and sprint performance. PLoS One 2018;13:e0205332.

37. Miranda C, Rago V, Silva JR, Rebelo A. Effects of traditional vs. complex strength training added to regular football training on physical capacities in U19 football players: a team study. Sport Sci Health 2021. [Epub ahead of print]

38. Sagelv EH, Pedersen S, Nilsen LP, Casolo A, Welde B, Randers MB, *et al.* Flywheel squats versus free weight high load squats for improving high velocity movements in football. A randomized controlled trial. BMC Sports Sci Med Rehabil 2020;12:61.

39. Rebelo A, Brito J, Maia J, Coelho-e-Silva MJ, Figueiredo AJ, Bangsbo J, *et al.* Anthropometric characteristics, physical fitness and technical performance of under-19 soccer players by competitive level and field position. Int J Sports Med 2013;34:312–7.

40. Nughes E, Rago V, Aquino R, Ermidis G, Randers MB, Ardigò LP. Anthropometric and Functional Profile of Selected vs. Non-Selected 13-to-17-Year-Old Soccer Players. Sports (Basel) 2020;8:E111.

41. Damas F, Libardi CA, Ugrinowitsch C. The development of skeletal muscle hypertrophy through resistance training: the role of muscle damage and muscle protein synthesis. Eur J Appl Physiol 2018;118:485–500.

Conflicts of interest.—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

*Authors' contributions.*Cristoforo Filetti has given substantial contributions to study design and data collection, Bruno Ruscello and Vincenzo Rago to data analysis, Carlos Miranda and Vincenzo Rago to manuscript writing, Italo Leo to data collection, Marco Porta, Aldo Chiari and Carlos Miranda to data acquisition, Cristoforo Filetti and Vincenzo Rago to study conception. All authors read and approved the final version of the manuscript.

Acknowledgements.—The authors acknowledge professor Mauro Testa for strongly assisting the collection of force and power data throughout video-analysis.

History.—Article first published online: April 12, 2022. - Manuscript accepted: March 31, 2022. - Manuscript revised: Match 4, 2022. - Manuscript received: January 12, 2022.

© 2022 EDIZIONI MINERVA MEDICA
Online version at https://www.minervamedica.it

The Journal of Sports Medicine and Physical Fitness 2023 February;63(2):213-22
DOI: 10.23736/S0022-4707.22.13822-3

ORIGINAL ARTICLE
EXERCISE PHYSIOLOGY AND BIOMECHANICS

Temporal patterns of fatigue in repeated sprint ability testing in soccer players and acute effects of different IHRs: a comparison between genders

Bruno RUSCELLO [1, 2, 3, 4] *, Laura PANTANELLA [2], Pietro IEMME [2], Cristoforo FILETTI [1, 2, 5], Marco PORTA [1], Stefano D'OTTAVIO [2], Lorenzo MARCELLI [3, 6], Gennaro APOLLARO [2], Gabriele MORGANTI [2], Alberto GROSSI [2], Mario ESPOSITO [2, 4, 7], Elvira PADUA [1, 2]

[1]Department of Human Sciences and Promotion of the Quality of Life, San Raffaele University, Rome, Italy; [2]School of Sports and Exercise Sciences, Faculty of Medicine and Surgery, Tor Vergata University, Rome, Italy; [3]Department of Industrial Engineering, Faculty of Engineering, Tor Vergata University, Rome, Italy; [4]LUISS SportLab, LUISS University, Rome, Italy; [5]Paris Saint Germain Football Club, Paris, France; [6]School of Sports and Exercise Sciences, UNICUSANO, Rome, Italy; [7]Faculty of Medicine, University of Ostrava, Ostrava, Czech Republic

*Corresponding author: Bruno Ruscello, Department of Human Sciences and Promotion of the Quality of Life, Tor Vergata University, Rome, Italy. E-mail: bruno.ruscello@uniroma2.it

ABSTRACT

BACKGROUND: Repeated sprint ability (RSA) in soccer is deemed fundamental to ensure high level of performance. The aim of this study was to investigate the acute effects of two different Initial Heart Rates (IHR) on fatigue when testing RSA in males and females' soccer players and to compare the respective patterns of fatigue.

METHODS: Nineteen female soccer players (age: 22.5±3.3 years, height 163.9±7.3 cm, body weight 54.3±6.4 kg, BMI 20.6±1.5 kg·m^{-2}) and 15 male soccer players (age: 17.9±1.5 years, height 175.9±5.8 cm, body weight 68.5±9.6 kg, BMI 22.3±1.5 kg·m^{-2}) participated in this study. HRs reached at the end of two different warm-up protocols (~90 *vs.* ~ 60% HR_{max}), have been selected and the respective RSA performances were compared, within and between the groups of participants. Two sets of ten shuttle-sprints (15+15 m) with a 1:3 exercise to rest ratio with different IHR% were administered, in different days, in randomized order. To compare the different sprint performances, we employed the calculated Fatigue Index (FI%). Blood lactate concentration (BLa^-) was also measured before and after testing, to compare metabolic energy.

RESULTS: Significant differences among trials within each set (P<0.01) were found in both genders. Differences between sets were found in male players, (Factorial ANOVA 2x5; P<0.001), not in female. BLa^- after warm-up was higher in 90% *vs.* 60% HR_{max} (P<0.05), in both genders but at the completion of RSA tests (after 3 minutes) the differences were not significant (P>0.05).

CONCLUSIONS: difference between genders were found, suggesting specific approach in testing and training RSA in soccer players.

(*Cite this article as:* Ruscello B, Pantanella L, Iemme P, Filetti C, Porta M, D'Ottavio S, *et al.* Temporal patterns of fatigue in repeated sprint ability testing in soccer players and acute effects of different IHRs: a comparison between genders. J Sports Med Phys Fitness 2023;63:213-22. DOI: 10.23736/S0022-4707.22.13822-3)

KEY WORDS: Lactates; Warm-up exercise; Heart rate; Soccer.

Repeated sprint ability (RSA), *i.e.* the ability to repeat and endure significant sprinting, lasting few seconds each time [≈ 1 -10"] with intermittent recovery periods taking place many times during a match, is considered an important requisite in sports games, and particularly in soccer, both in males and females.[1-11] Results from several studies have highlighted the key role played by RSA, considered as one of the most important indicators in discriminating elite soccer players from sub-elite or amateur players.[1, 5, 8, 12-17] Moreover, RSA is taken in consideration also in talent development programs, because of its variations related to the age of young players (*i.e.*, relative age effects).[18-20] The main goal of RSA is to delay fatigue onset during the game, thus ensuring high intensity of actions throughout the whole match.[21, 22] The advent of global positioning systems (GPS) analysis highlighted how fatigue progressively affects the performance of players during the match, both in males and females.[23-31]

Testing and training this ability is therefore an important goal to be considered in designing appropriate training plans for soccer players.

Several studies provided useful insights into the RSA training in soccer players,[9, 14-16, 22, 28, 32, 33] outlining the importance of proper interventions in designing RSA.

Often fatigue is investigated by means of the Index of Fatigue, that is a ratio between the best performance provided over a certain distance, in term of sprinting ability, and the actual timing, recorded in different repeated trials interspersed by a certain recovery time.[14-16, 33, 34]

In previous studies, Ruscello *et al.*[16, 33] advanced the hypothesis, that Initial Heart Rates (IHRs) (*e.g.*, 60%HR_{max} *vs.* 90%HR_{max}) while testing RSA might influence the overall performance during sets of sprint repetitions. The rationale of these studies was that also while testing, one should mimic as much as possible the real context in which performances normally occur, for the sake of ecological validity.

It is known that during RSA the warm-up procedures preceding the test do not provide an internal activation (*e.g.*, an increase in HR) similar to that occurring during a real match (85-90% HR_{max}).[33, 35-40]

Indeed, Ruscello *et al.*[16, 33] found different patterns of fatigue while performing RSA testing, starting with different IHR in male players. Conversely, they did not find any significant differences when tested female soccer players,[25] a finding suggesting a gender-related difference.

This finding gave raise to two questions: 1) are there any significant differences in fatigue patterns in RSA testing between male and female soccer players, when the IHR are different? 2) If so, should we take into consideration this difference when planning RSA testing/training sessions in males versus females?

Accordingly, in the present study we directly compared the temporal patterns of fatigue in male and female soccer players undergoing RSA testing with different IHR. To accomplish this aim, we investigated the acute effects of two induced different IHR (60 *vs.* 90% HR_{max}) before the first sprint of RSA testing in male and female soccer players. The different fatigue patterns were calculated by means of the Index of Fatigue.

Materials and methods

Subjects

Nineteen women well trained soccer players (age: 22.5±3.3 years, height 163.9±7.3 cm, body mass 54.3±6.4 kg, BMI 20.6±1.5 $kg \cdot m^{-2}$) volunteered to participate in the study. Inclusion criteria to participate in the study were: 1) to have regularly competed during the competitive season, 2) to be in their post-menstrual period at the time of testing and 3) possession of a valid medical certificate. The players had at least 4 years (range 1-11 years) of experience at this competitive level (*i.e.*, Italian *"Serie A"*) and performed at least 5 training sessions a week for the development of specific fitness. Sprinting, agility and repeated sprinting (RSA) have been always part of their usual training, especially in the competitive season, which is the period investigated in this paper.

Fifteen male soccer players (age: 17.9±1.5 years, height 175.9±5.8 cm, body mass 68.5±9.6 kg, BMI 22.3±1.5 $kg \cdot m^{-2}$) well trained volunteered to participate in the study. Inclusion criteria to participate in the study were: 1) to have regularly competed during the competitive season, and 2) possession of a valid medical certificate. The players had at least 1 year (range 1– 3 years) of experience at this competitive level (*i.e.*, Italian "Eccellenza") and performed at least 4 training sessions a week for the development of specific fitness. Sprinting, agility and RSA have been always part of their usual training, especially in the competitive season, which is the period investigated in this paper. All subjects were healthy and clear of any drug consumption. Each subject completed all trials in the same time period of test days to eliminate any influence of circadian variation. The Institutional Research Board (Tor Vergata University of Rome, Faculty of Medicine Ethical Committee) provided clearance for the procedures before the commencement of this study. Written informed consent was obtained from all the participants after familiarization and explanation of the benefit and risks involved in the procedures of the study. All participants were informed that they were free to withdraw from the study at any time without penalty. All procedures were carried out in accordance with the Declaration of Helsinki of the World Medical Association as regards the conduct of clinical research.

Experimental procedures

Using a cross-over study design, participants performed, in a randomized order and in different days, two set of 10 repetitions each of shuttle sprinting (15+15 m) with each set administered with a 1:3 exercise to rest ratio.[14] IHR were set at 60 and 90% of the individual maximum HRs. Blood lactate (BLa^-) concentrations were sampled during testing. The different IHR were set as independent variables and the RSA performance, expressed as Index of Fatigue,[9] as the dependent variable. All tests were performed on an outdoor synthetic soccer pitch. Players were familiarized with the exercise procedures prior the beginning of each test. They were told not to perform intense exercise in the 48 hours prior to testing sessions.

The RSA tests were performed in two separate days, for each gender, with one week between each testing day, at the same hours of the day (*i.e.*, 2-5 pm) and the same day of the week (Tuesday), in a sport center (Rome, Italy), on a synthetic surface soccer pitch, approved by the Italian Football Association for national level competitions.

The average weather conditions during the four testing days were fine, with an average temperature and wind speed of 15° and 3.6 $m \cdot s^{-1}$ on first day, 10° and 1.7 $m \cdot s^{-1}$ on last day respectively (females) and 15° and 5.5 m·s-1 on first day, 11° and 1.9 m·s-1 on last day respectively (males). To limit the influence of the wind, we oriented the direction of sprinting at right angles, in relation to the wind direction.

HR

One week before testing, the maximum heart rate (HR_{max} %) for each individual player was computed by the means of "Yo-Yo Recovery Test, Level 1" (YY). Each player wore a HR monitor chest strap (Team Polar™, Polar Electro OY, Kempele, Finland), which recorded HR every 5 seconds. Data was downloaded and processed using manufacturer supplied software (Polar™ Precision Performance v4.03.043). For each player, the targeted Heart Rates (60% and 90% HR_{max}, respectively) were then computed.

Blood lactate

Capillary blood samples were drawn from the ear lobe of the players, using a sterile lancet (Accu-Check Softclix, Roche—5 m) so blood lactate (BLa^-) was assessed after warm-up and 3' minutes after the end of the testing sets. Three BLa analyzers (Lactate Pro LT 1710 analyzers, Arkray, Japan) were used for the analysis of the samples.

Warm-up protocols

The RSA tests were performed at the end of two different warm-up protocols:

Protocol 1: 10 minutes of slow jogging followed by dynamic stretching (5 minutes) with agility and sprint practice (10 minutes). Following this procedure, the targeted heart rates (60%HR_{max}) was reached by a Yo-Yo Recovery Test routine by each participant. Immediately after, the player switched to the testing zone and performed the blood sampling and the required set of sprinting.

Protocol 2: as in Protocol 1, performing a Yo-Yo Recovery Test routine after the agility and sprint practice. Each player performed the Yo-Yo test until the target heart rate (90%HR_{max}) was reached. Immediately after, the player switched to the testing zone and performed the blood sampling and the required set of sprinting.

RSA test protocol

To test the RSA, we used an established protocol[9, 15, 16, 41] consisting of ten shuttle sprints over 30 meters (15+15m with a change of direction (COD) of 180°) and recovery in-between was 1:3 exercise to rest ratio. The level of decay of performance was measured as the ratio between the best personal performance on a single trial and the actual time, recorded during each trial of the set. This level of decay might be also assumed, according to Ruscello,[9] as Fatigue Index (FI%). Participants performed the testing as described in Table I.

To control the variables that suffer influences from repeated tests on different days, we designed a Latin Square protocol, in which the groups (N_1=19; N_2=15) were randomly split into two subgroups, for women and men respectively (A, N.=10; B, N.=9; C, N.=8; D, N.=7), working differently each testing day. The groups performed the different tests according to the sequence depicted in Table II.

TABLE I.—*Testing protocols.*

Test	Number of repetitions	Exercise to Rest Ratio	Type of recovery
Shuttle sprinting (15+15 m) with initial 60% HR_{max}	10	1:3	Passive
Shuttle sprinting (15+15 m) with initial 90% HR_{max}	10	1:3	Passive

HR_{max}: heart rate maximum.

TABLE II.—*Testing sequence: Latin Square protocol.*

Test	Day 1	Day 2	Day 3	Day 4
Shuttle sprinting (15+15 m) with initial 60% HR_{max} (protocol 1)	Group A	Group B	Group C	Group D
Shuttle sprinting (15+15 m) with initial 90% HR_{max} (protocol 2)	Group B	Group A	Group D	Group C

HR_{max}: heart rate maximum.

To avoid undue stress to the players, in the days preceding the testing, training loads were intentionally reduced, and familiarization sessions were performed. The players were advised to maintain a regular diet in the day before testing (*i.e.*, 60, 25, and 15% of carbohydrates, fat, and protein, respectively) and to refrain from smoking and caffeinated drinks during the 2 hours preceding testing. To avoid hypohydration, players were allowed to drink fluids *ad libitum.*

Instrumentation

The tests performance were assumed as total time and assessed using a telemetric photocells system (Witty System, Microgate, Bolzano, Italy). To avoid undue switch-on of the timing system, players had to position the front foot immediately before a line set 0.3-m from the photocell beam. The photocell beam was positioned at 1 m height and 2 m apart. All the players performed the tests with a self-administered start, and maximum performance was induced through strong verbal encouragements by the same test administrator during all the test duration. Recovery time was administered directly from the PC that ran the timing of the test procedure, according to the exercise to rest ratio 1:3.[9]

Statistical analysis

Data are presented as mean and standard deviation (M±SD) and 95% confidence intervals (95% CIs). The assumption of normality was assessed using the Shapiro-Wilk test. In order to normalize all the values recorded in different tests, the ratio between personal best (PB) and actual value (AV) for each trial was assumed as Fatigue Index (FI%). The Intraclass Correlation Coefficients (ICC) for mean measures were used as indices of relative reliability of the tests, along with the Cronbach Alpha. To identify significant points of fatigue (cut-off), Analysis of Variance (ANOVA) for repeated measures was performed, for each test. Data were analyzed as absolute values of time (s) recorded in each test, and as percentage, (FI%) of the PB recorded during testing. After performing, the Mauclhy Test of sphericity, the Greenhouse-Geisser ε, was used when appropriate.

To test the main effect and the interactions between factors (percentage of HR_{max} as independent variables, the IF% as a dependent variable) a factor ANOVA was performed. Effect Size (ES) in ANOVA was computed as η^2, according to Cohen (1988), to assess meaningfulness of differences, with $\eta^2<0.01$, $0.01<\eta^2<0.06$, $0.06<\eta^2<0.14$ and $\eta^2>0.14$, as trivial, small, moderate, and large ES, respectively. Paired *t*-tests were performed to assess the

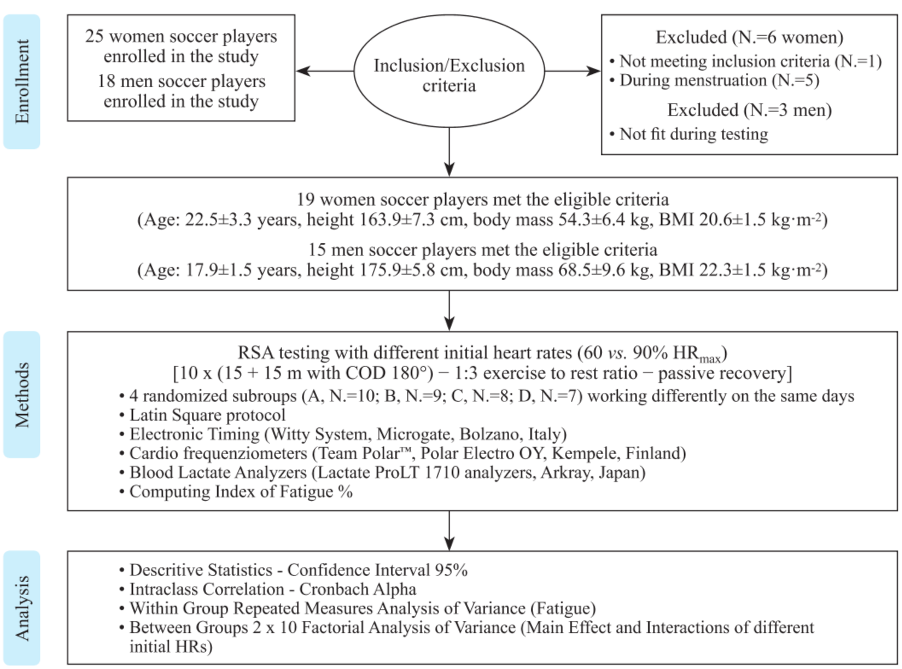


Figure 1.—Flow-diagram describing enrollment, methodological investigation and analysis of the soccer players undergone this research project.

significance of differences BLa⁻ when performing the sprint tests with two different IHRs. In addition to the null hypothesis testing, ES (Cohen's d) were reported. The negative effect size reflects a larger mean for Protocol 2 (90%HR_{max}) testing. Absolute ES of 0.20, 0.50, and 0.80 represented small, medium and large differences, respectively. The corresponding P values are provided for each analysis. The value of statistical significance was accepted with P<0.05. IBM SPSS 25 for Windows (SPSS Inc., Chicago, IL) was used to analyze and process the collected data.

A flow-chart diagram summarizing the study protocol is provided in Figure 1.

Results

Table III shows Intraclass Correlation Coefficients (ICC) computed for the two testing modes in both genders taken as a measure of the relative reliability of measurements obtained during testing.

In Figure 2, 3 are reported the graphs describing the patterns of fatigue in relation to the different IHR (HR60%$_{max}$ and HR90% $_{max}$) compared between genders. As shown, the pattern of fatigue was different in relation to IHR. While at 60% of HR_{max} there were no difference between genders, at 90% of HRmax there was a clear greater resistance to fatigue in females.

The descriptive statistics of the times recorded during testing are illustrated in Table IV that shows a substantial homogeneity of data, as indicated by the low CV. The ratios PB/ AV (that is, FI%), showing the performance decay as the decreasing percentage of the PB along the set, are reported in Table V indicating the pattern of fatigue over time, in both males and females.

