Montenegrin Journal of Sports Science and Medicine

www.mjssm.me

ISSN 1800-8755

SEPTEMBER 2022

VOL. 11

NO.2

Montenegrin Journal of Sports Science and Medicine

Editors-in-Chief

Dusko Bjelica | University of Montenegro (Montenegro)
Damir Sekulić | University of Split (Croatia)

Executive Editor

Selçuk Akpınar | Nevşehir Hacı Bektaş Veli University (Turkey)

Associate Editors

Mehmet Uygur | Rowan University (USA)
Catalina Casaru | Georgia Southwestern State University (USA)
Predrag Bozic | Serbian Institute of Sport and Sports Medicine (Serbia)

Editorial Board

Antonino Bianco | University of Palermo (Italy)
Branislav Antala | Comenius University in Bratislava (Slovakia)
Ferman Konukman | Qatar University (Qatar)
Gregor Starc | University of Ljubljana (Slovenia)
Gregor Jurak | University of Ljubljana (Slovenia)
Haris Pojskic | Mid Sweden University (Sweden)
Hugo Sarmento | University of Coimbra (Portugal)
Humberto Carvalho | University of Campinas (Brazil)
Juan Cortell-Tormo | University of Alicante (Spain)
Juel Jarani | Sport University of Tirana (Albania)
Kemal Idrizović | University of Montenegro (Montenegro)
Ligia Rusu | University of Craiova (Romania)
Nejc Sarabon | University of Primorska (Slovenia)
Rodica Traistaru | University of Medicine and Pharmacy of Craiova (Romania)
Sandra Mandic | University of Otago (New Zealand)
Sergej Ostojic | University of Novi Sad (Serbia)
Seyed Morteza Tayebi | Allameh Tabataba'i University (Iran)
Shaji John Kachanathu | College of Applied Medical Sciences, King Saud University (Saudi Arabia)
Yousef Saleh Khader | Jordan University of Science & Technology (Jordan)

Index Coverage

Emerging Sources Citation Index; Scopus; ProQuest; Index Copernicus; DOAJ; SCImago; SPORTDiscus; ERIH PLUS; Open Academic Journals Index; Google Scholar; SHERPA/RoMEO; Crossref; NLM Catalog; Islamic World Science Citation Center (ISC); ROAD

Proofreading Service

Terry Troy Jackson
Kristina Perovic Mijatovic

Prepress

Milicko Ceranic

Print

Art Grafika | Niksic

Print Run

700

CRNOGORSKA SPORTSKA AKADEMIJA • MONTENEGRIN SPORTS ACADEMY

UCG Univerzitet Crne Gore

Fakultet za sport i fizičko vaspitanje • Univerzitet Crne Gore

ISSN 1800-8755 eISSN 1800-8763

MONTENEGRIN JOURNAL OF SPORTS SCIENCE AND MEDICINE
International Scientific Journal

Vol. 11(2022), No.2 (1-85)

TABLE OF CONTENTS

Guidelines for authors are available at Journal's web page: https://www.mjssm.me/

Full-text available free of charge at https://www.mjssm.me/

ORIGINAL SCIENTIFIC PAPER

Monitoring Technical Performance in the UEFA Champions League: Differences Between Successful and Unsuccessful Teams

Toni Modric[1], Sime Versic[1,2], Mario Jelicic[1]

Affiliations: [1]Faculty of Kinesiology, University of Split, Split, Croatia, [2]HNK Hajduk Split, Split, Croatia

Correspondence: Toni Modric, University of Split, Faculty of Kinesiology, Teslina 6, Split 21000, Croatia. E-mail: toni.modric@yahoo.com

Abstract

This study attempted to identify associations between the TP (technical performance) of top-elite football (soccer) players according achievement of their teams and match outcome in UEFA Champions League (UCL). TP were evaluated by position specific InStat index which was calculated on the basis of a unique set of key parameters for each playing position. The participants (n = 179) were professional football players from teams that competed in the group stage of UCL in the 2020/21 season. Players were classified according to playing positions, and all data were obtained from 20 matches. Team achievement was defined by three criteria: (i) qualifying of the team from the group stage into the knockout stage of UCL, (ii) the final ranking of the team in the group, and (iii) total group points earned at the end of the group phase of UCL. The results indicated a higher InStat index when teams (i) won matches, (ii) qualified into the knockout stage, (iii) achieved a higher position on the table, and (iv) earned more group points. These findings confirmed that the InStat index is valid discriminator of TP between successful and unsuccessful teams.