BLa⁻ were measured after the warm-up procedures before testing and post testing, after three minutes from the completion of the trials (Table VI). The observed data indicate that the different warm-up protocols induced a significantly different production on lactate before testing, as evidence of the different initial metabolic status.

Analysis by gender: females

An ANOVA for repeated measures has been carried out to determine whether there were significant differences within each investigated protocol. In RSA tests performed with IHRs ~60% of HRmax, highly significant differences within trials have been found (ANOVA for repeated measures: $F_{9,162}$= 10.405, P<0.001, η^2= 0.366, power=1.00) as evidence of the progressive fatigue observed.

Subsequent *post-hoc* test, showed that there were statis-

Table III.—*Intraclass Correlation Coefficient (ICC) for each testing mode.*

Test	ICC	Confidence interval (95%)	P
Females - Protocol 1 (60%HR_{max})	0.970	0.944-0.986	<0.001
Females - Protocol 2 (90%HR_{max})	0.923	0.816-0.979	<0.001
Males - Protocol 1 (60%HR_{max})	0.873	0.797-0.920	<0.001
Males - Protocol 2 (90%HR_{max})	0.970	0.959-0.978	<0.001

Females (60%HR_{max}) Cronbach Alpha: 0.970 (N. trials=10); females (90%HR_{max}) Cronbach Alpha: 0.987 (N. trials=10); Males (60%HR_{max}) Cronbach Alpha: 0.925 (N. trials=10); males (90%HR_{max}) Cronbach Alpha: 0.973 (N. trials=10).

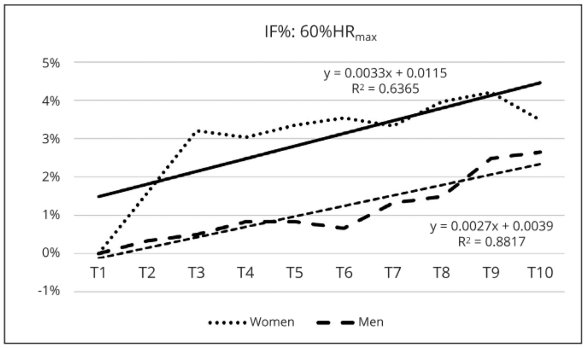


Figure 2.—Patterns of fatigue (IF%) observed in RSA testing, with IHR set at 60% of the maximal, women and men.

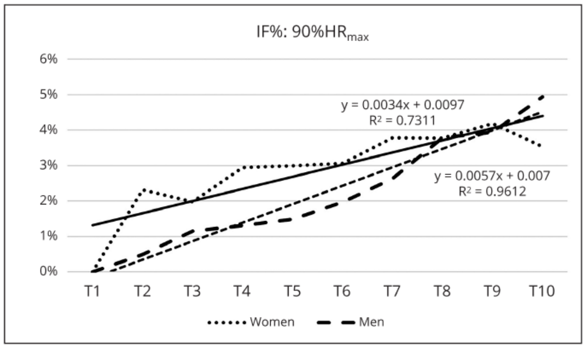


Figure 3.—Patterns of fatigue (IF%) observed in RSA testing, with IHR set at 90% of the maximal, females and males.

Table IV.—*Descriptive Statistics and Effect Size (Cohen d [IC95%]) from independent sample t-Test.*

Trials F/M	Prot 1 (Mean ±SD)	Prot 1 (CV %)	Prot 1 C.I. 95%	Prot 2 (Mean ± SD)	Prot 2 (CV %)	Prot2 (C.I. 95%)	Prot2 *vs.* Prot1 Effect size Cohen d; [IC 95%]
T1	6.48±0.22	3.40%	6.38-6.59	6.52±0.31	4,75%	6.37-6.66	-0.15 [-0.78; 0.49]
	6.06±0.16	2.64%	5.94-6.17	6.09±0.19	3.11%	5.97-6.20	-0.17 [-0.88; 0.55]
T2	6.55±0.20	3.05%	6.46-6.65	6.61±0.30	4.54%	6.47-6.76	-0.24 [-0.86; 0.41]
	6.08±0.10	1.64%	5.96-6.20	6.12±0.23	3.75%	6.00-6.24	-0.23 [-0.94; 0.50]
T3	6.66±0.17	2.55%	6.57-6.74	6.59±0.28	4.25%	6.45-6.73	0.30 [-0.34; 0.94]
	6.09±0.14	2.29%	5.95-6.23	6.16±0.27	4.38%	6.02-6.30	-0.30 [-0.99; -0,37]
T4	6.65±0.20	3.01%	6.55-6.75	6.66±0.28	4.20%	6.52-6.79	-0.04 [-0.68; 0.60]
	6.11±0.15	2.45%	6.01-6.22	6.17±0.17	2.75%	6.06-6.28	-0.37 [-1.09; 0.36]
T5	6.67±0.22	3.30%	6.57-6.78	6.66±0.30	4.50%	6.51-6.81	0.04 [-0.60; 0.67]
	6.11±0.18	2.94%	5.98-6.24	6.18±0.21	3.39%	6.05-6.30	-0.36 [-1.07; 0.37]
T6	6.68±0.22	3.29%	6.58-6.79	6.66±0.30	4.50%	6.52-6.81	0.08 [-0.56; 0.71]
	6.10±0.10	1.63%	5.98-6.21	6.21±0.23	3.70%	6.09-6.33	0.62 [-1.33; 0.13]
T7	6.67±0.22	3.30%	6.56-6.78	6.71±0.28	4.17%	6.58-6.85	-0.16 [-0.79; 0.48]
	6.14±0.16	2.60%	6.02-6.27	6.25±0.21	3.36%	6.13-6.38	-0.59 [-1.30; 0.16]
T8	6.72±0.22	3.27%	6.60-6.84	6.71±0.29	4.32%	6.57-6.86	0.04 [-0.60; 0.67]
	6.15±0.16	2.60%	6.02-6.28	6.32±0.21	3.32%	6.20-6.44	-0.91 [-1.64; -0.14]
T9	6.73±0.21	3.12%	6.63-6.83	6.74±0.29	4.30%	6.60-6.88	0.04 [-0.67; 0.60]
	6.21±0.18	2.89%	6.08-6.34	6.33±0.21	3.31%	6.20-6.46	-0.60 [-1.33; 0.13]
T10	6.68±0.19	2.84%	6.59-6.77	6.70±0.29	4.33%	6.56-6.84	0.08 [-0.72; 0.56]
	6.22±0.20	3.21%	6.10-6.35	6.39±0.16	2.50%	6.26-6.50	0.94 [-1.67; -0.16]

F/M: females/males; Prot 1: Protocol 1: 60%HR_{max} initial activation; Prot 2: Protocol 2: 90%HR_{max} initial activation.

Table V.—*Fatigue Index (FI%) recorded during RSA started at different initial heart rates conditions in females (F) and males (M).*

Trials F/*M*	FI% (60% HR_{max})	FI% (90% HR_{max})
T 1	0.00%	0.00%
	0.00%	0.00%
T 2	1.60%	2.31%
	0.33%	0.49%
T 3	3.20%	1.98%
	0.50%	1.15%
T 4	3.03%	2.94%
	0.83%	1.31%
T 5	3.35%	2.99%
	0.83%	1.48%
T 6	3.54%	3.06%
	0.66%	1.97%
T 7	3.33%	3.78%
	1.32%	2.63%
T 8	3.96%	3.77%
	1.49%	3.78%
T 9	4.21%	4.18%
	2.48%	3.94%
T 10	3.48%	3.53%
	2.64%	4.93%

T: trial; FI%: Fatigue Index %; 60-90%HR_{max}: 60-90% percent of maximal heart rate.

tically significant differences between the first and all the subsequent trials ($P<0.05$) in the set performed at this IHR, which may be considered as the cut-off points of fatigue.

In RSA tests performed with the IHRs ~90% of HR_{max}, highly significant differences within trials have been also found (ANOVA for repeated measures $F_{9,162}=8.949$, $P<0.001$, $\eta^2=0.332$, power=1.00) as evidence of the progressive fatigue observed. Subsequent *post-hoc* test showed that there were significant differences between the first and the seventh (P=0.045) and up to the tenth trials (P=0.015) in the set performed at this IHR, which may be considered as the cut-off points of fatigue.

A mixed factorial ANOVA 2×10 allowed us to highlight no statistically significant differences between the performances recorded during the tests performed at different IHRs (Mixed Factorial ANOVA $F_{1, 36}=0.059$, P=0.809, $\eta^2=0.002$, power=0.056).

Similarly, no differences were found performing a mixed factorial ANOVA 2×5, considering the last five trials, as we did in men (Mixed Factorial Anova $F_{1, 36}=0.004$, P=0.952, $\eta^2=0.000$, power=0.050).

BLa^-, sampled immediately before the tests carried out at two different IHRs on completion of the warm-up procedures, showed statistically significant differences and a large effect size (P<0.001; ES as Cohen d = 2.85). On the contrary, the differences in BLa^-, at the end of the test (after 3’), were not statistically significant (P=0.75, ES as Cohen d = 0.13).

Analysis by gender: males

An ANOVA for repeated measures has been carried out to determine whether there were significant differences

TABLE VI.—*Blood lactate concentrations sampled before and after testing (females/males).*

Blood Lactate sampling	60% HR_{max} BLa^- (mmol/L)	90% HR_{max} BLa^- (mmol/L)	Paired t-Test (60% HR_{max} *vs.* 90%HR_{max})
Immediately before testing, after the completion of the warmup procedures	3.48±0.40	5.02±0.65	t=-6.99 (DF=8) P<0.001 ES (d=2.85)
	2.52±1.40	4.12±1.15	t= 2.13 (DF=14) P=0.04 ES (d=1.2)
After testing (3’)	12.75±2.81	13.20±4.07	t= -0.33 (DF=8) P=0.75 ES (d = 0.13)
	14.05±0.79	15.02±1.64	t= 1.54 (DF=14) P=0.15 ES (d=-0.8)

Bla^-: blood lactate concentration; t: dependent sample t Test; df: degree of freedom; ES: effect size as Cohen d.

within each investigated protocol. In tests performed at the IHR ~60% of HR_{max}, highly significant differences within trials have been found (ANOVA for repeated measures: $F_{9,81}$= 3.505, P< 0.001, η^2= 0.280, power=0.981) as evidence of the progressive fatigue.

Post-hoc tests, showed that there were statistically significant differences between the first and the eighth (P=0.06), ninth (P<0.001) and the tenth trials (P=0.006) in the set performed at this IHR, which may be considered as the cut-off points of fatigue.

In tests performed with the IHR ~90% of HR_{max}, highly significant differences within trials have also been found (ANOVA for repeated measures $F_{9,81}$= 4.813, P<0.001, η^2=0.348, power= 0.998), as evidence of the progressive fatigue. *Post-hoc* test, showed that there were significant differences between the first and the eighth (P=0.034), ninth (P=0.001) and the tenth trials (P=0.002), which may be considered as the cut-off points of fatigue, in the set performed at this IHR.

A mixed factorial ANOVA 2×10 indicated statistically significant differences between the performances recorded during the tests performed at different IHR (Mixed Factorial Anova $F_{4.42,79.5}$=8,03, P<0.001, η^2=0.308, power=0.999). We also performed a mixed factorial Anova 2×5, to verify the extent of the differences observed in the comparison of the last 5 trials (tests 6<10) of the tests with different initial metabolic conditions and found highly significant differences ($F_{4,72}$=5.944, P<0.001, η^2=0.348, power=0.998).

BLa^-, before the tests carried out at two different IHR (Table VI) showed statistically significant differences and a large effect size (P=0.04; ES as Cohen d=-1.2). The observed differences in BLa^- at the end of the test (3’) were not significantly different, although a large ES (-0.8) was observed, indicating anyway a certain practical relevance.

Comparison between genders

After analyzing the dynamics that emerged within genders, we verified the existence of possible differences between genders in the fatigue patterns, after calculating the respective fatigue indices. When comparing those indices obtained in the testing trials with an IHR of 60% (Figure 2) we found no significant differences between male and female players (mixed factorial ANOVA 2×10: [$F_{1,32}$=0.018, P=0.895, η^2=0.001, power=0.052]). Similarly, we found no significant differences when comparing testing trials with an IHR of 90% (Figure 3) (mixed factorial ANOVA 2×10: [$F_{1,32}$= 2.178, P=0.150, η^2=0.064, power=0.299]). However, a moderate effect size as η^2 was found, indicating again a practical relevance.

Bla^- did not differ significantly between genders (see Table VII), both in pre and post testing, no matter the IHR. Nevertheless, we should consider the magnitude we found in Effect Sizes in pretesting phases (d ≈1), suggesting practical implications (females producing more lactate than males, Table VI).

TABLE VII.—*Blood lactate concentrations: comparison between genders, before and after testing.*

Blood lactate sampling	60% HR_{max} BLa^- (mmol/L)	90%HR_{max} BLa^- (mmol/L)
Immediately before testing, after the completion of the warmup procedures	t=1.99 (DF=13) P=0.07 ES (d=0.99)	t=1.96 (DF=13) P=0.07 ES (d=0.97)
After testing (3’)	t= -1.08 (DF=13) P=0.30 ES (d =-0.54)	t= -0.54 (DF=13) P=0.60 ES (d =-0.27)

Bla^-: blood lactate concentration; t: independent sample t Test; df: degree of freedom; ES: effect size as Cohen d.

Discussion

The main finding of this study is that heart rate just before starting RSA test significantly influences the fatigue process, as assessed by FI%, in male soccer players whereas no significant differences were found in female, suggesting a gender related difference in resistance to fatigue, when expressed as RSA.

Several studies in soccer have pointed out that during matches, the metabolic levels of soccer players, both males and females, can be described by means of heart rates,[42-46] the latter being almost constantly around 85-95% of the individual maximum heart rate for most part of the match.[47] Previous studies also indicated that the optimal development of RSA can be considered as one of the key goals to be achieved in elite soccer players.[1, 8, 9, 14-16, 33]

Several authors, however, have also reported some limiting factors of RSA. Among these, limitations to energy supply (*e.g.*, phosphocreatine resynthesis, aerobic and anaerobic glycolysis) and metabolite accumulation (*e.g.*, inorganic phosphate [P_i], H+) have been considered.[1, 8]

Failure to fully activate the contracting muscle may also limit the repeated sprint performances.[48] As the short recovery times between repeated sprints will lead to only a partial restoration of phosphocreatine stores, it has been suggested that the ability to resynthesize phosphocreatine may be an important determinant of the ability to reproduce sprint performance.[49] In this context, oxidative metabolism pathways are essential for the resynthesis of phosphocreatine during recovery from high-intensity exercise.[50] This suggests that individuals with a high aerobic capacity (*i.e.*, high maximal oxygen consumption [VO_{2max}] or lactate threshold) should be able to resynthesize phosphocreatine more rapidly between each short sprint. Several physiological adaptations related to an increased reliance on aerobic metabolism to resynthesize ATP have been associated with an increased ability of resisting to fatigue during repeated sprints, including increased mitochondrial respiratory capacity[50] faster oxygen uptake kinetics,[51] accelerated muscle reoxygenation rate after sprinting,[52] higher lactate threshold[42] and, most of all, higher VO_{2max}.[51, 53, 54]

Individuals with greater VO_{2max}[55] have a superior ability to resist to fatigue during RSA, especially during the latter stages of a repeated-sprint test, when subjects may reach their VO_{2max}. This suggests that improving VO_{2max} may allow for a greater aerobic energy contribution to repeated sprints, potentially improving the RSA performance.

HR has been often placed in relation to VO_{2max}, as an indicator of the overall metabolic commitment of an athlete engaged in a competition.[56] The simplicity of its monitoring, even in testing or match conditions, led scientists to consider HR as a good indicator of the metabolic commitment and to use it to effectively control the internal load in terms of training. Chronometric measurements, taken during testing, were also analyzed and then processed in order to derive the patterns of fatigue (FI%) specifically related to the different testing protocols.

To our knowledge, this is the first study to investigate the processes of fatigue in RSA testing, at different initial physiological conditions, as indicated by HR and BLa^-, and to directly compare the patterns of performance decay in males versus females' soccer players. Our aim was to check any differences that might justify a different methodological approach between genders in both the testing and training phases of RSA.

Performing specific warm-up protocols, like those performed in the present study, would permit the player to undergo training and/or RSA assessment under conditions that resemble, as much as possible, those encountered in the real soccer match scenario (*e.g.*, HR_{max} ≈85<90%; 4 mmol-L-1<BLa^-<15 mmol-L-1). Comparing the fatigue patterns in males versus females tested at different IHR, however, did not show significant differences, suggesting the same patterns of performance decay in both genders. Some slight differences in the patterns of fatigue were observed only in trials performed at IHR equal to 90% HR_{max} (Figure 3) that although not significant, showed a moderate effect size, that would suggest a greater resistance to repeated sprints in female athletes. Indeed, female players seem to have a greater organic resistance to repeated sprinting, in line with the findings by Archiza *et al.*[57] This greater resistance is evidenced by the same fatigue patterns found in tests at different IHR (60% and 90% HR_{max}), which was not the case for male players, suggesting the need for a different gender-related, methodological approach in RSA training. Therefore, it seems advisable to adopt an IHR of approximately 90% of the maximum HR in males, thus respecting the HR occurring during much part of the real competition. Further studies in larger sample sizes comparing male *versus* female soccer players would be needed to verify this hypothesis.

Conclusions

The ability to perform repeated sprints is certainly relevant in soccer, both in male and female athletes. RSA continues to be an important training routine to enable players to perform at their optimal and consistent level. Our study suggests that although the fatigue patterns found in timed trials are essentially the same in males and females, there is a greater influence of the IHR in males, suggesting, from a practical standpoint, that more attention should be paid to RSA assessment and training in this gender, by adopting a more ecological approach to the problem.

References

1. Bishop D, Girard O, Mendez-Villanueva A. Repeated-sprint ability - part II: recommendations for training. Sports Med 2011;41:741–56.

2. Bishop D, Edge J. The effects of a 10-day taper on repeated-sprint performance in females. J Sci Med Sport 2005;8:200–9.

3. Bishop D, Claudius B. Effects of induced metabolic alkalosis on prolonged intermittent-sprint performance. Med Sci Sports Exerc 2005;37:759–67.

4. Spencer M, Bishop D, Lawrence S. Longitudinal assessment of the effects of field-hockey training on repeated sprint ability. J Sci Med Sport 2004;7:323–34.

5. Spencer M, Lawrence S, Rechichi C, Bishop D, Dawson B, Goodman C. Time-motion analysis of elite field hockey, with special reference to repeated-sprint activity. J Sports Sci 2004;22:843–50.

6. Bishop D, Spencer M. Determinants of repeated-sprint ability in well-trained team-sport athletes and endurance-trained athletes. J Sports Med Phys Fitness 2004;44:1–7.

7. Bishop D, Lawrence S, Spencer M. Predictors of repeated-sprint ability in elite female hockey players. J Sci Med Sport 2003;6:199–209.

8. Girard O, Mendez-Villanueva A, Bishop D. Repeated-sprint ability - part I: factors contributing to fatigue. Sports Med 2011;41:673–94.

9. Ruscello B, Tozzo N, Briotti G, Padua E, Ponzetti F, D'Ottavio S. Influence of the number of trials and the exercise to rest ratio in repeated sprint ability, with changes of direction and orientation. J Strength Cond Res 2013;27:1904–19.

10. Chaouachi A, Manzi V, Wong P, Chaalali A, Laurencelle L, Chamari K, *et al.* Intermittent endurance and repeated sprint ability in soccer players. J Strength Cond Res 2010;24:2663–9.

11. Gabbett TJ. The development of a test of repeated-sprint ability for elite women's soccer players. J Strength Cond Res 2010;24:1191–4.

12. Arazi H, Keihaniyan A, EatemadyBoroujeni A, Oftade A, Takhsha S, Asadi A, *et al.* Effects of Heart Rate vs. Speed-Based High Intensity Interval Training on Aerobic and Anaerobic Capacity of Female Soccer Players. Sports (Basel) 2017;5:E57.

13. Lockie RG, Liu TM, Stage AA, Lazar A, Giuliano DV, Hurley JM, *et al.* Assessing Repeated-Sprint Ability in Division I Collegiate Women Soccer Players. J Strength Cond Res 2020;34:2015–23.

14. Ruscello B, Esposito M, Partipilo F, Di Cicco D, Filetti C, Pantanella L, *et al.* Exercise-to-rest ratios in repeated sprint ability training in women's soccer. J Sports Med Phys Fitness 2018;58:1790–9.

15. Ruscello B, Partipilo F, Pantanella L, Esposito M, D'Ottavio S. The optimal exercise to rest ratios in repeated sprint ability training in youth soccer players. J Sports Med Phys Fitness 2016;56:1465–75.

16. Ruscello B, Briotti G, Tozzo N, Partipilo F, Taraborelli M, Zeppetella A, *et al.* Acute effects of two different initial heart rates on testing the Repeated Sprint Ability in young soccer players. J Sports Med Phys Fitness 2015;55:1082–90.

17. Granatelli G, Gabbett TJ, Briotti G, Padulo J, Buglione A, D'Ottavio S, *et al.* Match analysis and temporal patterns of fatigue in rugby sevens. J Strength Cond Res 2014;28:728–34.

18. Altimari JM, Altimari LR, Bortolotti H, Junior AF, Gabardo JM, Buzzachera CF, *et al.* The Relative Age Effect on Anthropometry, Body Composition, Biological Maturation and Motor Performance in Young Brazilian Soccer Players. J Hum Kinet 2021;77:147–57.

19. Rowat O, Fenner J, Unnithan V. Technical and physical determinants of soccer match-play performance in elite youth soccer players. J Sports Med Phys Fitness 2017;57:369–79.

20. Duarte JP, Coelho-E-Silva MJ, Costa D, Martinho D, Luz LG, Rebelo-Gonçalves R, *et al.* Repeated Sprint Ability in Youth Soccer Players: Independent and Combined Effects of Relative Age and Biological Maturity. J Hum Kinet 2019;67:209–21.

21. Ramirez-Campillo R, Gentil P, Negra Y, Grgic J, Girard O. Effects of Plyometric Jump Training on Repeated Sprint Ability in Athletes: A Systematic Review and Meta-Analysis. Sports Med 2021;51:2165–79.

22. Manuel Clemente F, Ramirez-Campillo R, Nakamura FY, Sarmento H. Effects of high-intensity interval training in men soccer player's physical fitness: A systematic review with meta-analysis of randomized-controlled and non-controlled trials. J Sports Sci 2021;39:1202–22.

23. Cummins C, Orr R, O'Connor H, West C. Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. Sports Med 2013;43:1025–42.

24. Aughey RJ. Applications of GPS technologies to field sports. Int J Sports Physiol Perform 2011;6:295–310.

25. Schimpchen J, Gopaladesikan S, Meyer T. The intermittent nature of player physical output in professional football matches: an analysis of sequences of peak intensity and associated fatigue responses. Eur J Sport Sci 2021;21:793–802.

26. Rhodes D, Valassakis S, Bortnik L, Eaves R, Harper D, Alexander J. The Effect of High-Intensity Accelerations and Decelerations on Match Outcome of an Elite English League Two Football Team. Int J Environ Res Public Health 2021;18:9913.

27. Harkness-Armstrong A, Till K, Datson N, Emmonds S. Whole and peak physical characteristics of elite youth female soccer match-play. J Sports Sci 2021;39:1320–9.

28. Gonçalves L, Clemente FM, Barrera JI, Sarmento H, González-Fernández FT, Palucci Vieira LH, *et al.* Relationships between Fitness Status and Match Running Performance in Adult Women Soccer Players: A Cohort Study. Medicina (Kaunas) 2021;57:617.

29. Freire LA, de Brito MA, Esteves NS, Tannure M, Slimani M, Znazen H, *et al.* Running Performance of High-Level Soccer Player Positions Induces Significant Muscle Damage and Fatigue Up to 24 h Postgame. Front Psychol 2021;12:708725.

30. Lozano D, Lampre M, Díez A, Gonzalo-Skok O, Jaén-Carrillo D, Castillo D, *et al.* Global Positioning System Analysis of Physical Demands in Small and Large-Sided Games with Floaters and Official Matches in the Process of Return to Play in High Level Soccer Players. Sensors (Basel) 2020;20:E6605.

31. Filetti C, Ruscello B, Ascenzi G, Di Mascio M, D'ottavio S. Physical performance metrics in elite soccer: do power and acceleration metrics provide insight into positional demands and match-related fatigue in the 4-3-3 system? J Sports Med Phys Fitness 2019;59:1640–50.

32. Gonçalves L, Clemente FM, Barrera JI, Sarmento H, González-Fernández FT, Rico-González M, *et al.* Exploring the Determinants of Repeated-Sprint Ability in Adult Women Soccer Players. Int J Environ Res Public Health 2021;18:4595.

33. Ruscello B, Esposito M, Fusco C, Ceccarelli C, Pomponi S, Filetti C, *et al.* Acute effects of two different initial heart rates on testing the repeated sprint ability in elite women soccer players. J Sports Med Phys Fitness 2020;60:527–35.

34. Annino G, *et al.* Acute effects of whole-body vibrations on the fatigue induced by multiple repeated sprint ability test in soccer players. J Sports Med Phys Fitness 2022;62:788–94.

35. Teixeira JE, Forte P, Ferraz R, Leal M, Ribeiro J, Silva AJ, *et al.* Monitoring Accumulated Training and Match Load in Football: A Systematic Review. Int J Environ Res Public Health 2021;18:3906.

36. Panduro J, *et al.* Physical performance and loading for six playing positions in elite female football: full-game, end-game, and peak periods. Scand J Med Sci Sports 2021.

37. Jagim AR, Murphy J, Schaefer AQ, Askow AT, Luedke JA, Erickson JL, *et al.* Match Demands of Women's Collegiate Soccer. Sports (Basel) 2020;8:E87.

38. Póvoas S, Krustrup P, Castagna C. Estimation of maximal heart rate in recreational football: a field study. Eur J Appl Physiol 2020;120:925–33.

39. Paulsen KM, Butts CL, McDermott BP. Observation of Women Soccer Players' Physiology During a Single Season. J Strength Cond Res 2018;32:1702–7.

40. McLaren SJ, Macpherson TW, Coutts AJ, Hurst C, Spears IR, Weston M. The Relationships Between Internal and External Measures of Training Load and Intensity in Team Sports: A Meta-Analysis. Sports Med 2018;48:641–58.

41. Ruscello B, *et al.* Exercise to rest ratios in RSA training in women's soccer. J Sports Med Phys Fitness 2017.

42. da Silva JF, Guglielmo LG, Bishop D. Relationship between different measures of aerobic fitness and repeated-sprint ability in elite soccer players. J Strength Cond Res 2010;24:2115–21.

43. Ferrari Bravo D, Impellizzeri FM, Rampinini E, Castagna C, Bishop D, Wisloff U. Sprint vs. interval training in football. Int J Sports Med 2008;29:668–74.

44. Dellal A, Hill-Haas S, Lago-Penas C, Chamari K. Small-sided games in soccer: amateur vs. professional players' physiological responses, physical, and technical activities. J Strength Cond Res 2011;25:2371–81.

45. Owen AL, Wong P, McKenna M, Dellal A. Heart rate responses and technical comparison between small- vs. large-sided games in elite professional soccer. J Strength Cond Res 2011;25:2104–10.

46. Charron J, Garcia JE, Roy P, Ferland PM, Comtois AS. Physiological Responses to Repeated Running Sprint Ability Tests: A Systematic Review. Int J Exerc Sci 2020;13:1190–205.

47. Iaia FM, Rampinini E, Bangsbo J. High-intensity training in football. Int J Sports Physiol Perform 2009;4:291–306.

48. Mendez-Villanueva A, Hamer P, Bishop D. Physical fitness and performance. Fatigue responses during repeated sprints matched for initial mechanical output. Med Sci Sports Exerc 2007;39:2219–25.

49. Dawson B, Goodman C, Lawrence S, Preen D, Polglaze T, Fitzsimons M, *et al.* Muscle phosphocreatine repletion following single and repeated short sprint efforts. Scand J Med Sci Sports 1997;7:206–13.

50. Haseler LJ, Hogan MC, Richardson RS. Skeletal muscle phosphocreatine recovery in exercise-trained humans is dependent on O2 availability. J Appl Physiol 1999;86:2013–8.

51. Rampinini E, Sassi A, Morelli A, Mazzoni S, Fanchini M, Coutts AJ. Repeated-sprint ability in professional and amateur soccer players. Appl Physiol Nutr Metab 2009;34:1048–54.

52. Buchheit M, Ufland P. Effect of endurance training on performance and muscle reoxygenation rate during repeated-sprint running. Eur J Appl Physiol 2011;111:293–301.

53. Bishop D, Edge J, Goodman C. Muscle buffer capacity and aerobic fitness are associated with repeated-sprint ability in women. Eur J Appl Physiol 2004;92:540–7.

54. Tomlin DL, Wenger HA. The relationships between aerobic fitness, power maintenance and oxygen consumption during intense intermittent exercise. J Sci Med Sport 2002;5:194–203.

55. Bishop D, Edge J. Determinants of repeated-sprint ability in females matched for single-sprint performance. Eur J Appl Physiol 2006;97:373–9.

56. Makaje N, Ruangthai R, Arkarapanthu A, Yoopat P. Physiological demands and activity profiles during futsal match play according to competitive level. J Sports Med Phys Fitness 2012;52:366–74.

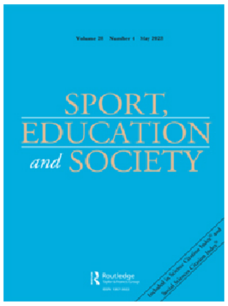
57. Archiza B, Andaku DK, Beltrame T, Libardi CA, Borghi-Silva A. The Relationship Between Repeated-Sprint Ability, Aerobic Capacity, and Oxygen Uptake Recovery Kinetics in Female Soccer Athletes. J Hum Kinet 2020;75:115–26.

Conflicts of interest.—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions.—Bruno Ruscello, Laura Pantanella, Pietro Iemme, Marco Porta, Stefano d'Ottavio, Lorenzo Marcelli, Gennaro Apollaro, Gabriele Morganti, Alberto Grossi, Mario Esposito, Elvira Padua have given substantial contributions to the conception or the design of the manuscript to acquisition, analysis and interpretation of the data. All authors have participated to drafting the manuscript revised it critically. All authors read and approved the final version of the manuscript.

Acknowledgements.—The authors wish to thank for their precious help all the players participating to the study.

History.—Article first published online: July 11, 2022. - Manuscript accepted: July 1, 2022. - Manuscript revised: June 15, 2022. - Manuscript received: January 18, 2022.



Sport, Education and Society

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/cses20

(Beyond) the field of play: contrasting deterministic and probabilistic approaches to talent identification and development systems

Gabriele Morganti, Alexandra Lascu, Gennaro Apollaro, Laura Pantanella, Mario Esposito, Alberto Grossi & Bruno Ruscello

SPORT, EDUCATION AND SOCIETY
https://doi.org/10.1080/13573322.2023.2212689

Routledge
Taylor & Francis Group

Check for updates

RESEARCH ARTICLE

(Beyond) the field of play: contrasting deterministic and probabilistic approaches to talent identification and development systems

Gabriele Morganti [a], Alexandra Lascu [b], Gennaro Apollaro [a], Laura Pantanella[a], Mario Esposito[a], Alberto Grossi[a] and Bruno Ruscello [a,c,d,e]

[a]National Talent Observatory, School of Sports and Exercise Sciences, Faculty of Medicine and Surgery, "Tor Vergata" University, Rome, Italy; [b]Faculty of Health, Research Institute of Sport and Exercise, University of Canberra, Canberra, Australia; [c]Department of Human Sciences and Promotion of the Quality of Life, San Raffaele Roma Open University, Rome, Italy; [d]Department of Industrial Engineering, Faculty of Engineering, "Tor Vergata" University, Rome, Italy; [e]LUISS SportLab, LUISS University, Rome, Italy

Talent identification and development systems (TIDS) adopt a deterministic perspective (i.e. athletes' future state/performances can be predicted by observations of their initial state/performance), which encourages early identification and specialisation in sport. In this framework, the main aim of sport systems is to enhance predictability and reduce uncertainty, by investigating the causal relationship between entering a talent pathway and becoming an expert performer. Generally, athletes who display ideal body proportions and attain certain performance standards in early developmental stages are labelled as talented (i.e. they display the potential to succeed) and are selected by TIDS, which afford them a superior developmental opportunity (i.e. better training facilities, certified coaching staff, and higher competition levels), to realise their potential. A deterministic approach, thus, (a) sees talent as a fixed capacity, whereby future successful athletes can be identified early (i.e. early identification); and (b) considers entering at an earlier age in a talent pathway a pre-requisite for sporting success (i.e. early specialisation). Contrary to deterministic expectations, recent research has highlighted how being considered talented from the early stages does not guarantee a better likelihood of successfully achieve senior sporting success. In this paper, taking ideas from ecological anthropology, a new probabilistic approach is proposed which considers TIDS as a process (i.e. being talented is about remaining responsive to what you *could become*), dialogical (i.e. athlete selection and development are not done in isolation, but both influenced by sociocultural constraints), and open-ended (i.e. unpredictability related to future outcomes). If sport systems embrace the uncertainty of developmental pathways and join with the conversation across and within TIDS to support systemic change. We conclude by proposing four key foundations of any probabilistic TIDS: give sport back to kids, ethos of amateurism, delaying selection processes, and early diversification.

ARTICLE HISTORY
Received 13 December 2022
Accepted 6 May 2023

KEYWORDS
Talent; early specialisation; early identification; youth sport; athlete development

CONTACT Gabriele Morganti gabriele.morganti@libero.it National Talent Observatory, School of Sports and Exercise Sciences, Faculty of Medicine and Surgery, "Tor Vergata" University, Rome, Italy

The term talent has different meanings. It can be used to describe the athletes' biological predispositions, the athletes' quality being developed and the athletes themselves (Till & Baker, 2020). Commonly talent has been defined as: 'a set of characteristics, skill sets and abilities that are developed on the basis of innate potential and many years of practice, competition and interaction with the surrounding environment' (Henriksen, 2008; cited in Aggerholm, 2015, p. 24). By considering talent through this definition, many sport systems are focused on the identification and selection of athletes early in the developmental stage (Baker et al., 2018). They search for participants who display similar physical prowess and technical competencies to those of an elite athlete, to provide them with the greatest possible developmental opportunities (Rothwell et al., 2020). When sport systems claim to identify talented athletes as young as nine years of age, they are reinforcing the notion of talent as a fixed capacity that can be identified early in the developmental stages and does not change over time (Baker et al., 2018). Thus, the system's decision-making is guided by determinacy, assuming that a system's future state (i.e. athletes' future level of ability) can be definitively predicted from observations of initial states (i.e. athletes' early level of ability; Araujo & Davids, 2011).

In a deterministic world, a major aim is to enhance predictability and reduce uncertainty through establishing the causal relationship formed by related phenomena (i.e. early ability and achievement of expertise; Araujo & Davids, 2011). As an example, in a sporting context, the equation is as follows: high early performance standard to enter the talent development pathway in the first developmental stage, plus the accumulation of practice hours and experiences equals future positive career attainment (Larkin & O'Connor, 2017; Wrigley et al., 2014). Consequently, deterministic approaches to talent identification (TI) and development (TD) place an overemphasis on the early identification and specialisation of a talented child (Rothwell et al., 2020); promoting a highly selective process which inducts children as young as five years of age into intensive sporting environments to provide the purposeful and dedicated training needed to become elite athletes (Baker et al., 2009; Martindale et al., 2005).

Researchers have regularly been divided on the notion of talent as an innate characteristic, and whether exceptional competencies are the result of biological and genetic factors (i.e. Nature), or of the environment (i.e. Nurture; Davids & Baker, 2007). Historically, the two factions (i.e. Nature and Nurture) have been two opposing views, and generally advocates for one side of the debate give little credit to the merits of opposing arguments (Ward et al., 2017). Although divided, the two factions have both favoured discourses on early identification and specialisation: (a) from the Nature perspective, the assumption is that talented athletes are the ones who display physical prowess and technical competencies that resemble those of elite athletes (Rothwell et al., 2020), and thus can be identified early, and trained in order to fulfil their potential; and (b) from the Nurture perspective, the assumption is that time spent on deliberate practice is what makes talented athletes, and therefore a great amount of training is conductive to becoming an expert performers (i.e. early identification and specialisation; Ericsson et al., 1993). The Nature-Nurture factions can indeed be considered complementary, both founded on deterministic discourse in which early identification and specialisation are simultaneously encouraged.

A deterministic approach to talent identification and development systems (TIDS) assumes life is a passive process, whereby future form can be predicted by observations of the present form, and life itself is the mere realization of what the future has in store: the realization of pre-specified forms (Ingold, 2000). In a sporting context, young athletes who possess predisposed superior technical, physical, and/or tactical qualities than their peers show the potential to succeed. Sport systems thus guarantee them all the necessities (i.e. facilities, certified coaching staff, and higher competition levels) to realise their potential (i.e. a pre-specified form). As such, TIDS appears an easy task: athletes who show the greatest potential are selected for development and the rest are de-selected (Baker et al., 2018). But contrary to expectations, research in this area highlights how despite the enormous amount of money, time, and effort involved, the evaluation of potential is quite poor and unreliable (Koz et al., 2012). Therefore, we should ask ourselves whether young athletes' current performances can truly inform us about their future performances (i.e. potential); and then, whether early identification and specialisation are sufficient to realise an athletes' pre-determined patterns.

Sport systems adopting a deterministic approach to TIDS act on a fear of uncertainty (Reed, 1993), not recognising that athlete development follows a non-linear path and that different individuals present different learning profiles and curves (Liu et al., 2006). This approach assumes a reductionist perspective which does not recognise that athlete development happens in a larger sociocultural context (e.g. O'Sullivan et al., 2021a; 2021b; Vaughan et al., 2021). For instance, early developmental experiences are known to contribute to early skill development (Lascu et al., 2020), but importantly not everyone is raised in a community which encourages sporting activities (i.e. presence and proximity to green areas, open spaces, clubs, and/or sport organisations). Consequently, youth sports performance is dependent on longer developmental advantages, which could also be exacerbated by the presence of birth advantages (Finnegan et al., 2017). Moreover, growth processes are purely unique. The physical and physiological effects of puberty occur at different rates across different individuals, and this can have a key impact on young athletes' performance levels (Hill et al., 2021) and trainability (McBurnie et al., 2021). As such, analysing early performance standards appears quite unreliable to gain knowledge about athletes' future performance.

In this opinion paper, first, the deterministic approach to talent identification and selection is presented. It will be highlighted that athletes involved in youth sports do not navigate between fixed points (Woods et al., 2020), meaning that their journey does not guarantee a certain destination (i.e. being a top performer at a young age does not indicate the certainty of being a future senior top performer and/or accumulated hours of practice does not guarantee the development of expertise). Then, by joining with the conversations of both the ecological anthropologist Tim Ingold, and the seminal works of sports science researcher Carl T. Woods, a probabilistic approach to TIDS is proposed which embraces the human-environment relationship as mutual, ever in-becoming, and time dependant. TIDS will be considered as process (i.e. being a talent is about developing to become who you can be, and who you are not yet), dialogical (i.e. athlete selection and development are not done in isolation, but both influenced by sociocultural constraints), and open-ended (i.e. uncertainty and unpredictability related to future outcomes). This paper aims to explore and expand the existing literature regarding TIDS, in search of new ways of approaching TI and TD.

Talent identification and development systems

TI processes are defined as 'recognising players participating in the sport who have the potential to excel' (Williams et al., 2020, p. 1). Entering the talent pathway at a young age is considered a prerequisite for sporting success as sport organisations provide selected athletes with additional and advanced learning environments (e.g. coaches, training facilities, and higher competition level), maximising their opportunity to fulfil their potential (Ibàñez et al., 2018). TD is indeed defined as a 'relatively systematic combination of coaching, support, training, and match play designed to progress players' (Williams et al., 2020, p. 1). Bailey and Collins (2013) proposed the Standard Model of Talent Development (SMTD) to summarise a common set of assumptions and characteristics the majority of sports organisations share in terms of athlete selection and development. The SMTD is a pyramidical system based on a logic of progression, starting from a broad base of foundational skills participation, to an increasingly higher levels of performance (i.e. next developmental stages), which engages fewer and fewer people (i.e. removal of large numbers of athletes from the system), aiming to develop the few athletes that will eventually reach the top of the pyramid.