Keywords: *soccer, success, technical abilities, match outcome*

@MJSSMontenegro
MONITORING TECHNICAL PERFORMANCE IN ELITE FOOTBALL
http://mjssm.me/?sekcija=article&artid=236

Cite this article: Modric, T. Versic S., & Jelicic M. (2022). Monitoring Technical Performance in the UEFA Champions League: Differences Between Successful and Unsuccessful Teams. *Montenegrin Journal of Sports Science and Medicine*, 11 (2), 3–11. https://doi.org/10.26773/mjssm.220901

Introduction

Performance indicators are defined as a "selection and combination of variables that define some aspect of performance and that help achieve athletic success" (Lago-Peñas & Lago-Ballesteros, 2011). In general, performance indicators in football (soccer) can be observed as: (i) indicators of technical abilities; (ii) indicators of physical abilities; and (iii) indicators of tactical abilities. To evaluate technical abilities, the most frequently used performance indicators are passes, shots, crosses or dribbles (Yi, Jia, Liu, & Gómez, 2018; Konefał et al., 2019a). The most frequently used performance indicators for evaluating physical abilities are different kinematic data (i.e., total distance covered, distance covered in different speed zones, accelerations/decelerations) (Modric, Versic, & Sekulic, 2021; De Albuquerque Freire et al., 2022). Finally, to evaluate tactical abilities, inter-player coordination, inter-team coordination before critical events and team-team interaction and compactness coefficients are mostly used (Memmert, Lemmink, & Sampaio, 2017). Interpretation of such data seeks to generate knowledge about team properties and the patterns that

Received: 22 April 2022 | Accepted after revision: 29 May 2022 | Early access publication date: 12 June 2022 | Final publication date: 1 September 2022

© 2022 by the author(s). License MSA, Podgorica, Montenegro. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY).

Conflict of interest: None declared.

characterize their organization, with implications for designing strategies to achieve success (Travassos, Davids, Araújo, & Esteves, 2013; Sarmento et al., 2018).

Success in football is dependent on the cooperative and competitive interactions between individuals (Ribeiro, Silva, Duarte, Davids, & Garganta, 2017; Aquino et al., 2018). Therefore, to identify the factors that lead to success in football, it is necessary to determine performance indicators that significantly distinguish winners from losers (Lepschy, Wäsche, & Woll, 2018). For instance, some studies have reported that running performance is not the best discriminator between successful and unsuccessful teams (Hoppe, Slomka, Baumgart, Weber, & Freiwald, 2015; Asian Clemente et al., 2019), while other studies have reported that technical variables were important discriminators between winners and losers (Lago-Peñas, Lago-Ballesteros, Dellal, & Gómez, 2010; Castellano, Casamichana, & Lago, 2012; Zhou, Zhang, Lorenzo Calvo, & Cui, 2018). In general, there is a global consensus that technical parameters should be observed as better predictors of success in football than pure physical parameters (Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2009; Lago-Peñas et al., 2010; Lago-Peñas, Lago-Ballesteros, & Rey, 2011; Castellano et al., 2012; Liu, Gómez, Gonçalves, & Sampaio, 2016).

However, most of the previous studies utilized technical variables separately, one by one. Such a unidimensional approach is incapable of describing a multidimensional view of football performance, seen as a combination of different technical features (Pappalardo & Cintia, 2018). To the best of our knowledge, only two multidimensional approaches are known to be valid for determining the technical performance of players: sports profiling techniques and position-specific performance statistics indices (InStat index) (Butterworth, O'Donoghue, & Cropley, 2013; Modric, Versic, Sekulic, & Liposek, 2019).