Critically, this focus on eventual performance has been often confused with the concept of achievement now (Collins et al., 2019). Selections for talent pathways are indeed made on young athletes' current performance level, early ability, and/or on displaying the 'ideal' body proportions (Bailey & Collins, 2013). These parameters are considered indicators for future sporting success (Baker et al., 2018), but could be misleading. Performance levels and early ability are the results of developmental advantages, consequential of one or more (de)selection decisions, and possibly exacerbated by birth advantages and biological maturation (Barraclough et al., 2022).

On determinism

The SMTD presented in the previous section of the paper is based on a deterministic world view. Determinism, being founded on a fully predictable world view (Glimcher, 2005), assumes that given the way things are at present, considering that causes lead inevitably to their consequences, there is only one possible way for the future to turn out (e.g. Baumeister et al., in press; Loewer, 2013; Müller & Placek, 2018). In other words, sports organisations first pretend to gain *knowledge about* the future (i.e. athletes future career outcomes) by analysing and making sense of young athletes' current performance level (early identification), and then by developing the causal relationships between environment, organism, and response (i.e. accumulated hours of practice), reduce the *uncertainty* of future performance by providing developmental support for selected athletes (early specialisation). Accordingly, research has examined the multiple factors associated with successful development (e.g. Ericsson et al., 1993; Phillips et al., 2010); and psychological constructs and/or taxonomies of characteristics needed for elite sport success have been recently explored (Collins et al., 2019).

Deterministic perspective on TIDS

Sport systems, by deciding who enters talent pathways, act as talent selectors and their primary interest is the organisational purpose (i.e. producing top performers capable of winning titles for their clubs and/or nation; John & Thiel, 2022). Young athletes are seen as a form of capital which should benefit both the results and economies of their sporting clubs (Ojala, 2021) and selected athletes are considered a form of investment, which sport organisations cannot afford to get wrong as they have an impact on their measures of success and financial status. Sport systems adopting a deterministic approach to TIDS act on a fear of uncertainty. In an attempt to develop *certainty* and *knowledge* (i.e. enhance the predictability of their investments; Araujo & Davids, 2011), they (a) see talent as a fixed capacity, reflected in performance at some specific time point during development (Bailey & Collins, 2013; Baker et al., 2018), whereby future greatest performers can be identified early in the first developmental stages (i.e. Nature); and (b) consider entering at a very young age in talent pathways the pre-requisite for elite sport success (i.e. Nurture), assuming the development of expertise has to do with the accumulated volume of practice (Seifert et al., 2019).

The purely deterministic notion that given the present, there is only one way for the future to turn out (Müller & Placek, 2018) assumes (a) life is reactive, as nothing more than a programme of construction, under given environmental circumstances (Ingold, 2000) and (b) athletes are passive agents/products, resultant of a pre-determined route (Woods, 2021). The deterministic approach to TIDS considers talent as a capacity individuals have, observable and present a priori (Olesen et al., 2020). Whereby as soon as young athletes prove themselves as the best of their age groups, sports organisations will attempt to guarantee them optimal learning environments to best realise their pre-specified form (i.e. their potential derived from observation of early performances; Ingold, 2000).

Limitations of a deterministic TIDS

Gaining *knowledge about* the future by observing and analysing current performance level (i.e. early identification), and *reduce the uncertainty* of the future by meaning of early specialisation (i.e. the required steps to achieve senior sport success), may not be enough to augment the predictability of future performance levels. Research has shown how results obtained at the first developmental stages do not predict success at adult age (Barth et al., 2022; Brustio et al., 2021; Mostaert et al., 2022); and how early recruitment correlates negatively with senior world-class performance (Güllich et al., 2022).

Moreover, overemphasising early identification and specialisation causes the marginalisation, exclusion, and consequent drop-out from sports by athletes who do not display the required traits to fit into sport organisations (e.g. Bailey & Collins, 2013; Gatouillat et al., 2020; Uehara et al., 2018). Drop-out from sports is often followed by psychological, social, and emotional problems, thus it negatively impacts de-selected athletes' mental health (Vella et al., 2015).

The focus on higher performance standards undermines selected young athletes' development as well. O'Sullivan and colleagues (2021b) distinguished that when head coaches in football are asked to produce winning age-group teams, they adopt a teacher-centred approach to produce knowledge about the game (i.e. in-game decisions, principles of performance, and instructions) that must be internalised by the players, requiring them to do what they are told to, negatively impacting their decision-making. If youth players become reliant upon such pre-determined decisions to make, they eventually develop unskilled intentionality, being able to coordinate only with a narrow range of affordances (i.e. opportunities for action; O'Sullivan et al., 2021b; Vaughan et al., 2021).

Beyond the field of play

The impact of a deterministic approach to TIDS extends beyond the pages of this literature review. While it is important to understand the components of this framework, the impact that it has on youth athletes cannot be overlooked. To ground the research presented above, and the alternative perspective presented below, I (as the second author) believe a narrative perspective is needed here. The narrative that follows is based on my experiential knowledge as a coach and skill acquisition specialist. My career has been one of swimming against the deterministic tide, which has had significant implications for my practice and the learners I interact with. Furthermore, this narrative serves to express why sport science may *almost* be ready to adopt an alternative TIDS framework from an applied perspective.

I have seen a TIDS system at its best, and at its worst as a coach. While my practice intentionally counteracts an overemphasis on early success and specialisation, the negative impacts of de-selection and omission from talent programs is something I cannot design against as just one coach. I may be able to create an athlete-centred learning environment, one that explicitly values their voice and needs, but this does not permeate beyond the two afternoons they spend training with me each week. It takes a considerable amount of rapport before my questions and any attempt of co-designing training with the learners yields anything other than what they think *I* want to hear. When they explore beyond my field of play, either through selection into a talent program or (hopefully) sampling other sports, there is no guarantee that this autonomous, supportive experience prevails. In other words, *there is little value in being an innovative coach within a dysfunctional system*.

Being thrust back into a world of determinism after experiencing an alternative approach to TIDS can make for a difficult adjustment period as an athlete. Each unique sport, and each level of that sport, may subscribe to determinism at varying degrees. Any dissonance between sporting experiences becomes increasingly burdensome as learners face mixed messages about their worth, their 'potential', and their future in the sport. If their autonomy, curiosity, and exploration are reinforced in my coaching interactions but criticised in another context, or replaced by prescribed ways of doing and being, then this dissonance becomes difficult to bear.

It is worth stressing here that the negative outcomes of this dissonance can be severe: I once requested assistance for an athlete who was considered a suicide risk. At a selection trial for a junior talent pathway team, they were unsuccessful in being selected and genuinely believed that this was their last opportunity to pursue a career in sport. Their identity and self-worth were deeply entangled with their experience of being omitted from the talent pathway, reinforced by the dissonance of being autonomously supported in one context and disregarded in the next. Adolescents are acutely aware that delayed entry into talent pathways is not possible due to pervasive determinism; a realisation that has traumatised young people and their relationship with sport and physical activity.

It may be tempting to suggest here that coach education and development should therefore be the focus of future research, but this too is a reductionist approach. Instead, as Woods and colleagues (2022) eloquently suggest, we need to *join with the conversation* across and within TIDS. It may be worth paying particular attention to the coach experience, and how their evolution and shift in pedagogy occurs at both an individual and systemic level so they can be better supported. The organisational perspective should not be overlooked as well, given in many sports settings it is their values and game models that underpin coaching approaches. And finally, it is worth emphasising that neither of these perspectives exist in isolation. The entangled nature of coaching within an organisation that exists within a TIDS for one particular sport can seem difficult to capture, but this is only one aspect, one season of the athlete experience. If our mandate is to objectify, categorise, and know **about** TIDS, we risk closing ourselves off from the conversation. Instead, the aim of future research should be that of sustainability: '*to be response-able to the experiences of others so that, together, we can find reliable and longstanding ways of carrying on*' (Woods et al., 2022, p. 3; emphasis in original).

An alternative perspective on TIDS is therefore needed, one which provides opportunities to engage in conversations and be response-able to the athlete-learners within the TID system, with the aim of reducing the negative impact traditional TID practices have on young athletes.

Probabilistic perspective on talent identification and development systems

First, every correspondence is a *process*: it carries on. Secondly, correspondence is *open-ended*: it aims for no fixed destination or final conclusion, for everything that may be said or done invites a follow-on. Thirdly, correspondences are *dialogical*. They are not solitary but go on between and among participants (Ingold, 2000, p. 12; emphasis in original).

This epigraph embodies the salient features of a probabilistic TIDS. First, *every TIDS is a process*, in that the very notion of talent itself implies the transition from an athlete with the potential to succeed, to a successful senior athlete. Second, *every TIDS is open-ended*, in that they are characterised by a high-level of uncertainty and unpredictability related to future outcomes (Phillips et al., 2010). Third, *every TIDS is dialogical*, in that athlete selection and development are not done in isolation but are both influenced by different sociocultural constraints (O'Sullivan et al., 2021a, 2021b; Uehara et al., 2018; Vaughan et al., 2021).

Temporality: every TIDS is a process

Time from a chronological perspective consists of any regular system of dates and intervals in which events take place. From this point of view, time and history appear independent of one another, and the present is considered as ' … marked off from a past that it has replaced or a future that will, in turn, replace it' (Ingold, 1993, p. 159). Alternatively, the passage of time can also be seen as *temporality*, in which time appears immanent to the passage of events rather than transcendent them. The concept of temporality is not chronology and is not opposed to history, but rather temporality merges with history. It gathers the past and future into itself together, encompassing a pattern of retention from the past and pretension for the future (Ingold, 1993).

In the talent sphere, the idea of temporality has been presented by Aggerholm (2015), who described the expressions *to have talent* and *to be talent*. Generally, talent is considered something individuals *have*. It could be a property, an inner quality, and/or an ability for a particular performance, meaning young athletes who *have talent* are the ones able to perform at a higher level than their peers. Accordingly, the expression *to have talent* describes the relation between past experiences (e.g. accumulated hours of training) and present state (e.g. current level of performance; Aggerholm, 2015), and thus does not appear related to future outcomes. In terms of temporality, this means that *to have talent* encompasses a pattern of retention from the past, and it clearly omits the other half of the story: the pretension for the future. TIDS aim to predict the future and are constantly projected towards a finality (i.e. develop the athlete who will be able to reach the highest level of performance). Talent selectors are required to identify athletes who can eventually make it to the top of the pyramid, but analysing early ability and/or performance standards can only give an indication about the athletes who have or do not have talent, not about the ones with the potential to succeed: 'in testing procedures we evaluate that which exists in actuality, not in possibility' (Heilbrun, 1966; cited in Régnier et al., 1993, p. 290).

For talent in sporting contexts, the pretension for the future is exemplified by the expression *to be talent*, which describes a relation between the present (i.e. current level of performance) and the future (i.e. the athletes' potential; Aggerholm, 2015). *Being a talent* is defined towards an end goal: athletes are talented when they are considered able to eventually achieve the top of the pyramid. But as presented by Aggerholm (2015), they have not yet realised their potential, they are in a not-yet-condition. In other words, they are in-becoming (Woods, 2021). Indeed, *being a talent* is about developing to become who you can be, and who you are not yet: an elite athlete. From these considerations, athletes are not 'objects', intended as fixed states, known about by means of observation; they are rather an on-going and dynamic 'thing', who comes into being through movement (e.g. Heidegger, 1971; Ingold, 1993). Based on Ingold (2015), our world is stretched somewhere between the happened and the not yet. Athletes involved in a talent pathway are stretched between their actual performance (i.e. the happened), and their future potential (i.e. the not yet). Hegel in his 'Encyclopaedia of Philosophical Sciences' (1817/2010) differentiated between existence, which he considered as the immediate, and essence, intended as something else, hidden by curtains behind the immediate. By adapting Hegel's distinction between existence and essence to talent in sport, we can consider performance as existence (i.e. what exists here and now, the happened, the immediate) and potential as essence (i.e. what has yet to come into being, hidden by curtains behind the immediate). Consequently, potential means something that does not exist yet, as it exists only in possibility, and not in actuality (Olesen et al., 2020; Régnier et al., 1993). When defining human potential as something which exists only in possibility, there will always be a dimension of *uncertainty* (Aggerholm, 2015).

Talent selectors are trained to attune to specific young athletes' characteristics, which may be signs of future expertise, but it is in the practical act of doing (i.e. playing a certain sport), through the passage of time, and constantly relating with other figures, that the athletes come into being (i.e. a process). As such, one can get to know young athletes' true potential only when it is eventually fulfilled. Thus, the talent selector living in a world stretched between the happened and the not yet ' … must wait for signs that reveal the path ahead, with *no surety* of where it will lead … ' (Ingold, 2015, p. 138, emphasis added). Current performance values need to be considered only as tendencies, which describe a condition of *having talent*, and that may or may not eventually correlate with future performance. They do not encompass the *being a talent*, the potential (Ribeiro et al., 2021).

Interdependences of human life: every TIDS is dialogical

In contrast to a reductionist approach, athletes are embedded in a deep socio-cultural-historical context (e.g. O'Sullivan et al., 2021a; Rothwell et al., 2019, 2020; Uehara et al., 2018; Vaughan et al., 2021), whereby both their current performance (Bailey & Collins, 2013), and development (O'Sullivan et al., 2021b), are not just a mere result of accumulated hours of practice. Perturbations from the social environment, such as coaches' interventions and/or training practices, can precede changes in athletes' behaviour but these perturbations do not have a direct input-output relationship (John & Thiel, 2022). Context and history, athletes' past and anticipated future, contribute all together to the emergence of every act and moment (John & Thiel, 2022; Thelen, 2005).

The form of life concept describes everyday practices of groups and/or organisation and captures how the expression of values, traditions, customs, and even behaviours are shaped by wider social, cultural, and historical constraints which all have an impact on motor learning (Rothwell et al., 2019, 2020). In line with these, O'Sullivan et al. (2021a) used Bronfenbrenner's bioecological model (2004) to explore the *dialogical* part of every TIDS. They highlighted how current performance and development are dependent on and resultant of an entangled relationship between the 'microsystem – immediate environment' (e.g. structured and unstructured practice); the 'mesosystem – interconnection of family and peer settings' (e.g. parental influence and peer relations); the 'exosystem – formal and informal social structures' (e.g. neighbourhood community); and the 'macrosystem – cultural elements' (e.g. socioeconomic recourses and historical pillars).

Life is active: every TIDS is open-ended

The consequence of time dependant and dialogical human development is to consider life as active. This underpins the very process wherein forms are generated and held in place during the continuous interactions between the organism and his environment (Ingold, 2000). Organisms taken in any moment of their life-cycle are the product of a complex relation and connection between their genetic endowments (i.e. genotype), neurobiology, personality traits, psychological skills (Den Hartigh et al., 2016), and environmental factors. Therefore, every athlete arises as a unique centre of awareness and agency (Ingold, 2000), who is constantly in-becoming (i.e. under continuous construction and development), as a result of the multiple interactions which happen over time between their intrinsic dynamics and the outer world (i.e. dialogical process). Consequently, athletes: (a) cannot be captured in 'snapshots' (i.e. static moment throughout the course of the process of becoming; Szokolszky & Read, 2018) and (b) are governed by indeterminacy (i.e. the tendency for system outcomes to be difficult to predict from current system states; Araujo & Davids, 2011). In other words, while the present rises in meaning when put in relation to the past, and therefore current performance levels are explained by past developmental experiences and athletes' histories, future performance is in the process of ever-becoming, multidimensional, and asynchronous, making it difficult to predict from examination of current performance standard (i.e. open-ended).

The probabilistic perspective requires to overcome the fear of uncertainty, embracing the fact the only developable certainty is *uncertainty* (Woods, 2021). Being an elite player at a youth level is not the prelude of being an elite player at the adult level, as sport expertise can be achieved by a number of different developmental routes (i.e. *uncertainty of developmental pathways*; Abbott et al., 2005), and only few athletes are able to climb the entire talent development pyramid (Bailey & Collins, 2013). Moreover, if one can only be aware of *uncertainty*, then as a consequence, it is worthwhile to dwell in a profession of *not knowing* (Woods, 2021), whereby it is impossible to predict performance at the senior level (i.e. playing with the senior national team; future career outcome), by observations of the performance at the youth level (i.e. playing at an elite level when U15; initial career state); put differently sport systems cannot presume to have the ability to identify future elite athletes from analysis of their early performance (i.e. *profession of not knowing the future best performers in years*; Barth et al., 2022; Brustio et al., 2021; Dugdale et al., 2021; Güllich et al., 2022; Mostaert et al., 2022). Indeed, selection accuracy is extremely low (Güllich, 2014) and biased by a range of potential mechanisms (Johnston & Baker, 2020).

Based on these considerations, TIDS are considered as an *open-ended dialogical process*, in which talent does not appear as something individuals inherently possess or not. Indeed, a probabilistic TIDS is in line with Olesen and colleagues' (2020) conceptualization and consider talent an *assemblage*, dependent on and consisting of the multiple intertwined relationships between the athlete and other human (e.g. coaches, peers, physiotherapist, psychologist, and nutritionist), and non-human actors (e.g. competitions' structures and equipment). A *talent assemblage* is only finished once the athlete achieves elite sport success (Aggerholm, 2015), so until then, the entire TIDS will be characterised by *uncertainty* and *a profession of not knowing* the real athlete's potential (Olesen et al., 2020).

Practical applications: corresponding with TID

There is an excerpt in Ingold's book 'Correspondences' (2020), that describes the grandmother's footsteps game in which the world creeps up on us, behind our back, and then freezes the instant we turn around to look. Hence, things appear already settled into the shapes and categories, as if they were statues and/or snapshots (i.e. objects), fixed and static waiting to be *known about* (Ingold, 2020; Woods & Davids, 2022). In a sporting context, this is reflected in recording data about young athletes' performance levels in a given moment, analysing their ability and their body proportions to decide whom, from a very young age possesses the attributes needed for the next stage of development. In contrast, a probabilistic approach to TIDS is an invitation to correspond with the athletes *in their becoming*, 'to go behind the scenes, to join with the creepers and to move along with them in real time' (Ingold, 2020, p. 8), so what were once only statues now come to life, being in a stance of becoming. The metaphor of the grandmother's footsteps game opens to a particular shift in methodology, one that encourages the passage from ontology, which is about what it takes for a thing to exist (i.e. the needed step for achievement of senior elite performance: early identification and early specialisation), to ontogeny, which is about how things are generated, their growth and formation (i.e. joining the athletes through their becoming; Ingold, 2020). Accordingly, probabilistic TIDS discourage early identification and specialisation policies that cause athletes to *prematurely stop their process of becoming* (i.e. de-selection decisions and/or unskilled intentionality), and are about observation and active participation, requiring spending time with athletes to *grow knowledge of their becoming* (Woods & Davids, 2022). In the current section, we present four key foundations of probabilistic TIDS (see Figure 1), which suggest possible ways of engaging with TIDS by contrasting the limitations of a deterministic approach.

The first key foundation of probabilistic TIDS requires sport organisations and systems to put a break to the endless quest of youth sport performance and proposes *to give sport back to kids.* In modern adult elite sport, seasonal and long-run successes teams cannot be attained by buying

talent identification and development systems

determinism	**probabilism**
Give sport back to the kids	
Endless quest for youth high performance. Seasonal, long-run team success. Professionalised reources and expectations.	Centre developmental needs of learners. Adapt elements of "backyard games" to bring autonomy, problem solving, agency and enjoyment.
Ethos of amateurism	
Imposed behaviours, patterns of play, pre-determined outcomes may lead to drop out. Impact judged by success of the few.	Prioritises experiential knowledge, exploration, collaboration, inclusion and humility. Assess sport organisation impact on the many.
Delaying selection processes	
Identify functional players based on early ability and/or performances. Influenced by birth/maturational advantages.	Give all youth access to optimal learning environments. Promote wellbeing and participation. Long-term performance and personal development.
Early diversification	
Focus on early specialisation. Does not predict adult success. Exclusion, marginalisation and drop out.	Diverse participation in sports has positive impact on motor skill and long-term development. Encourages continuous engagement in sport.

Figure 1. The four key foundations of Probabilistic TIDS.

expensive players. Professional sporting organisations must also think about potential future athletes (Ojala, 2021). Consequently, TID processes have become results-driven, a balance between short-term success and long-term development. Growing professionalisation of youth sport has also involved a significant investment of resources (e.g. financial, personnel, and time; Williams et al., 2020). This has caused: (a) augmented adult involvement in youth sport, whereby well-funded coaches, scouts, sports scientists, and administrators are employed to engage in the process of developing young athletes (Ford et al., 2020) and (b) augmented expectations on athletes to become adaptable, and ready to improve themselves (Gershon, 2018).

In contrast, probabilistic TIDS put youth athletes and their developmental needs at the centre of attention. Informally, an athlete-centred approach is often seen in backyard games (Devereux, 1976). In such games, kids learned to negotiate a whole series of problems for themselves, including: designing and revising game to maintain interest (i.e. the what, where, and how to play), applying rules (i.e. field limits; when it's foul? When a penalty shot is called?), and on field disposition (i.e. team roles). According to Devereux (1976), the problem solving often done by kids in such informal settings permitted the development of kids' important social skills, such as the individual and collective agency. Furthermore, backyard games permitted peer connections (e.g. Erikstad et al., 2021; O'Sullivan et al., 2021a) and allowed kids to experience the immediate gratification and enjoyment of playing sport (Côté & Abernethy, 2012). Thus, previously when kids arrived at the youth sport schools and/or clubs, they already had established an emotional bond with the sport in question (Machado et al., 2018). Now, much of the problem-solving and decision-making is done by adults (i.e. coaches and referees), interrupting the learning opportunities that young people would normally have in elementary sporting experiences. Therefore, adults should adapt key elements of backyard games into youth academies and sport training programmes (Machado, 2019), such as: different surfaces, conditions, contexts, high movement variability (i.e. explore a vast array of different tactical and motor problems solution), reduced coaches' intervention (i.e. reduced feedback and instruction), and emphasise the joy of playing the game (adapted from Araujo et al., 2010). Beyond the psychosocial benefits of enjoyment and autonomy, this approach will also help young athletes establish a functional relationship with their performance environment, which is a characteristic of expert performance. By educating their attention towards relevant environmental properties available, and without regular coach intervention, young athletes can explore what helps them perform goal-directed behaviours (i.e. skilled intentionality; Vaughan et al., 2021).

In line with this, probabilistic TIDS should aim to avoid professionalism in youth sport training academies, where individuals (i.e. coaches and athletes) are constantly evaluated based on objective performance measures, and ranked against competitors (Said, 1993). As presented by Rothwell and colleagues (2022), the professionalisation of talent development academies occurs in contrast with the love of playing the game. Imposing certain types of behaviours on athletes may undermine youth athletes' ability to explore the extent of their capabilities. If such imposed behaviours include the monotonous repetition of rigid and decided patterns practiced hard at training that need to be perfectly replicated during match-play for a pre-determined outcome, this can lead to dropping out of sport (e.g. O'Sullivan et al., 2021b; Rothwell et al., 2022). Consequently, *being guided by an ethos of amateurism* is the second key foundation of probabilistic TIDS. This would limit the imposition of pre-determined methodologies and routes to instead prioritise experiential knowledge, exploration, collaboration, inclusion, and humility. An ethos of amateurism pushes and challenges young athletes to search, develop, adapt, and self-regulate their skills (adapted from Rothwell et al., 2022). Moreover, an amateur does not work to produce, and it is not demand driven (Masschelein & Simons, 2013). Amateurism stems from the Latin derivative to love which evolved into doing something for the love rather than the money, and professionalism is often seen as the absence of amateurism. Whereas a deterministic framework is based on professionalisation and values sport organisations for their ability to produce a few athletes who eventually make it to the elite level, a probabilistic approach to TIDS would assess the impact sport organisations have on the *many*, as encouraged by Rongen et al. (2018).

Delaying selection processes is the third key foundation of probabilistic TIDS. This shift would discourage a functional perspective on TI (i.e. identify the most functional player of the team), based on early ability and/or early performance standards (Morganti et al., 2022). Instead, TIDS should emphasise the ongoing participation of children and adolescents in sports. Later selection polices are important to ensure that sport systems give every child the opportunity to develop in optimal learning environments and minimizing selection processes guided by any birth and/or maturational advantages. By disbanding early selection policies, sports organisations can build a player development framework that puts the needs of the athlete at the centre of attention, promoting well-being, and prolonged participation in sport (O'Sullivan et al., 2021b). A case-study conducted by Erikstad and colleagues (2021) on an age-restricted team from the Norwegian soccer club Bryne FC has demonstrated how delaying selection processes can promote long-term performance, participation, and personal development (Côté et al., 2014). Moreover, Bryne FC featured the motto 'as many as possible, for as long as possible', whereby skilled and less-skilled players played in the same team. Playing time was equally distributed and winning was not emphasised, which prevented lesser skilled players from being demotivated and dropping out from sport (i.e. social well-being and continued participation). Furthermore, the additional responsibility for more skilled players was considered a positive for their development (Erikstad et al., 2021). A shift from a functional perspective on TI to talent *development* instead (i.e. develop the next most functional player) aligns with a probabilistic approach to TIDS (Morganti et al., 2022).

The fourth key foundation of probabilistic TIDS is *early diversification* and requires sport organisations to follow recommendations suggested by the Developmental Model of Sport Participation (DMSP; Côté et al., 2007). The DMSP argues that athletes should not specialise in one sport and should not being intensively engaged in deliberate practice until late adolescence (Côté et al., 2007). Côté and colleagues introduced the concept of deliberate play in various sports: activities regulated by participants themselves, undertaken for the enjoyment of the game. Multisport deliberate play during childhood and early adolescence promotes future intrinsic motivation, prolonged engagement, and transfer of perceptual-motor skills and of physical conditioning across related sports (e.g. Côté et al., 2007; Murata et al., 2022).

If sporting systems are truly ready to address the significant health, wellbeing, and drop out issues currently plaguing youth sport, then considering the four key foundations of probabilistic TIDS may be one way towards reducing these issues. By supporting all youth athletes in their search for physical, psychological, technical, and tactical growth, we can avoid the need to (poorly) predict who the next elite athlete will be. A shift towards probabilistic TIDS may seem seismic now, but it is the next phase of evolution for sporting systems; a change that some organisations and coaches are already making but cannot effectively maintain without significant change.

Acknowledgements

GM and AL have given substantial contributions to the conception and design of the manuscript. GM and AL have participated to draft the manuscript. GM, AL, GA, and BR have revised it critically. All authors read and approved the final version of the article.

Disclosure statement

No potential conflict of interest was reported by the author.

ORCID

Gabriele Morganti http://orcid.org/0000-0001-9448-3872
Alexandra Lascu http://orcid.org/0000-0003-0336-4654
Gennaro Apollaro http://orcid.org/0000-0002-0427-037X
Bruno Ruscello http://orcid.org/0000-0002-5381-9146

References

Abbott, A., Button, C., Pepping, G. J., & Collins, D. (2005). Unnatural selection: Talent identification and development in sport. *Nonlinear Dynamics, Psychology, and Life Sciences*, *9*(1), 61–88.

Aggerholm, K. (2015). *Talent development, existential philosophy and sport: On becoming an elite athlete*. Routledge.

Araujo, D., & Davids, K. (2011). What exactly is acquired during skill acquisition? *Journal of Consciousness Studies*, *18*(3-4), 7–23.

Araujo, D., Fonseca, C., Davids, K., Garganta, J., Volossovitch, A., Brandão, R., & Krebs, R. (2010). The Role of Ecological Constraints on Expertise Development. *Talent Development & Excellence*, *2*(2), 165–179.

Bailey, R. P., & Collins, D. (2013). The standard model of talent development and Its discontents. *Kinesiology Review*, *2*(4), 248–259. https://doi.org/10.1123/krj.2.4.248

Baker, J., Cobley, S., & Fraser-Thomas, J. (2009). What do we know about early sport specialization? *Not Much! High Ability Studies*, *20*(1), 77–89. https://doi.org/10.1080/13598130902860507

Baker, J., Schorer, J., & Wattie, N. (2018). Compromising talent: Issues in identifying and selecting talent in sport. *Quest (grand Rapids, Mich)*, *70*(1), 48–63. https://doi.org/10.1080/00336297.2017.1333438

Barraclough, S., Till, K., Kerr, A., & Emmonds, S. (2022). Methodological approaches to talent identification in team sports: A narrative review. *Sports*, *10*(6), 81. https://doi.org/10.3390/sports10060081

Barth, M., Güllich, A., Macnamara, B. N., & Hambrick, D. Z. (2022). Predictors of junior versus senior elite performance are opposite: A systematic review and meta-analysis of participation patterns. *Sports Medicine*, https://doi.org/10.1007/s40279-021-01625-4. Advance online publication.

Baumeister, R. F., Clark, C. J., & Lau, S. (in press). Determinism. In V. Glavineau (Ed.), *The palgrave encyclopedia of possibility* (pp. 375–380). Palgrave.

Bronfenbrenner, U. (2004). Bioecological theory of human development. In U. Bronfenbrenner (Ed.), *Making human beings human: Bioecological perspectives on human development* (pp. 3–15). Sage.

Brustio, P. R., Cardinale, P., Lupo, C., Varalda, M., De Pasquale, P., & Boccia, G. (2021). Being a top swimmer during the early career is not a prerequisite for success: A study on sprinter strokes. *Journal of Science and Medicine in Sport*, *24*(12), 1272–1277. https://doi.org/10.1016/j.jsams.2021.05.015

Collins, D., MacNamara, A., & Cruickshank, A. (2019). Research and practice in talent identification and development—some thoughts on the state of play. *Journal of Applied Sport Psychology*, *31*(3), 340–351. https://doi.org/10.1080/10413200.2018.1475430

Côté, J., & Abernethy, B. (2012). A developmental approach to sport expertise. In S. M. Murphy (Ed.), *The Oxford handbook of sport and performance psychology* (pp. 435–447). Oxford University Press.

Côté, J., Baker, J., & Abernethy, B. (2007). Practice and play in the development of sport expertise. In R. Eklund, & G. Tenenbaum (Eds.), *Handbook of sport psychology* (pp. 184–202). Wiley.

Côté, J., Turnnidge, J., & Evans, M. B. (2014). The dynamic process of development through sport. *Kinesiologia Slovenica*, *20*(3), 14–26.

Davids, K., & Baker, J. (2007). Genes, environment and sport performance: Why the nature-nurture dualism is no longer relevant. *Sports Medicine*, *37*(11), 961–980. https://doi.org/10.2165/00007256-200737110-00004

Den Hartigh, R. J., Van Dijk, M. W., Steenbeek, H. W., & Van Geert, P. L. (2016). A dynamic network model to explain the development of excellent human performance. *Frontiers in Psychology*, *7*, 532. https://doi.org/10.3389/fpsyg.2016.00532

Devereux, E. (1976). Backyard v little league baseball: The impoverishment of children's games. In D. M. Landers (Ed.), *Social problems in athletics: Essays in the sociology of sport* (pp. 37–56). University of Illinois.

Dugdale, J. H., Sanders, D., Myers, T., Williams, A. M., & Hunter, A. M. (2021). Progression from youth to professional soccer: A longitudinal study of successful and unsuccessful academy graduates. *Scandinavian Journal of Medicine & Science in Sports*, *31*(1), 73–84. https://doi.org/10.1111/sms.13701

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, *100*(3), 363–406. https://doi.org/10.1037/0033-295X.100.3.363

Erikstad, M., Johansen, B., Johnsen, M., Haugen, T., & Côté, J. (2021). "As many as possible for as long as possible"-A case study of a soccer team that fosters multiple outcomes. *Sport Psychologist*. https://doi.org/10.1123/tsp.2020-0107

Finnegan, F., Richardson, D., Littlewood, M., & McArdle, J. (2017). The influence of date and place of birth on youth player selection to a national football association elite development programme. *Science and Medicine in Football*, *1*(1), 30–39. https://doi.org/10.1080/02640414.2016.1254807

Ford, P. R., Bordonau, J. L. P., Bonanno, D., Tavares, J., Groenendijk, C., Fink, C., Gualtieri, D., Gregson, W., Varley, M. C., Weston, M., Lolli, L., Platt, D., & Di Salvo, V. (2020). A survey of talent identification and development processes in the youth academies of professional soccer clubs from around the world. *Journal of Sports Sciences*, *38*(11-12), 1269–1278. https://doi.org/10.1080/02640414.2020.1752440

Gatouillat, C., Griffet, J., & Travert, M. (2020). Navigating the circles of social life: Understanding pathways to sport drop-out among French teenagers. *Sport, Education and Society*, *25*(6), 654–666. https://doi.org/10.1080/13573322.2019.1643300

Gershon, I. (2018). Employing the CEO of Me, Inc.: US corporate hiring in a neoliberal Age. *American Ethnologist*, *45*(2), 173–185. https://doi.org/10.1111/amet.12630

Glimcher, P. W. (2005). Indeterminacy of brain and behavior. *Annual Review of Psychology*, *56*(1), 25–56. https://doi.org/10.1146/annurev.psych.55.090902.141429

Güllich, A. (2014). Selection, de-selection and progression in German football talent promotion. *European Journal of Sport Science*, *14*(6), 530–537. https://doi.org/10.1080/17461391.2013.858371

Güllich, A., Macnamara, B. N., & Hambrick, D. Z. (2022). What makes a champion? Early multidisciplinary practice, Not early specialization, predicts world-class performance. *Perspectives on Psychological Science: A Journal of the Association for Psychological Science*, *17*(1), 6–29. https://doi.org/10.1177/1745691620974772

Hegel, G. W. F. (1817/2010). *Encyclopaedia of the Philosophical Sciences in Basic Outline: Part 1: Science of Logic*. In K. Brinkmann & D. O'Dahlstrom (Eds.). Cambridge University Press.

Heidegger, M. (1971). *Poetry, language, thought* (A. Hofstadter, Trans.). Harper and Row.

Heilbrun, A. B. (1966). Testing for potentialities. In H. A. Otto (Ed.), *Explorations in potentialities* (pp. 286–292). Thomas.

Henriksen, K. (2008). 'Fra talentspotting til talentudviklingsmiljøer. Paradigmer i arbejdet med talentudvikling.'. In K. Henriksen (Ed.), *Inspiration til talentudvikling – et psykologisk perspektiv* (pp. 21–49). Syddansk Universitetsforlag.

Hill, M., Scott, S., McGee, D., & Cumming, S. P. (2021). Are relative age and biological ages associated with coaches' evaluations of match performance in male academy soccer players? *International Journal of Sports Science & Coaching*, *16*(2), 227–235. https://doi.org/10.1177/1747954120966886

Ibàñez, S. J., Mazo, A., Nascimento, J., & Garcìa-Rubio, J. (2018). The relative Age effect in under-18 basketball: Effects on performance according to playing position. *PLoS ONE*, *13*(7), e0200408. https://doi.org/10.1371/journal.pone.0200408

Ingold, T. (1993). The temporality of the landscape. *World Archaeology*, *25*(2), 152–174. https://doi.org/10.1080/00438243.1993.9980235

Ingold, T. (2000). *The perception of the environment: Essays on livelihood, dwelling and skill*. Routledge.

Ingold, T. (2015). *The life of lines*. Routledge.

Ingold, T. (2020). *Correspondences*. John Wiley & Sons.

John, J. M., & Thiel, A. (2022). Talent as a social construction: Proposing a constructivist conceptualization of athletic talent. *Z Erziehungswiss*. https://doi.org/10.1007/s11618-022-01110-2

Johnston, K., & Baker, J. (2020). Waste reduction strategies: Factors affecting talent wastage and the efficacy of talent selection in sport. *Frontiers in Psychology*, *10*, 2925. https://doi.org/10.3389/fpsyg.2019.02925

Koz, D., Fraser-Thomas, J., & Baker, J. (2012). Accuracy of professional sports drafts in predicting career potential. *Scandinavian Journal of Medicine and Science in Sports*, *22*(4), e64–e69. https://doi.org/10.1111/j.1600-0838.2011.01408.x

Larkin, P., & O'Connor, D. (2017). Talent identification and recruitment in youth soccer: Recruiter's perceptions of the key attributes for player recruitment. *PLoS ONE*, *12*(4), e0175716. https://doi.org/10.1371/journal.pone.0175716

Lascu, A., Spratford, W., Pyne, D. B., & Extebarria, N. (2020). Practical application of ecological dynamics for talent development in cricket. *International Journal of Sports Science & Coaching*, *15*(2), 227–238. https://doi.org/10.1177/1747954120908816

Liu, Y. T., Mayer-Kress, G., & Newell, K. M. (2006). Qualitative and quantitative change in the dynamics of motor learning. *Journal of Experimental Psychology: Human Perception and Performance*, *32*(2), 380–393. https://doi.org/10.1037/0096-1523.32.2.380

Loewer, B. (2013). Determinism. In M. Curd, & S. Psillos (Eds.), *The routledge companion to philosophy of science* (2nd ed, pp. 371–380). Routledge.

Machado, J. C., Barreira, D., Galatti, L., Chow, J. Y., Garganta, J., & Scaglia, A. J. (2018). Enhancing learning in the context of Street football: a case for Nonlinear Pedagogy. *Physical Education and Sport Pedagogy*, *24*(2), 176–189. https://doi.org/10.1080/17408989.2018.1552674

Martindale, R. J., Collins, D., & Daubney, J. (2005). Talent development: A guide for practice and research within sport. *Quest (grand Rapids, Mich)*, *57*(4), 353–375. https://doi.org/10.1080/00336297.2005.10491862

Masschelein, J., & Simons, M. (2013). *In defence of the school: A public issue*. Leuven.