The basic principle of the sports profiling technique is to combine a set of valid and reliable performance-related variables within a given sport to properly describe a certain performance/performer using normative match data (Butterworth et al., 2013). Not surprisingly, authors have regularly applied this technique to assess technical performance among football players (Liu, Yi, Giménez, Gómez, & Lago-Peñas, 2015; Liu et al., 2016; Konefał et al., 2018). Despite its anticipated usefulness, the InStat index is a relatively new technique for assessing technical performance in football. In detail, the InStat index is calculated on the basis of a unique set of key parameters for each playing position (i.e., 12–14 performance parameters, depending on the playing position), with a higher numerical value indicating better performance (Modric, Versic, & Sekulic, 2020). While sports profiling techniques use the same variables to evaluate technical performance at different playing positions, the InStat index uses position-specific variables (i.e., different for each playing position) to determine technical performance at different playing positions. Considering that different playing positions require different tactical roles, which means different technical performances as well (Konefał et al., 2019b), it is questionable whether the InStat index can be used as a tool for assessing position-specific technical performances in football.

The validity of the InStat index has been demonstrated recently using data from the Croatian league (Modric et al., 2019). Specifically, authors confirmed the validity of the InStat index throughout the analysis of the association between InStat index parameters and final game achievement in Croatian professional football, indicating higher technical performance when teams win (Modric et al., 2019). However, that study did not include important indicators of the team achievement, such as position on the table or earned points (Modric et al., 2019). Collectively, to the best of our knowledge, there is no information on how technical performance evaluated by the InStat index affects team success. Therefore, the main objective of this study was to identify the association between technical performance evaluated with the InStat index and (i) match outcome, (ii) team achievement in elite football, specifically the UEFA Champions League (UCL). The authors were of the opinion that the findings could enable a better understanding of the technical performances of the most successful football teams in the world. Initially, we hypothesized that better values of technical performance evaluated with the InStat index would be associated with the success of teams competing in the UCL.

Methods

Participants and Design

Participants (n=179) in this study were top-elite football players from teams that competed in the group stage of the UEFA Champions League in the 2020/21 season. All technical performances, evaluated by the InStat index, were obtained from the 20 matches from groups A (n=3), B (n=3), C (n=4), E (n=4), F (n=3) and G (n=3), resulting in 244 technical performances used as cases for this study. Only the results of those players who participated in whole matches were analyzed. Goalkeepers were excluded from the analysis due to the specificity of the position. Players' performance were divided according to football-specific playing positions as follows: central defenders (CD; n=79), fullbacks (FB; n=65), central midfielders (CM; n=55), wide midfielders (WM; n=28), and forwards (FW; n=17).

Technical performances (i.e., values of the InStat index) were classified according to the: (i) match outcomes of analyzed matches (win: n=68, draw: n=96, lost: n=80); (ii) qualification of the team from the group stage into the knockout stage of the UCL (qualified: n = 99, not-qualified: n=145); and (iii) final position at the end of the group stage of the UCL (1^{st}; n=51, 2^{nd}; n=48, 3^{rd}; n=73, 4^{th}; n=72). The investigation was approved by the Ethical Board of Faculty of Kinesiology, University of Split.

Procedures

Technical performances for each player were evaluated by the position-specific InStat index (InStat Limited, Limerick, Republic of Ireland). The InStat index is calculated on the basis of a unique set of key parameters for each playing position (12–14 performance parameters, depending on the position during the game), with a higher numerical value indicating better performance. The exact calculations are trademarked and known only to the manufacturer of the platform. In the most general terms, an automatic algorithm considers the player's contribution to the team's success, the significance of his or her actions, the opponent's level and the level of the competition in which the team plays (i.e., the same performance in the European Champions League and some national-level first division play is not rated with the same values). The rating is created automatically, and each parameter has a factor that changes depending on the number of actions and events in the match. The weight of the action factors differs depending on the player's position. For example, grave mistakes made by