McBurnie, A. J., Dos'Santos, T., Johnson, D., & Leng, E. (2021). Training management of the elite adolescent soccer player throughout maturation. *Sports (Basel, Switzerland)*, *9*(12), 170. https://doi.org/10.3390/sports9120170

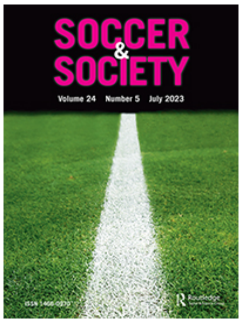
Morganti, G., Kelly, A. L., Apollaro, G., Pantanella, L., Esposito, M., Grossi, A., & Ruscello, B. (2022). Relative age effects and the youth-to-senior transition in Italian soccer: The underdog hypothesis versus knock-on effects of relative age. *Science & Medicine in Football*, 1–7. https://doi.org/10.1080/24733938.2022.2125170

Mostaert, M., Vansteenkiste, P., Pion, J., Deconinck, F. J. A., & Lenoir, M. (2022). The importance of performance in youth competitions as an indicator of future success in cycling. *European Journal of Sport Science*, *22*(4), 481–490. https://doi.org/10.1080/17461391.2021.1877359

Müller, T., & Placek, T. (2018). Defining determinism. *British Journal for the Philosophy of Science*, *69*(1), 215–252. https://doi.org/10.1093/bjps/axv049

Murata, A., Goldman, D. E., Martin, L. J., Turnnidge, J., Bruner, M. W., & Côté, J. (2022). Sampling between sports and athlete development: A scoping review. *International Journal of Sport and Exercise Psychology*, *20*(6), 1752–1776. https://doi.org/10.1080/1612197X.2021.1995021

Ojala, A. L. (2021). Nurturing and sidelining capitalism in discourses of player potentiality in Finnish ice hockey. *Sport in Society*, *24*(9), 1574–1589. https://doi.org/10.1080/17430437.2020.1763309
Olesen, J. S., Nielsen, J. C., & Søndergaard, D. M. (2020). Disassembling and reassembling a sports talent. *Culture Unbound: Journal of Current Cultural Research*, *12*(2), 311–331. https://doi.org/10.3384/cu.2000.1525.20200526a
O'Sullivan, M., Bespomoshchnov, V. A., & Mallett, C. J. (2021a). Pavel datsyuk: Learning, development, and becoming the "magic Man". *Case Studies in Sport and Exercise Psychology*, *5*(1), 173–183. https://doi.org/10.1123/cssep.2021-0022
O'Sullivan, M., Vaughan, J., Rumbold, J. L., & Davids, K. (2021b). The learning in development research framework for sports organizations. *Sport, Education and Society*. https://doi.org/10.1080/13573322.2021.1966618
Phillips, E., David, K., Renshaw, I., & Portus, M. (2010). Expert performance in sport and the dynamics of talent development. *Sports Medicine*, *40*(4), 271–283. https://doi.org/10.2165/11319430-000000000-00000
Reed, E. S. (1993). The intention to use a specific affordance: A framework for psychology. In R. Wozniak, & K. Fissher (Eds.), *Development in contest: Acting and thinking in specific environments* (pp. 45–76). Lawrence Erlbaum Associates.
Régnier, G., Salmela, J. H., & Russell, S. J. (1993). Talent detection and development in sport. In R. N. Singer, M. Murphey, & I. K. Tennant (Eds.), *Handbook of research in sport psychology* (pp. 290–313). Macmillan.
Ribeiro, J., Davids, K., Silva, P., Coutinho, P., Barreira, D., & Garganta, J. (2021). Talent development in sport requires athlete enrichment: Contemporary insights from a nonlinear pedagogy and the athletic skills model. *Sports Medicine*, *51*(6), 1115–1122. https://doi.org/10.1007/s40279-021-01437-6
Rongen, F., McKenna, J., Cobley, S., & Till, K. (2018). Are youth sport talent identification and development systems necessary and healthy? *Sports Medicine - Open*, *4*(1), 18. https://doi.org/10.1186/s40798-018-0135-2
Rothwell, M., Davids, K., & Stone, J. (2019). Exploring forms of life in player development pathways-the case of British rugby league. *Journal of Motor Learning and Development*, *7*(2), 242–260. https://doi.org/10.1123/jmld.2018-0020
Rothwell, M., Davids, K., Stone, J., Araujo, D., & Shuttleworth, R. (2020). The talent development process as enhancing athlete functionality: Creating forms of life in an ecological niche. In J. Baker, S. Cobley, & J. Schorer (Eds.), *Talent identification and development in sport. International perspectives* (2nd ed, pp. 34–49). Routledge.
Rothwell, M., Davids, K., Woods, C. T., Otte, F., Rudd, J., & Stone, J. A. (2022). Principles to guide talent development practices in sport: The exemplar case of British rugby league football. *Journal of Expertise*, *5*(1), 28–37.
Said, E. (1993). *Representations of the intellectual*. Vintage.
Seifert, L., Papet, V., Strafford, B. W., Coughlan, E., & Davids, K. (2019). Skill transfer, expertise and talent development: An ecological dynamics perspective. *Movement Sport Sciences/Science & Motricité*, *102*, 39–49. https://doi.org/10.1051/sm/2019010
Szokolszky, A., & Read, C. (2018). Developmental ecological psychology and a coalition of ecological–relational developmental approaches. *Ecological Psychology*, *30*(1), 6–38. https://doi.org/10.1080/10407413.2018.1410409
Thelen, E. (2005). Dynamic systems theory and the complexity of change. *Psychoanalytic Dialogues*, *15*(2), 255–283. https://doi.org/10.1080/10481881509348831
Till, K., & Baker, J. (2020). Challenges and [possible] solutions to optimizing talent identification and development in sport. *Frontiers in Psychology*, *11*, 664. https://doi.org/10.3389/fpsyg.2020.00664
Uehara, L., Button, C., Araújo, D., Renshaw, I., Davids, K., & Falcous, M. (2018). The role of informal, unstructured practice in developing football expertise: The case of Brazilian pelada. *Journal of Expertise*, *1*(3), 162–180.
Vaughan, J., Mallett, C. J., Potrac, P., López-Felip, M. A., & Davids, K. (2021). Football, culture, skill development and sport coaching: Extending ecological approaches in athlete development using the skilled intentionality framework. *Frontiers in Psychology*, *12*, 635420. https://doi.org/10.3389/fpsyg.2021.635420
Vella, S. A., Cliff, D. P., Magee, C. A., & Okely, A. D. (2015). Associations between sports participation and psychological difficulties during childhood: A two-year follow up. *Journal of Science and Medicine in Sport*, *18*(3), 304–309. https://doi.org/10.1016/j.jsams.2014.05.006
Ward, P., Belling, P., Petushek, E., & Ehrlinger, J. (2017). Does talent exist? A re-evaluation of the nature-nurture debate. In J. Baker, S. Cobley, J. Shorer, & N. Wattie (Eds.), *Routledge handbook of talent identification and development in sport* (1st ed, pp. 19–34). Routledge.
Williams, M. A., Ford, P. R., & Drust, B. (2020). Talent identification and development in soccer since the millennium. *Journal of Sports Sciences*, *38*(11-12), 1199–1210. https://doi.org/10.1080/02640414.2020.1766647
Woods, C. T. (2021). Toward ithaka: Hiking along paths of knowing of/in an ecologically dynamic world. *Sport, Education and Society*. https://doi.org/10.1080/13573322.2021.1994939
Woods, C. T., Araújo, D., & Davids, K. (2022). Joining with the conversation: Research as a sustainable practice in the sport sciences. *Sports Medicine - Open*, *8*(1), 102. https://doi.org/10.1186/s40798-022-00493-0
Woods, C. T., & Davids, K. (2022). Thinking through making and doing: Sport science as an art of inquiry. *Sport, Education and Society*. https://doi.org/10.1080/13573322.2022.2054792
Woods, C. T., Rudd, J., Robertson, S., & Davids, K. (2020). Wayfinding: How ecological perspectives of navigating dynamic environments Can enrich Our understanding of the learner and the learning process in sport. *Sports Medicine – Open*, *6*(1), 51. https://doi.org/10.1186/s40798-020-00280-9
Wrigley, R. D., Drust, B., Stratton, G., Atkinson, G., & Gregson, W. (2014). Long-term soccer-specific training enhances the rate of physical development of academy soccer players independent of maturation status. *International Journal of Sports Medicine*, *35*(13), 1090–1094. https://doi.org/10.1055/s-0034-1375616



Soccer & Society

Routledge
Taylor & Francis Group

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/fsas20

All roads lead to Rome? Exploring birthplace effects and the ‘southern question’ in Italian soccer

Gabriele Morganti, Adam L. Kelly, Gennaro Apollaro, Laura Pantanella, Mario Esposito, Alberto Grossi & Bruno Ruscello

To cite this article: Gabriele Morganti, Adam L. Kelly, Gennaro Apollaro, Laura Pantanella, Mario Esposito, Alberto Grossi & Bruno Ruscello (2023): All roads lead to Rome? Exploring birthplace effects and the ‘southern question’ in Italian soccer, Soccer & Society, DOI: 10.1080/14660970.2023.2226077

To link to this article: https://doi.org/10.1080/14660970.2023.2226077

Published online: 19 Jun 2023.

SOCCER & SOCIETY
https://doi.org/10.1080/14660970.2023.2226077

All roads lead to Rome? Exploring birthplace effects and the 'southern question' in Italian soccer

Gabriele Morganti[a], Adam L. Kelly[b], Gennaro Apollaro[a], Laura Pantanella[a], Mario Esposito[a], Alberto Grossi[a] and Bruno Ruscello[a,c,d,e]

[a]National Talent Observatory, School of Sports and Exercise Sciences, Faculty of Medicine and Surgery, "Tor Vergata" University, Rome, Italy; [b]Centre for Life and Sport Sciences (CLaSs), Faculty of Health, Education and Life Sciences, Birmingham City University, Birmingham, UK; [c]Department of Human Sciences and Promotion of the Quality of Life, San Raffaele Roma Open University, Rome, Italy; [d]Department of Industrial Engineering, Faculty of Engineering, "Tor Vergata" University, Rome, Italy; [e]LUISS SportLab, LUISS University, Rome, Italy

ABSTRACT

The expression "southern question" is used in reference to the poverty and economic underdevelopment, less advanced social relations, and clientelist style of politics that characterize South-Italy compared to North and Central Italy. This study aimed to investigate the presence of the "southern question" in Italian soccer. Accordingly, we examined the birthplace distribution of 2,012 Italian soccer players who have played in any national representative team (U15: $n = 466$; U16-U21: $n = 1,939$; Senior Team: $n = 217$). Chi-square analysis revealed an overrepresentation of players born in North and Central Italy, in all cohorts, compared to national norms (all P values < 0.0001). Odds ratios showed that players born in North and Central Italy had the greatest likelihood of representing Italy internationally at both youth and senior levels compared to players born in South Italy (ranging from 2 to 3.2). Factors that negatively impact upon South-Italy players' soccer developmental journey have been proposed and discussed.

Introduction

Since its unification in 1861, Italy has been characterized by a strong North-South divide.[1] Throughout the years, the southern region of Italy has generally been underdeveloped compared to the northern region, despite the large amount of attention that this part of Italy has received by academics, scientists, and politicians.[2] Dating back to 1861, Pasquale Villari, writing in the Milanese magazine *La Perseveranza* [Perseverance], proposed the expression "southern question". This referred to the banditry, the mafia, and the poverty of the southern citizens, which were typical aspects coupled with South Italy and indicates the possible historical manner of the social and political issues of this part of Italy.[3] Today, the expression "southern question" is still used in reference to the assortment of problems (e.g. weaker economic development, less advanced social relations, and lower key aspects of civil life) that characterize the southern part of Italy compared to the rest of the country.[4]

The discourse of the "southern question" contrasts the industrialized and civilized Northern territory, rational and orderly, to a backward South, mainly agricultural, poor, and underdeveloped from an economic perspective.[5] Typically, the expression "southern question" depicts the South as

CONTACT Gabriele Morganti gabriele.morganti@libero.it National Talent Observatory, School of Sport and Exercise Sciences, Faculty of Medicine and Surgery, "Tor Vergata" University, Rome, Italy

a weight that hinders the North, also describing the South as an internal "other" with respect to the rest of the country. These regional disparities were frequently object of national policies, which starting from the 1950s have been focussed on the industrial development of the South, particularly with the state-owned agency *Cassa per il Mezzogiorno* (Fund for the South). This was initially effective in tackling most of the dualisms present in the country, but progressively became an instrument of waste and money misallocation (i.e. poor investments and rampant corruption),[6] and ended up re-exacerbating the regional disparities that are often seen today.[7]

The territorial inequalities in Italy reveal a dualism [i.e. North vs. South] without equal in any Western countries, encompassing the entire gamut of civil and economic development indicators.[8] Gross Domestic Product (GDP) per head (i.e. a monetary measure to assess the economic output of a particular area per person) of a certain nation or region is considered a useful indicator to understand the level of development and prosperity of respective areas, as well as being correlated to the quality of infrastructures and of institutions, scientific endowments, and levels of education.[9] In 2018, Rosès and Wolf explored Western-Europe's economic development based on 173 regions, which revealed the five poorest (i.e. the ones that recorded the lowest level of GDP per head) were all concerningly from South Italy (i.e. Apulia, Basilicata, Calabria, Campania, and Sicily).[10] In line with this, Iammarino and colleagues outlined how South Italy recorded a much lower GDP per head when compared to the European and national averages.[11] Additionally, in 2010, the Italian National Institute of Statistics (ISTAT) launched the project "Benessere Equo e Sostenibile" (BES; Fair and Sustainable Wellbeing), with the aim of assessing the progress of society from an economic perspective as well as from a social and environmental outlook.[12] The data from the BES project are open access, released from ISTAT, and underscore the socioeconomic and cultural differences present between the North, Centre, and South of Italy. Some examples from the BES include: (a) employment rates (North = 72.9%; Centre = 68.3%; South = 48.5%), (b) the proportion of people with at least a diploma (North = 65.7%; Centre = 68.1%; South = 54%), and (c) the number of people suffering from severe material deprivation (North = 3.6%; Centre = 5.5%; South = 13.6%).[13] Moreover, recent data from ISTAT shows how families' average annual incomes are higher in the North and Central macro-regions (North = €43,908; Centre = €38,689; South = €32,801).[14]

Italian territorial inequalities are also underlined by an heterogenous distribution of sporting facilities and infrastructures throughout the nation. To be specific, six (Apulia, Basilicata, Calabria, Campania, Sardinia, and Sicily) of South Italy's *micro-regions* (i.e. distinct territorial unit with clearly marked boundaries below the regional level) are under several levels of criticality regarding their sporting facilities.[15] As an example, in 2012, the North-West had 52,330 sport facilities (354 for 100,000 inhabitants), the North-East had 37,200 (352 for 100,000 inhabitants), the Centre had 29,080 (271 for 100,000 inhabitants), and the South had 30,280 (149 for 100,000 inhabitants), which was in comparison to the national average of 264 facilities for 100,000 inhabitants. This suggested how, in 2012, the only *macro-region* (i.e. territorial entity made up of several regions; North, Centre, and South) of Italy to have less sport facilities than the national average was South Italy. The distinct lack of sport facilities in southern Italy could have important implications on physical activity and youth sport participation, particularly since research has shown how proximity to sport infrastructures as well as both public and private recreational facilities is positively associated with physical activity and sport participation (see Wicker and colleagues for a discussion[16]), in both children and adolescents.[17]

Where someone is born and raised can directly impact their access and opportunities to engage in youth sport activities, which has a subsequent influence on talent identification and development processes.[18] For example, Côté and colleagues highlighted the extent to which one's place of birth can affect youth sport opportunities and subsequent developmental outcomes. They showed how birthplace (i.e. where someone is born) was a greater contributor to success in professional sport compared to relative age (i.e. when someone is born).[19] However, research conducted in this discipline has revealed inconsistent results. In Swedish tennis, for instance, early research from Carlson concluded how elite players predominantly came from rural areas,[20] whereas, in North American ice-hockey, Curtis and Birch demonstrated that living in remote areas negatively impacted the likelihood of being identified as talented for the National Hockey League.[21] In the same way, more recent studies that have focussed on community size and community density for investigations of birthplace effects continued to record inconsistent findings,[22] underlining a considerable variation in the advantage of where someone is born.[23]

With the exception of size and density, there are many other environmental features that characterize the community in which sport is practiced. For instance, communities' physical aspects (i.e. access to facilities, presence of green spaces, open spaces, playgrounds, and proximity to sport clubs and/or organizations) can influence the types of activities performed by the younger generation (i.e. structured practice and unstructured play), thus favouring interactions with coaches and peers.[24] Other variables that influence sport participation rates are the communities' socioeconomic and cultural status. Generally, research has highlighted a positive relationship between sports participation and higher socioeconomic status of parents.[25] But similarly, literature has produced some inconclusive results across different nations and sports regarding the direction of the effect. For example, soccer is considered a relatively cheap sport to engage in from a very young age.[26] Based on this notion, Uehara and colleagues in their study suggested how poorer children have an increased likelihood of participating in soccer-specific play and thus facilitating their development of expertise in Brazilian soccer.[27] In contrast, however, a recent study by Allison and Barranco revealed how North American female soccer players participating in the National Women's Super League (the first soccer tier in the United States) generally derived by "whiter, less black or Latino, more suburban, and less socioeconomically disadvantaged [hometowns] than the national averages, with higher per capita, median household, and median family incomes" (pp. 8–9)[28]. This is largely due to the "pay-to-play" model via private academies that is adopted across the United States, which subsequently limits the access to organized youth soccer activities to those who cannot afford the fees.[29] These within-sport and between-country differences may reflect variances in the youth soccer development systems of those countries (e.g. formal vs. less formal participation and recruitment systems),[30] further highlighting the need to better understand the role of birthplace effects based on individual sociocultural circumstances.

The territorial inequalities of the various macro-regions and micro-regions of Italy could influence Italian children's and adolescents' development in sport. Accordingly, the purpose of our study was to investigate the presence of the "southern question" (i.e. birthplace effects) phenomena and its impact on Italian soccer. Specifically, our aim was to examine the birthplace of both youth and senior Italian national soccer team players and whether it influences the likelihood of being selected. Due to Italian territorial inequalities that favour the North and Centre of the country, we hypothesized that Italian soccer players born in the South are underrepresented across every national youth and senior team in comparison to those from the North and Centre who are overrepresented.

Methods

Subjects

A total sample of 2,103 Italian male soccer players were included in this current study. To be eligible for inclusion, a player must have been born from 1975 onwards (2005 was the year of birth of the youngest player), and must have been selected at least once by the date of the study (May, 2021) to play for any youth (Under 15 [U15]: $n = 466$; U16, U17, U18, U19, U20, and U21 [U16-U21]: $n = 1,939$) or senior ($n = 217$) national Italian soccer team. One player could have been registered in more than one youth team depending on how many times they were selected (i.e. a player could have been selected to play for the U15 team and for the U16 team during their youth career). Players not born in Italy and players whose birthplaces were not retrievable were omitted from the study ($n = 180$). Because all data were freely available from the internet, no approval by an ethical committee was required.

Procedures

The data for this study (i.e. player's birthplace and team selection) were obtained from the official data centre of the Italian Soccer Federation (Federazione Italiana Giuoco Calcio; FIGC), which were open access on the FIGC website (https://www.figc.it/it/nazionali/nazionali-in-cifre/convocazioni-di-un-giocatore/?squadraid=12) and Transfermarkt website (https://www.transfermarkt.it/). Italy is comprised of 20 micro-regions (see Figure 1), subdivided into the three macro-regions (i.e. North, Centre, and South). Players were classified based on both their macro-region and micro-region of birth. Youth and senior national teams' observed birthplace distribution was calculated for every macro-region and micro-region and then compared to the expected distribution, which was based on the general population norms that were obtained by census statistics.[31]

Figure 1. Italian map showing the micro-regions of Italy, divided by macro-regions (North, Center, South).

Data analysis

A Chi-Square (χ^2) goodness-of-fit test was used to compare the observed birthplace distribution of each soccer cohort against the expected birthplace distribution based on general population norms. Since chi-square statistics cannot reveal the magnitude and the direction of an existing relationship, the effect size (Cramer's V) and odds ratios (Ors) were calculated. The Cramer's V was interpreted as follows: a value of 0.06 or more indicated a small effect size, a value of 0.17 or more indicated a medium effect size, and a value of 0.29 or more indicated a large effect size.[32] The Ors and 95% confidence intervals (CIs) were calculated for the macro-regions (i.e. North vs. Centre; North vs. South; Centre vs. South), as well as for the micro-regions, as previously conducted in other birthplace effects studies.[33] The Ors were calculated and interpreted following the procedures outlined by Szumilas,[34] with CIs including 1 (i.e. CI 0.90–1.10) marked no association. Results were considered significant for $P < 0.05$. Statistical Analysis were conducted using Microsoft Excel,[35] and maps of Italy were produced using Microsoft Excel.[36]

Results

The observed birthplace distribution of each macro-region for the youth and senior national teams, as well as the general population norms, are presented in Figure 2. Descriptive statistics, in terms of frequency and percentage of distribution of players' macro-region of birth for each national team, as well as the results from chi-square statistics, are shown in Table 1. The observed macro-region distributions for U15, U16-U21, and the senior national team were significantly different from the general population norms (all P values < 0.0001; effect sizes ranged from medium to large; North observed mean (expected mean) = 48.1% (38.9%), Centre observed mean = 27% (17%), South observed mean = 24.9% (44%)). Table 2 shows the observed distribution of each micro-region across all Italian national soccer teams, which was also significantly different from the expected distribution ($\chi^2 = 491.15$; $P < 0.001$; small effect size).

The descriptive Ors for the macro-regions are presented in Table 3. The Ors showed an increased likelihood of players born in the North and in the Centre of being selected for the U15 national team and U16-U21 national teams compared to players born in the South, with the highest

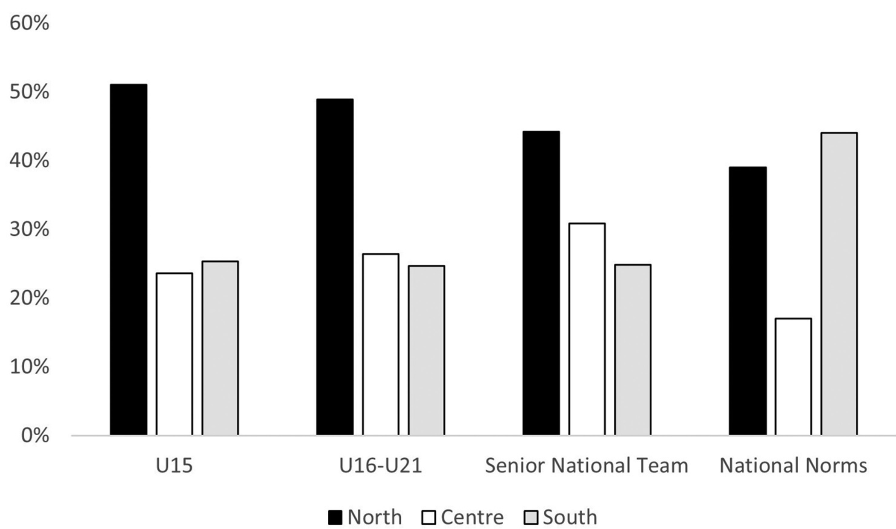


Figure 2. Birthplace distribution per macro-regions for the Italian national soccer teams.