DOI 10.26773/mjssm.220901

CDs and their frequency affect the InStat index to a greater extent than those made by FWs. The key factors included in the calculation of the InStat index are position specific and include tackling, aerial duels, set pieces in defense, and interceptions (for CDs); number of crosses, number of passes to the penalty area, and pressing (for FBs); playmaking, number of key passes, and finishing (for CMs); pressing, dribbling, finishing, and counterattacking (for WMs); and shooting, finishing, pressing, and dribbling (for FWs). To calculate the InStat index, the player must spend a certain amount of time on the field and perform a minimum number of actions, but in this study, this issue was resolved simply by including only those players who played the whole game. The example calculation of InStat index is presented in Figure 1. The use of the InStat index has appeared in previous studies (Modric et al., 2019; Modric et al., 2020).

Technical parameters	Quantity / percentage	Factor
Pass accuracy	83.60%	1.075104
Key and extra-attacking passes	1	1.075104
Accurate passes into the box	1	1.024528
Shots (number)	0	1.007670
Share of successful dribbles	23.10%	1.041387
Participation in the goal attack	25%	1.053333
Grave mistakes	0	1.007670
Inaccurate key and extra-attacking passes	1	1.016667
Share of challenges won	90.10%	1.142537
Shots wide	1	1.016667
	Multiplying all factors	= 1.557639
	The weighted match level coefficient that takes into account the player's level, and the levels of his team-mates and opponents	= 0.9988165276
	Base level of the InStat index	= 220
The final InStat indeks = 1.557639 x 0.9988165276 x 220 = 342		

** Not all technical parameters were included

Figure 1. Example of calculated InStat index for the fullback players

Team achievement in this study was defined by three criteria: (i) qualifying of the team from the group stage into the knockout stage of the UCL (Qualification); (ii) the final ranking of the team at end of the group stage of the UCL (Placement); and (iii) total group points earned at the end of the group phase of UCL competition (Points). The UCL group contained 8 groups, and each group consisted of 4 teams. After 6 played matches in the group, the first- and second-ranked teams from each group advanced for competition in the knockout stage, actually meaning that qualifying for the knockout stage promotes teams into the "best 16 teams" in Europe. Therefore, the teams were classified as either "qualified" (placed 1st and 2nd in the group) or "nonqualified" (placed 3rd and 4th in the group phase), observed as the first criterion of team achievement. Also, the final team rankings and total group points after all played matches in the group stage of the UCL were used as second and third criteria of team achievement, respectively.

Additionally, the variables in this study included match outcome (win, draw, loss) and playing positions (CD, FB, CM, WM, FW).

Statistics

The normality of the distributions was checked by the Kolmogorov-Smirnov test, and the statistics included means ± standard deviations. The homoscedasticity of all of the variables was confirmed by Levene's test.

Differences among playing positions in the InStat index were analyzed by ANOVA. The validity of the InStat index was checked in four phases.

As a preliminary analysis of this study we correlated technical variables obtained from technical performance-related match data and InStat index, in order to evaluate validity of InStat Index as an indicator of technical performance. For such purpose we calculated multiple regression analysis with technical variables as predictors, and InStat index as criterion. Multiple correlations (multiple R) and coefficient of determination (R^2) were calculated and reported for total sample.

In the first phase, the technical performances evaluated by the InStat index were associated with the final match outcome by one-way analysis of variance (ANOVA), with the match outcomes (loss, draw, win) as independent variables. The differences were established for the total sample of players and separately for each playing position. This process allowed for the identification of the validity of the InStat index as an indicator of the final match achievement for the total sample and for the five observed playing positions.

Next, technical performances evaluated by the InStat index were associated with team success indicators. Specifically, using two-factor ANOVA, the InStat index was associated with "Qualification" and "Placement" (as previously described in the Procedures section). For this procedure, "Qualification" (yes/no) and "Placement" (1st, 2nd, 3rd, 4th) were considered the main factors and were additionally checked for interaction (Position x Qualification). Apart from the F-test and significance, the effect size was determined through the calculation of partial eta squared (η^2) (>0.02 is small; > 0.13 is medium; > 0.26 is large) (Ferguson, 2016).