Table 1. Birthplace distribution per macro-region for the international youth and senior Italian soccer players compared to the general population norms.

National Team	North (expected)	Center (expected)	South (expected)	χ2	*P*	*V*	Effect
Senior National Team	96 (84.6)	67 (36.9)	54 (95.5)	44.123	**<0.0001**	0.32	Large
%	44.2 (38.9	30.9 (17)	24.9 (44)				
U16-U21	948 (756.2)	512 (329.6)	479 (853.2)	313.705	**<0.0001**	0.28	Medium
%	48.9	26.4	24.7				
U15	238 (181.7)	110 (79.2)	118 (205)	80.460	**<0.0001**	0.29	Large
%	51.1	23.6	25.3				

Note: Bold = statistically significant at $P < 0.05$.

Table 2. Birthplace distribution per micro-region for the international Italian soccer players compared to the general population norms.

Birthplace (Micro-Regions)	N° of total players observed	N° of total players expected	*% observed*	*% expected*
Aosta Valley (North)	4	3.6	0.19	0.17
Piedmont (North)	146	130.7	6.95	6.22
Liguria (North)	60	43.3	2.85	2.06
Lombardy (North)	402	301.4	19.12	14.34
Trentino A-A (North)	17	35.7	0.81	1.70
Veneto (North)	177	150.9	8.42	7.18
FVG (North)	49	35.1	2.33	1.67
Emilia-Romagna (North)	167	112.9	7.94	5.37
Tuscany (Centre)	198	103.2	9.42	4.91
Umbria (Centre)	33	26.1	1.57	1.24
Marche (Centre)	48	46.9	2.28	2.23
Lazio (Centre)	270	188.3	12.84	8.96
Abruzzo (South)	23	43.5	1.09	2.07
Molise (South)	1	11.6	0.05	0.55
Campania (South)	235	282.7	11.18	13.45
Apulia (South)	92	182.7	4.38	8.69
Basilicata (South)	3	23.1	0.14	1.10
Calabria (South)	62	89.5	2.95	4.26
Sicily (South)	80	227.9	3.81	10.84
Sardinia (South)	35	63.7	1.67	3.03

Table 3. Ors of the birthplace distribution (macro-regions) for the international youth and senior Italian soccer players.

National Team	OR North vs. South (95% CI)	OR Center vs. South (95% CI)	OR Center vs. North (95% CI)
U15	**2.28 (1.69–3.06)**	**2.41 (1.67–3.48)**	0.94 (0.67–1.33)
U16-U21	**2.23 (1.93–2.59)**	**2.76 (2.31–3.30)**	**1.24 (1.05–1.46)**
Senior National Team	**2.01 (1.29–3.13)**	**3.21 (1.35–2.81)**	1.60 (0.97–2.63)

Note: Bold = statistically significant (CIs including 1 mark no association).

Ors being Centre vs. South (U15: 2.41, CI 1.67–3.48; U16-U21: 2.76, CI 2.31–3.30). Furthermore, players born in the Centre and in the North also recorded an increased likelihood of being selected for the senior national team compared to players born in the South, with the highest Ors being Centre vs. South (3.21, CI 1.35–2.81).

Figure 3 shows a map of Italy's micro-regions, coloured with different gradations of blue according to Ors' values (darker colour indicate higher Ors). Ors for all micro-regions were calculated based on the likelihood of players of being selected to play for any of the Italian national soccer teams. Players born in Tuscany (a central micro-region) had the greatest likelihood of representing Italy compared to the rest of the country (1.92, CI 1.50–2.45). In contrast, players born in the eight of South Italy's micro-regions recorded the lowest likelihood of being selected to play for the national squads compared to the rest of the country, having recorded the following Ors: Abruzzo = 0.53 (CI 0.32–0.88), Apulia = 0.50 (CI 0.39–0.65), Basilicata = 0.13 (CI 0.03–0.43), Calabria = 0.69 (CI 0.50–0.96), Campania = 0.83 (CI

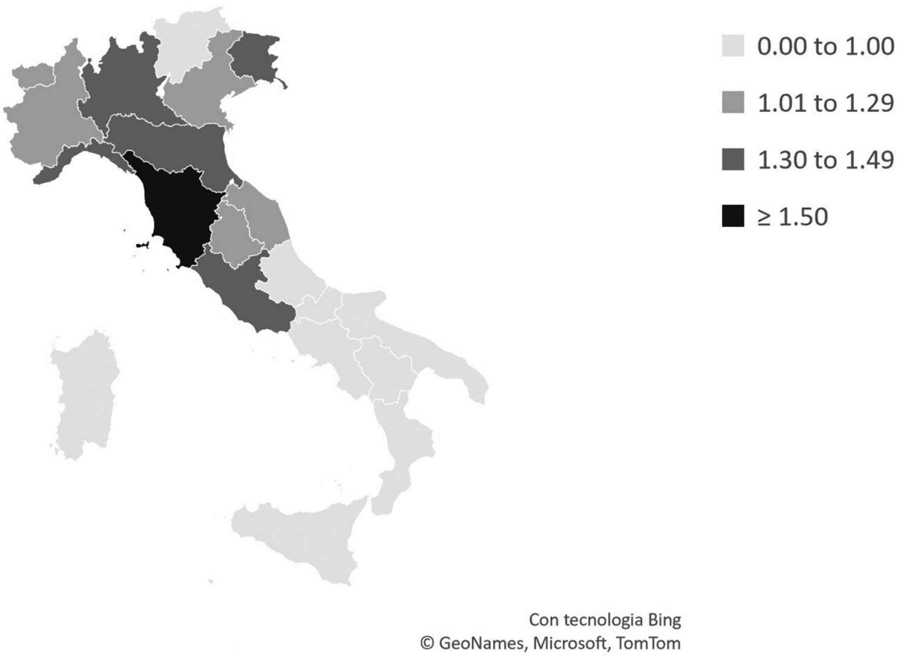


Figure 3. Map of Italy with micro-regions separated by white lines and coloured according to ORs for being selected to play for any of the Italian national soccer team.

Table 4. Ors of the birthplace distribution (micro-regions) for gaining selection into a national Italian team.

Comparison (Regions)	OR (95% CI)
Lombardy vs. Campania	**1.60 (2.02–1.28)**
Lazio vs. Campania	**1.72 (1.34–2.22)**
Tuscany vs. Campania	**2.31 (1.72–3.10)**
Lombardy vs. Sicily	**3.80 (2.83–5.10)**
Lazio vs. Sicily	**4.08 (2.98–5.60)**
Tuscany vs. Sicily	**5.47 (3.86–7.75)**
Lombardy vs. Apulia	**2.65 (1.98–3.55)**
Lazio vs. Apulia	**2.85 (2.08–3.89)**
Tuscany vs. Apulia	**3.81 (2.70–5.38)**

Note: Bold = statistically significant (CIs including 1 mark no association).

0.69–1.00), Molise = 0.09 (CI 0.01–0.67), Sardinia = 0.55 (CI 0.36–0.83), and Sicily = 0.35 (CI 0.27–0.46).

Additional analyses were conducted to further explore the possible Italian territorial inequalities, in terms of progressing towards national soccer squads. Three micro-regions of Italy were taken as reference (i.e. Lombardy [North]; Lazio and Tuscany [Centre]) and compared to other three micro-regions of Italy (i.e. Apulia, Campania, and Sicily [South]). The results from these comparisons are shown in Table 4. These underlined Lombardy, Lazio, and Tuscany (North and Centre) had an increased likelihood of being selected for the national teams, with the highest OR being Tuscany vs. Sicily (5.47, CI 3.86–7.75).

Overall, these results showed an overrepresentation of players born in North and Central Italian regions compared to their compatriots born in the South in both youth and senior teams.

Discussion

Italy is characterized by socioeconomic and cultural differences between the North, Centre, and South of the country that has been labelled as the "southern question".[37] To our knowledge this was the first study that has explored the "southern question" (i.e. birthplace effects) in the Italian soccer landscape. The results highlighted soccer players born in the North and Centre of the country have, from a young age and during the initial entry point into the national pathway (i.e. U15), the greatest likelihood of being selected to play for the Italian national squads compared to their equivalents born in the South.

There is a common belief that players need to be exposed to large volumes of structured practice to acquire expertise in soccer.[38] As a result, a large proportion of countries have started offering players more practice and competition in their primary sport (i.e. soccer) during childhood.[39] In line with this, Italian soccer has adopted an early specialization and identification pathway, which encourages children to enter soccer academies from a very young age (e.g. 6-years-old). Importantly, Italian children and adolescents' access to these optimal developmental environments is based on a "pay-to-play" model, whereby parents are required to pay an annual fee. Accordingly, the help and financial support of parents (i.e. their socioeconomic status) may act as a constraint on Italian individuals' development in soccer.[40] In the context of the current findings, South Italy's disadvantages in terms of the socioeconomic and cultural status compared to the rest of the country,[41] may limit access to talent pathway of children and adolescents born and raised in the Southern regions, eventually limiting their long-term development in soccer. A recent study conducted by the FIGC highlighted how South Italy recorded fewer players aged between 5 and 16 years involved in organized soccer activities compared to North and Central Italy.[42] Enrolment in soccer at early ages enables children to acquire early skill advantages, which could inevitably cause a rise in performance levels.[43] As such, children from North and Central Italy are more likely to be recognized as talented and may dispose of greater openings to talent pathways later in their young career.

Research has highlighted how the sport spatial landscape (e.g. distribution of athletes and clubs, structures competitions, and location of successful underage clubs) could offer critical information regarding athletes' equity of opportunity for development in every sport association.[44] In this regard, the Italian soccer spatial landscape appears unequal across the country. More specifically, soccer in Italy has always been a place where the geographical divisions between the North and the South of the country are shown. Historically, soccer in Italy was mostly present in the North, where there were cities, green grass, free time, and, above all, finances were often held.[45] Contrarily, in South Italy, soccer has increased at a slower rate. For instance, ten years after the first world conflict, only 11% of the players lined up from the South's soccer teams were born in South Italy.[46] Today, the Italian national training soccer centre is in Central Italy. In line with this, the Serie A (i.e. Italy's top male league) has often showed an overrepresentation of teams from the North and the Centre, with northern teams generally more successful than any other team across the country,[47] while southern teams often in a struggle to maintain their elite status.[48] As an example, from 1975 onwards, on 46 seasons of the Serie A, only five of these were won by a club not from North Italy (AS Roma in 1982–83 and 2000–01; SSC Napoli 1986–87 and 1989–90; SS Lazio 1999–00). This is an important factor to consider, because from U15 onwards, the FIGC organize elite youth national championships in which professional teams' youth teams take part. Considering that the majority of professional clubs reside in the North and Centre of Italy, these two macro-regions are over-represented across all age-groups categories.

Elite youth clubs are high-quality environment where young players can fulfil their potential. Recent findings have highlighted how proximity to successful youth clubs is a central factor in talent development,[49] as once young athletes reach a high level of performance, they are often required to leave their former local club in favour of a high-performance club where they can have access to better training facilities and are followed by expert coaches.[50] As such, young players born in North and Central Italy may have access to greater developmental opportunities, as well as benefit from the increased exposure to sport specific motor experiences, to quality coaches and facilities, and from the regular involvement in higher competition levels from a young age.[51] In contrast, in South Italy, the lack of talent clubs and facilities means youngsters born in this macro-region have less openings for higher-level developmental opportunities in soccer. Accordingly, this creates differences in opportunity for soccer growth between players born in North and Central Italy and players born instead in the South. Moreover, young players who play in elite youth clubs are exposed to a greater social visibility, which could augment their likelihood of being selected to play for the youth national teams.[52] For instance, in Brazilian soccer, Teoldo and colleagues showed how a large pool of young talented players use to migrate from their hometowns to develop in high-performance youth teams, which ensure them better training conditions and facilities, also augmenting their visibility to youth national teams' head coaches.[53] Indeed, it is worth presuming national teams' head coaches select players from the best elite youth clubs throughout the country. As such, in our study, the lower presence of players from the South in the Italian national youth representatives could be attributed to the underrepresentation of South Italy's youth soccer clubs at national level.

Young athletes who grow up at a greater distance from high performance clubs may face additional challenges, such as requiring additional resources for transportation,[54] or may need to leave their families to be able to continue chase their dream of becoming successful senior athletes.[55] In other words, because of the distance and/or lack of elite youth clubs in South Italy, many soccer talents born in the South: (a) will not have the possibility of developing in high-quality environment, and (b) will not have a higher social visibility, unless they are willing to migrate in the North and Central regions. Therefore, presuming that the underrepresentation in the national soccer representatives of players born in the South is due to a lack of talent in these regions, it would be unfair and unlikely to be true. Rather, these birthplace effects, cause a loss of talent, as players born in the South who may have the potential to succeed are being overshadowed by players born in other regions of the country; particularly as soccer in the South is no less popular in comparison to North and Central regions.[56] As such, similarly to relative age effects (RAEs),[57] the regional disparities in the Italian soccer presented in this paper represents an unintended form of talent wastage.[58] This could have adverse implications for the Italian Soccer Federation, as it could impact the pool of talented players to select from senior level and therefore need to be managed accordingly.

The Matthew effect is used to describe how, in society, "the rich get richer" and "the poor get poorer".[59] This notion has been already explored in sport as part of a theoretical framework (i.e. the Social Agent's Model) used to explain RAEs.[60] The Matthew effect can also be used here to explain longer developmental advantages experimented by children and adolescents from North and Centre Italy. The socioeconomic constraints that characterize youth Italian soccer (i.e. the "pay-to-play" model), may impact on children and adolescents' access to first developmental experiences in soccer. Families with lower socioeconomic and cultural conditions, mostly present in the Southern regions, may be discouraged to have children involved in soccer activities, undermining their interactions with the soccer environment (e.g. early abilities, connections with peers and coaches) and their development. This causes an initial performance gap between children and adolescents from South Italy and players from North and Central Italy, who, due to their higher social class and have greater access to facilities, are more likely of being involved in soccer practices. This will have a subsequent impact on their subsequent selection opportunities, eventually widen the already existent gap in terms of long-term developmental soccer opportunities between players from North and Central Italy and players from the South (i.e. "the rich get richer" and "the poor get poorer"). As such, these longer developmental advantages experimented over time (i.e. training sessions and seasons) by Italian children and adolescents born in the regions of the North and Centre impact on their likelihood of becoming the better players in the future (i.e. career), and indeed the results of our study showed how they remain to be overrepresented even at senior level.

Summing up, human development is dependent on an intertwined relationship between the individual and their environment. Our study highlighted how talent selection and development processes in Italian soccer are not done on a levelling playing field, and proposed how in South Italy, the lack of sporting infrastructures, lower socioeconomic status, and fewer professional soccer clubs and youth academies, negatively impact on soccer developmental trajectory for children born in this macro-region. Considering that every sport association's aim should be providing equitable opportunities for participation and success in sport, the FIGC should evolve accordingly by increasing its awareness of its developmental soccer pathways to try to give every talent a chance.

Limitations

When interpreting the results of this study, it is important to consider its limitations. First, only one appearance with any of the Italian national soccer teams was required to be included in this study. However, some players could have played in considerably more games. Career duration and/or appearances could be a variable included to understand the influence of birthplace on long-term development outcomes. Second, this study did not make a distinction between playing a friendly or an official match. Considering the different requirements needed for players to play internationally during a major tournament and to play in a friendly match, a more appropriate data analysis could have included such distinction. Third, this study has only taken in consideration players' place of birth. However, a player may be born in a particular region of Italy and then moved elsewhere in the country in their younger age. Finally, we derived the sociocultural and economic status from census statistics. Another possible method could have been to investigate the sociocultural and economic status associated with national representatives. It is, however, worth considering that this evaluation of the "southern question" provides valuable insights on birthplace effects in Italy and offers a foundational approach for future studies.

Conclusions

The *Stadio Olimpico* [Olympic Stadium] is the largest sports stadium in Rome, Italy, seating over 70,000 spectators. Rebuilt for the Men's FIFA World Cup in 1990, the Stadio Olimpico is home to AS Roma and SS Lazio as well as host of the Coppa Italia final and many national team fixtures. Indeed, thousands of young (and senior) Italian soccer players dream of representing their national team in their capital at the Stadio Olimpico. However, in the context of the male Italian national teams, we questioned whether *all roads lead to Rome*. This figurative expression means that all choices, methods, or actions lead to the same result or goal, and a metaphor that nicely queries the reality of Italian soccer players. Based on our findings, it appears not all roads necessarily lead to Rome for aspiring Italian soccer players. Specifically, this paper was the first to examine the presence of the "southern question" (i.e. birthplace effects) in the Italian national soccer teams, with results showing the presence of a skewed distribution of birthplaces that favours players born in North and Central Italy. Moving forward, key stakeholders employed within the FIGC are encouraged to focus their attention on creating more equitable talent pathways across the country and widen the pool of potential talent. Moreover, future research in this area would benefit from examining the socioeconomic and cultural backgrounds of selected payers and further explore the Italian soccer landscape (i.e. distribution of players across the national territory). This would highlight some patterns of migration and help to better understand the challenges that youth Italian players need to overcome to become successful senior players.

Notes

1. Pescosolido, *La questione meridionale in breve: Centocinquant'anni di storia.*
2. Capello, 'What makes Southern Italy still lagging behind? A diachronic perspective of theories and approaches'.
3. Urbinati, "The Souths of Antonio Gramsci and the Concept of Hegemony".
4. Pescosolido, *Questione meridionale in breve.*
5. Greco, 'Blaming the southern victim: Cancer and the Italian 'Southern Question' in Terra dei fuochi and Taranto'; and Schneider, "Introduction: The dynamics of neo-orientalism in Italy (1848–1995)".
6. Felice and Lepore, 'State intervention and economic growth in Southern Italy: the rise and fall of the 'Cassa per il Mezzogiorno' (1950–1986)'; and Pescosolido, "Italy's Southern Question: long-standing thorny issues and current problems".
7. Greco, 'Cancer and the Italian 'Southern Question'.
8. Pescosolido, 'Italy's Southern Question'.
9. Iammarino, 'Regional inequality in Europe: evidence, theory and policy implications'.
10. Rosès and Wolf, 'Regional economic development in Europe, 1900–2010: A description of the patterns'.
11. Iammarino, 'Regional inequality in Europe'.
12. BES, 'Rapporto BES 2020: il Benessere Equo e Sostenibile in Italia'.
13. Ibid.
14. ISTAT, 'Reddito medio annuale delle famiglie (in euro)'.
15. CONI, 'Il libro bianco dello sport italiano'.
16. Wicker, Breuer and Pawlowski, "Promoting Sport for All to Age-specific Target Groups: the Impact of Sport Infrastructure".
17. Dowda et al, "Commercial facilities, social cognitive variables, and physical activity of 12th grade girls"; and McCormack et al, "The relationship between destination proximity, destination mix and physical activity behaviours".
18. Hancock, Vierimaa and Newman, "The geography of talent development".
19. Côté et al, 'When 'where' is more important than 'when': Birthplace and birthdate effects on the achievement of sporting expertise'.
20. Carlson, "The socialization of elite tennis players in Sweden: An analysis of the players" backgrounds and development'.
21. Curtis and Birch, 'Size of community of origin and recruitment to professional and Olympic hockey in North America'.
22. Hancock et al, 'Influences of population size and density on birthplace effects'; Lidor et al, "Relative age effect and birthplace effect in Division 1 female ballgame players: the relevance of sport-specific factors"; Maayan, Lidor and Arnon, "The Birthplace Effect in 14–18-Year-Old Athletes Participating in Competitive Individual and Team Sports"; and Turnnidge, Hancock and Côté, "The influence of birth date and place of development on youth sport participation".
23. Hancock, Vierimaa and Newman, "Geography of talent development".
24. Côté et al, "Situating birth advantages within the youth sport system"; and Erikstad et al, "'As Many as Possible for as Long as Possible'—A Case Study of a Soccer Team That Fosters Multiple Outcomes".
25. Federico, Falese and Capelli, "Socio-economic inequalities in physical activity practice among Italian children and adolescents: a cross-sectional study"; and Vella, Cliff and Okely, "Socio-ecological predictors of participation and dropout in organized sports during childhood".
26. Hodkinson and Sparkes, 'Careership: A sociological theory of career decision making'.
27. Uehara et al, 'The Poor 'Wealth' of Brazilian Football: How Poverty May Shape Skill and Expertise of Players'.
28. Allison and Barranco, 'A rich white kid sport?' Hometown socioeconomic, racial, and geographic composition among U.S. women's professional soccer players'.
29. Ibid.
30. Ford et al, 'The developmental activities of elite soccer players aged under-16 years from Brazil, England, France, Ghana, Mexico, Portugal and Sweden'.
31. ISTAT, 'Number of live Births per Regions, by 1975 to 1998, in Italy"; and idem, "Number of live Births per Regions, by 1999 to 2005, in Italy".
32. Cohen, 'Statistical Power Analysis for the Behavioral Sciences'.
33. Finnegan et al, 'The influence of date and place of birth on youth player selection to a National Football Association elite development programme'; and Rossing et al, 'The role of community in the development of elite handball and football players in Denmark'.
34. Szumilas, 'Explaining odds ratios'.
35. Microsoft Corporation, *Microsoft Excel Ver. "17.0"*.
36. Ibid.

37. Asso, ‘New perspectives and old inequalities: Italy’s north-south divide’; Pescosolido, *Questione meridionale in breve*; and idem, “Italy’s Southern Question”.
38. Uehara et al, ‘The role of informal, unstructured practice in developing football expertise: The case of Brazilian pelada’.
39. Ford et al, ‘Developmental activities of elite soccer players’; and Forsman et al, ‘The role of sport-specific play and practice during childhood in the development of adolescent Finnish team sport athletes’.
40. Bloom, *Developing Talent in young People.*
41. BES, ‘Rapporto BES 2020’.
42. FIGC, ‘Report Calcio 2022’.
43. Hancock, Adler and Côté, ‘A proposed theoretical model to explain relative age effects in sport’.
44. Finnegan et al, ‘Influence of date and place of birth on youth player selection’; idem, ‘Stepping stones? An exploration of internal football player migration in the Republic of Ireland’; and Rossing, “Influence of population size, density, and proximity to talent clubs on the likelihood of becoming elite youth athlete”.
45. McCarthy, ‘Sport and society in Italy today’.
46. Panico, ‘Il Calcio’.
47. Lewis, “From Alpine clubs to Baggio and Berlusconi: Italy reflected through sport”.
48. Sisti, ‘Benevento e Crotone fanno festa, ma in A la ‘questione meridionale’ resta’.
49. Finnegan et al, “Influence of date and place of birth on youth player selection”; and Rossing et al, “Role of community in the development of elite players”.
50. Rossing et al, ‘Likelihood of becoming elite youth athlete’.
51. Ibàñez et al, “The relative age effect in under-18 basketball: effects on performance according to playing position”.
52. Teoldo, Cardoso and Garganta, ‘Could the human development index and birthdate of the players influence on the ability of Brazilian soccer players to enter top-level competition?’.
53. Ibid.
54. Rossing et al, ‘Likelihood of becoming elite youth athlete’.
55. Finnegan, ‘Exploration of internal football player migration’; and Teoldo, Cardoso and Garganta, “Could human development index and birthdate influence enter top-level competition?”.
56. FIGC, ‘Report Calcio 2022’.
57. Morganti et al, ‘Relative age effects and the youth-to-senior transition in Italian soccer: the underdog hypothesis versus knock-on effects of relative age’.
58. Doyle, Bottomley and Angell, ‘Tails of the travelling Gaussian model and the relative age effect: tales of age discrimination and wasted talent’.
59. Merton, ‘The Matthew effect in science: The reward and communication systems of science are considered’.
60. Hancock, Adler and Côté, ‘Theoretical model to explain RAEs in sport’.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Author contributions

GM, AK, GA, and BR have given substantial contribution to the conception and design of the manuscript. GM and AK have participated to drafting the manuscript. GM, AK, GA, and BR have revised it critically. All authors read and approved the final version of the article.

Bibliography

Allison, R., and R. Barranco. ’“A Rich White Kid sport?” Hometown Socioeconomic, Racial, and Geographic Composition Among U.S. Women’s Professional Soccer Players’, *Soccer and Society* 22, no. 5 (2021): 457–469. doi:10.1080/14660970.2020.1827231.

Asso, P.F. ’New Perspectives on Old Inequalities: Italy’s North–South Divide’, *Territory, Politics, Governance* 9, no. 3 (2021): 346–364. doi:10.1080/21622671.2020.1805354.

Benessere Equo e Sostenibile (BES). ‘Rapporto BES 2020: il Benessere Equo e Sostenibile in Italia.’ 2020. https://www.istat.it/it/files//2021/03/BES_2020.pdf.

Bloom, B.S., *Developing Talent in Young People*. New York: Ballantine Books, 1985.

Capello, R. ’What Makes Southern Italy Still Lagging Behind? A Diachronic Perspective of Theories and Approaches’, *European Planning Studies* 24, no. 4 (2016): 668–686. doi:10.1080/09654313.2015.1128402.

Carlson, R.C. ’The Socialization of Elite Tennis Players in Sweden: An Analysis of the players’ Backgrounds and Development’, *Sociology of Sport Journal* 5, no. 3 (1988): 241–256. doi:10.1123/ssj.5.3.241.

Cohen, J., *Statistical Power Analysis for the Behavioral Sciences* (Hillsdale, NJ: L. Erlbaum Associates, 1998).

Comitato Olimpico Nazionale Italiano (CONI). ‘Il libro bianco dello sport italiano.’ 2012. http://www.coni.it/images/Libro_Bianco_-_Sito.pdf.

Côté, J., D.J. Macdonald, J. Baker, and B. Abernethy. ’When “Where” is More Important Than “When”: Birthplace and Birthdate Effects on the Achievement of Sporting Expertise’, *Journal of Sports Sciences* 24, no. 10 (2006): 1065–1073. doi:10.1080/02640410500432490.

Côté, J., A. Murata, J. Turnnidge, and D. Hancock. Situating Birth Advantages within the Youth Sport System. in *Birth Advantages and Relative Age Effects in Sport*. ed. A. L. Kelly, J. Coté, M. Jeffreys, and J. Turnnidge (London: Routledge, 2021). 10.4324/9781003163572-4

Curtis, J.E., and J.S. Birch. ’Size of Community of Origin and Recruitment to Professional and Olympic Hockey in North America’, *Sociology of Sport Journal* 4, no. 3 (1987): 229–244. doi:10.1123/ssj.4.3.229.

Dowda, M., R.K. Dishman, D. Porter, R.P. Saunders, and R.R. Pate. ’Commercial Facilities, Social Cognitive Variables, and Physical Activity of 12th Grade Girls’, *Annals of Behavioral Medicine: A Publication of the Society of Behavioral Medicine* 37, no. 1 (2009): 77–87. doi:10.1007/s12160-009-9080-0.

Doyle, J.R., P.A. Bottomley, R. Angell, and C.M. Schooling. ’Tails of the Travelling Gaussian Model and the Relative Age Effect: Tales of Age Discrimination and Wasted Talent’, *PLoS One* 12, no. 4 (2017): e0176206. doi:10.1371/journal.pone.0176206.

Erikstad, M.K., B. Tore Johansen, M. Johnsen, T. Haugen, and J. Côté. ’“As Many as Possible for as Long as Possible”—A Case Study of a Soccer Team That Fosters Multiple Outcomes’, *The Sport Psychologist* 35, no. 2 (2021): 131–141. doi:10.1123/tsp.2020-0107.

Federazione Italiana Giuoco Calcio (FIGC). ‘Report Calcio 2022.’ 2022. https://www.figc.it/it/federazione/federazione-trasparente/reportcalcio/.

Federico, B., L. Falese, and G. Capelli. ’Socio-Economic Inequalities in Physical Activity Practice Among Italian Children and Adolescents: A Cross-Sectional Study’, *Zeitschrift fur Gesundheitswissenschaften = Journal of public health* 17, no. 6 (2009): 377–384. doi:10.1007/s10389-009-0267-4.

Felice, E., and A. Lepore. ’State Intervention and Economic Growth in Southern Italy: The Rise and Fall of the “Cassa per Il Mezzogiorno” (1950–1986’, *Business History* 59, no. 3 (2017): 319–341. doi:10.1080/00076791.2016.1174214.

Finnegan, L. ’Stepping Stones? An Exploration of Internal Football Player Migration in the Republic of Ireland’, *Regional Studies, Regional Science* 6, no. 1 (2019): 596–606. doi:10.1080/21681376.2019.1685905.

Finnegan, L., D. Richardson, M. Littlewood, and J. McArdle. ’The Influence of Date and Place of Birth on Youth Player Selection to a National Football Association Elite Development Programme’, *Science and Medicine in Football* 1, no. 1 (2017): 30–39. doi:10.1080/02640414.2016.1254807.

Ford, P.R., C. Carling, M. Garces, M. Marques, C. Miguel, A. Farrant, A. Stenling, et al. ’The Developmental Activities of Elite Soccer Players Aged Under-16 Years from Brazil, England, France, Ghana, Mexico, Portugal and Sweden’, *Journal of Sports Sciences* 30, no. 15 (2012): 1653–1663. doi:10.1080/02640414.2012.701762.

Forsman, H., M. Blomqvist, K. Davids, N. Konttinen, and J. Liukkonen. ’The Role of Sport-Specific Play and Practice During Childhood in the Development of Adolescent Finnish Team Sport Athletes’, *International Journal of Sports Science & Coaching* 11, no. 1 (2016): 69–77. doi:10.1177/1747954115624816.

Greco, C. ’Blaming the Southern Victim: Cancer and the Italian “Southern Question” in Terra Dei Fuochi and Taranto’, *Anthropology Today* 32, no. 3 (2016): 16–19. doi:10.1111/1467-8322.12255.

Hancock, D.J., A.L. Adler, and J. Côté. ’A Proposed Theoretical Model to Explain Relative Age Effects in Sport’, *European Journal of Sport Science* 13, no. 6 (2013): 630–637. doi:10.1080/17461391.2013.775352.

Hancock, D.J., P. Coutinho, J. Côté, and I. Mesquita. ’Influences of Population Size and Density on Birthplace Effects’, *Journal Sports Sciences* 36, no. 1 (2018): 33–38. doi:10.1080/02640414.2016.1276614.

Hancock, D.J., M. Vierimaa, and A. Newman, ’The Geography of Talent Development’, *Frontiers in Sports and Active Living* 4 (2022): 1031227. doi:10.3389/fspor.2022.1031227.

Hodkinson, P., and A.C. Sparkes. ’Careership: A Sociological Theory of Career Decision Making’, *British Journal of Sociology of Education* 18, no. 1 (1997): 29–44. doi:10.1080/0142569970180102.

Iammarino, S., A. Rodriguez-Pose, and S. Storper. ’Regional Inequality in Europe: Evidence, Theory and Policy Implications’, *Journal of Economic Geography* 19, no. 2 (2019): 273–298. doi:10.1093/jeg/lby021.

Ibàñez, S.J., A. Mazo, J. Nascimento, J. Garcìa-Rubio, and K. Till. ’The Relative Age Effect in Under-18 Basketball: Effects on Performance According to Playing Position’, *PLoS One* 13, no. 7 (2018): e0200408. doi:10.1371/journal.pone.0200408.

Istituto Nazionale di Statistica (ISTAT). ‘Number of Live Births per Regions, by 1975 to 1998, in Italy.’ 1998.

Istituto Nazionale di Statistica (ISTAT). ‘Number of Live Births per Regions, by 1999 to 2005, in Italy.’ 2005

Istituto Nazionale di Statistica (ISTAT). ‘Reddito medio annual delle famiglie (in euro).’ 2020. http://dati.istat.it/.

Lewis, A. 'From Alpine Clubs to Baggio and Berlusconi: Italy Reflected Through Sport', *Journal of Modern Italian Studies* 14, no. 1 (2009): 96–103. doi:10.1080/13545710802647890.
Lidor, R., M. Arnon, Z. Maayan, T. Gershon, and J. Côté. 'Relative Age Effect and Birthplace Effect in Division 1 Female Ballgame Players: The Relevance of Sport-Specific Factors', *International Journal of Sport & Exercise Psychology* 12, no. 1 (2014): 19–33. doi:10.1080/1612197X.2012.756232.
Maayan, Z., R. Lidor, and M. Arnon. 'The Birthplace Effect in 14–18-Year-Old Athletes Participating in Competitive Individual and Team Sports', *Sports* 10, no. 4 (2022): 59. doi:10.3390/sports10040059.
McCarthy, P. 'Sport and Society in Italy Today', *Journal of Modern Italian Studies* 5, no. 3 (2000): 322–326. doi:10.1080/1354571X.2000.9728257.
McCormack, G.R., B. Giles-Corti, and M. Bulsara. 'The Relationship Between Destination Proximity, Destination Mix and Physical Activity Behaviors', *Prev Med (Baltim)* 46, no. 1 (2008): 33–40. doi:10.1016/j.ypmed.2007.01.013.
Merton, R.K. 'The Matthew Effect in Science: The Reward and Communication Systems of Science are Considered', *Science* 159, no. 3810 (1968): 56–63. doi:10.1126/science.159.3810.56.
Microsoft Corporation. 'Microsoft Excel,' 17, 2019.
Morganti, G., A.L. Kelly, G. Apollaro, L. Pantanella, M. Esposito, A. Grossi, and B. Ruscello. 'Relative Age Effects and the Youth-To-Senior Transition in Italian Soccer: The Underdog Hypothesis versus Knock-On Effects of Relative Age', *Science and Medicine in Football* (2022): 1–7. Advance online publication 10.1080/24733938.2022.2125170
Panico, G. Il Calcio. in *Storia degli Sport in Italia (1861-1960)*, In ed. A. Lombardo, 85–105. Rome: Il Vascello, 2004.
Pescosolido, G., *La questione meridionale in breve: Centocinquant'anni di storia* (Rome: Donzelli, 2017).
Pescosolido, G. 'Italy's Southern Question: Long-Standing Thorny Issues and Current Problems', *Journal of Modern Italian Studies* 24, no. 3 (2019): 441–455. doi:10.1080/1354571X.2019.1605726.
Rosés, J.R., and N. Wolf. Regional Economic Development in Europe, 1900–2010: A Description of the Patterns. in *The Economic Development of Europe's Regions: A Quantitative History Since 1900*, In ed. J. R. Rosés and N. Wolf, 3–41. London: Routledge, 2018.
Rossing, N.N., A.B. Nielsen, A.M. Elbe, and D.S. Karbing. 'The Role of Community in the Development of Elite Handball and Football Players in Denmark', *European Journal of Sport Science* 16, no. 2 (2016): 237–245. doi:10.1080/17461391.2015.1009492.
Rossing, N.N., D. Stentoft, A. Flattum, J. Côté, and D.S. Karbing. 'Influence of Population Size, Density, and Proximity to Talent Clubs on the Likelihood of Becoming Elite Youth Athlete', *Scandinavian Journal of Medicine & Science in Sports* 28, no. 3 (2018): 1304–1313. doi:10.1111/sms.13009.
Schneider, J. "Introduction: The Dynamics of Neo-Orientalism in Italy (1848–1995)." in *Italy's 'Southern Question': Orientalism in One Country*, In ed. J. Schneider, 1–23. London: Routledge, 1998.
Sisti, E. 'Benevento e Crotone fanno festa, ma in A la "questione meridionale" resta.' *La Repubblica*. July 20, 2020. https://www.repubblica.it/sport/calcio/serie-a/2020/07/26/news/benevento_crotone_meridione_in_a-262886022/.
Szumilas, M., 'Explaining Odds ratios' [Published Correction Appears in *J Can Acad Child Adolesc Psychiatry* 24, No. 1 (2015): 58]', *Journal Can Acad Child Adolesc Psychiatry* 19, no. 3 (2010): 227–229.
Teoldo, I., F. Cardoso, and J.O. Garganta. 'Could the Human Development Index and Birthdate of the Players Influence on the Ability of Brazilian Soccer Players to Enter Top-Level Competition?', *Motriz Revista de Educacocao Fisica* 19, no. 1 (2013): 34–45. doi:10.1590/S1980-65742013000100004.
Turnnidge, J., D.J. Hancock, and J. Côté. 'The Influence of Birth Date and Place of Development on Youth Sport Participation', *Scandinavian Journal of Medicine & Science in Sports* 24, no. 2 (2014): 461–468. doi:10.1111/sms.12002.
Uehara, L., C. Button, D. Araújo, I. Renshaw, K. Davids, and M. Falcous, 'The Role of Informal, Unstructured Practice in Developing Football Expertise: The Case of Brazilian Pelada,' *Journal of Expertise* 1 no. 3 (2018): 162–180. https://journalofexpertise.org/articles/JoE_2018_1_3_Uehara_earlyview.pdf.
Uehara, L., M. Falcous, C. Button, K. Davids, D. Araújo, A.R. de Paula, and J. Saunders, 'The Poor "Wealth" of Brazilian Football: How Poverty May Shape Skill and Expertise of Players', *Frontiers in Sports and Active Living* 3 (2021): 635241. doi:10.3389/fspor.2021.635241.
Urbinati, N. "The Souths of Antonio Gramsci and the Concept of Hegemony." in *Italy's 'Southern Question': Orientalism in One Country*, In ed. J. Schneider, 135–156. London: Routledge, 1998.
Vella, S.A., D.P. Cliff, and A. Okely. 'Socio-Ecological Predictors of Participation and Dropout in Organised Sports During Childhood', *International Journal of Behavioral Nutrition and Physical Activity* 11, no. 1 (2014): 62. doi:10.1186/1479-5868-11-62.
Wicker, P., C. Breuer, and T. Pawlowski. 'Promoting Sport for All to Age-Specific Target Groups: The Impact of Sport Infrastructure', *European Sport Management Quarterly* 9, no. 2 (2009): 103–118. doi:10.1080/16184740802571377.

EPILOGO

Concludiamo questa stimolante raccolta di articoli scientifici curata dal Luiss Sport Lab, un centro studi di eccellenza dedicato all'analisi e alla ricerca nel campo dello sport. Questa pubblicazione riflette l'impegno costante e l'entusiasmo dei ricercatori, degli esperti e degli appassionati che compongono la comunità del Luiss Sport Lab.

Attraverso gli articoli raccolti, abbiamo esplorato le dinamiche complesse del mondo dello sport, sia sul campo che al di fuori. Dai meccanismi fisiologici che guidano le prestazioni atletiche, alle implicazioni sociali e psicologiche degli eventi sportivi, ogni contributo ha offerto una prospettiva unica su uno degli aspetti più affascinanti della vita umana: il movimento e di conseguenza lo sport.

Il Luiss Sport Lab racchiude la necessaria innovazione per la crescita nel campo della ricerca sportiva. La diversità di argomenti trattati in questa raccolta, riflette la multidisciplinarietà che ha caratterizzato il nostro approccio. Questa diversità è la chiave per comprendere le molteplici sfaccettature dello sport e per sviluppare soluzioni innovative, che possano migliorare attraverso l'applicazione non solo la performance ma anche il benessere degli atleti.

Chiudiamo questo lavoro con la consapevolezza che il Luiss Sport Lab potrà rappresentare un'area d'interesse e di sviluppo non solo dello sport all'interno dell'Università ma diventare anche un acceleratore di innovazione per tutta la metodologia dell'allenamento da utilizzare.
Si ringraziano tutti coloro che contribuiscono quotidianamente allo studio con l'intento di migliorare comportamenti e metodiche per la crescita non solo del singolo ma anche della squadra.

Infine, tutti quelli che hanno lavorato alla raccolta di pubblicazioni scientifiche che hanno menzionato il Luiss Sport Lab.


arena
Federazione
Italiana Nuoto
UnipolSai
ASSICURAZIONI
FRECCIAROSSA

A cura del Luiss Sport Lab

LUISS