In the last phase, Pearson's correlation was used to identify associations between the InStat index and total group points. Correlations were calculated for the total sample and stratified for playing positions.

The level of statistical significance was set at $p < 0.05$. For all of the analyses, Statistica software, version 13.0 (TIBCO Software Inc., Greenwood Village, CO, USA), was used.

Results

Technical variables as predictors obtained from technical performance-related match data were significantly correlated with InStat index as criterion, evidencing the appropriate validity of InStat index as an indicator of technical performance during the game. In brief, predictors explained 60% of criterion's variance (Table 1). Significant partial influence (significant beta ponders) was evidenced for: defensive challenges won (0.77), total defensive challenges (-0.69), attacking challenges won (0.40), percent of accurate passes (0.48), percent of tackles won (0.19), total shots (0.16) and assists (0.12).

Table 1. Multiple regression calculation with technical variables as predictors and InStat index as criterion

	β	Std.Err. β	b	Std.Err. b	t(206)	p
Intercept			24.27	56.83	0.43	0.67
Goals	0.15	0.12	24.01	18.77	1.28	0.20
Assists	0.12	0.05	18.31	8.02	2.28	0.02
Chances	0.03	0.09	1.25	4.15	0.30	0.76
Chances created	0.01	0.12	0.77	6.17	0.12	0.90
Chances successful	0.11	0.12	15.26	16.64	0.92	0.36
Shots	0.16	0.08	6.49	3.02	2.15	0.03
Shots on target	0.17	0.12	11.90	8.82	1.35	0.18
Shots on target (%)	-0.16	0.09	-20.89	12.20	-1.71	0.09
Passes	1.55	0.81	2.85	1.49	1.91	0.06
Passes accurate	-1.62	0.85	-3.06	1.61	-1.90	0.06
Passes accurate (%)	0.48	0.13	253.24	66.66	3.80	0.00
Key passes	0.14	0.10	6.27	4.22	1.48	0.14
Key passes accurate	0.05	0.12	3.29	8.29	0.40	0.69
Crosses	0.00	0.09	-0.10	1.92	-0.05	0.96
Crosses accurate	0.13	0.11	7.20	6.19	1.16	0.25
Accurate crosses (%)	-0.05	0.08	-9.71	13.72	-0.71	0.48
Lost balls	0.06	0.11	0.69	1.31	0.53	0.60
Lost balls in own half	-0.02	0.06	-0.59	1.90	-0.31	0.76
Ball recoveries	0.05	0.10	0.62	1.24	0.50	0.62
Ball recoveries in opponent's half	-0.01	0.06	-0.32	1.85	-0.17	0.86
Defensive challenges	-0.69	0.21	-7.40	2.28	-3.25	0.00
Defensive challenges won	0.77	0.25	10.65	3.44	3.09	0.00
Defensive challenges won (%)	-0.03	0.11	-5.50	19.71	-0.28	0.78
Attacking challenges	-0.32	0.20	-2.70	1.71	-1.58	0.12
Attacking challenges won	0.40	0.18	6.53	2.94	2.23	0.03
Attacking challenges won (%)	-0.07	0.07	-9.65	9.73	-0.99	0.32
Air challenges	0.18	0.15	2.63	2.26	1.16	0.25
Air challenges won	-0.19	0.18	-3.87	3.63	-1.07	0.29
Air challenges won (%)	0.06	0.07	7.20	9.13	0.79	0.43
Dribbles	-0.05	0.16	-1.03	3.19	-0.32	0.75
Dribbles successful	0.07	0.18	1.96	4.98	0.39	0.69
Dribbles successful (%)	0.04	0.08	4.33	7.87	0.55	0.58
Tackles	0.09	0.13	1.82	2.81	0.65	0.52
Tackles successful	-0.04	0.16	-1.23	4.64	-0.26	0.79
Tackles won (%)	0.19	0.09	21.87	10.04	2.18	0.03
Ball interceptions	0.03	0.07	0.41	0.94	0.44	0.66
Free ball pick ups	0.07	0.06	1.10	0.83	1.32	0.19
R	0.77					
R^2	0.60					
p	0.001					

Intercept – interception coefficient, β – standardized regression coefficient, B – non-standardized regression coefficient, R – coefficient of the multiple correlation, R^2 – coefficient of determination

 DOI 10.26773/mjssm.220901

There were no differences in the InStat index among players at different playing positions (F-test: 0.57; p=0.68; η2=0.009). Specifically, the average values of InStat index were: CD=290±46, FB=292±43, CM=282±40, WM=293±46, and FW=281±43.

Table 2 presents results of multifactorial ANOVA calculations for: (i) match outcome x playing position, (ii) placement x playing position, and (iii) qualification x playing position. In all three calculations, achievement of the teams (match outcome, placement, and qualification) were found as significant main effects, evidencing the significant influence of InStat on achievement of the teams.

Table 2. Multifactorial ANOVA of InStat index with (i) Match outcome and Playing position, (ii) Placement and Playing position, (iii) Qualification and Playing position as main factors

	Main factors		Interaction
	Match outcome	Playing position	Match outcome x Playing position
F test	22.33	0.96	1.47
p	0.001	0.43	0.17
η^2	0.16	0.02	0.05
	Placement	Playing position	Placement x Playing position
F test	17.09	1.66	1.01
p	0.001	0.16	0.44
η^2	0.16	0.03	0.05
	Qualification	Playing position	Qualification x Playing position
F test	44.25	1.32	0.91
p	0.001	0.26	0.46
η^2	0.16	0.02	0.02

Differences in the InStat index for total sample and stratified for playing positions, with regard to match outcome (win, draw, loss) are presented in Figure 2. When total sample was observed (i.e. not dividing players according to playing position) players achieved significantly higher (F-test=26.52, p<0.01) values of the InStat index when their teams won the matches and the lowest values when their teams lost the matches (312 and 264, respectively). Similar associations were found for CD (F-test=8.61, p<0.01), FB (F-test=12.68, p<0.01), WM (F-test=4.67, p<0.02), and FW (F-test=5.36, p<0.02).

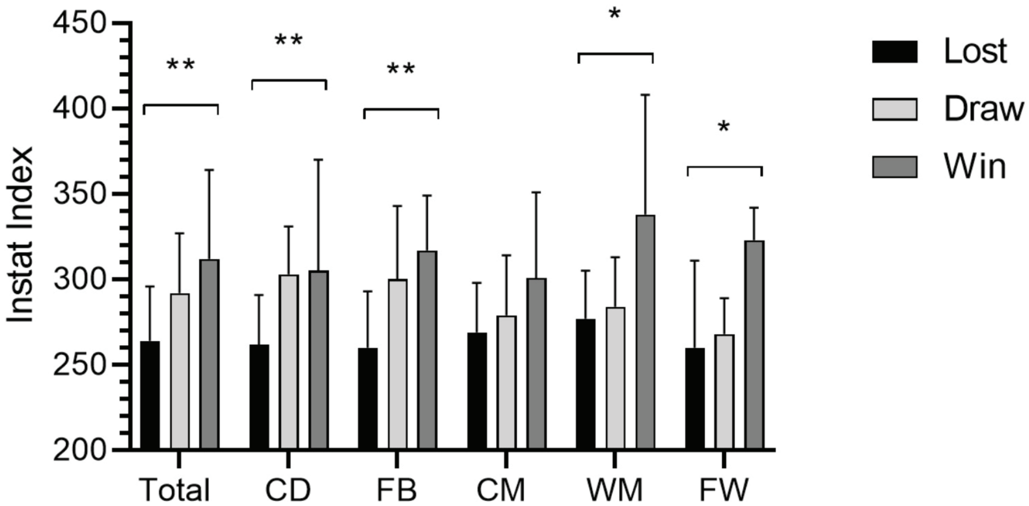


Figure 2. Differences in the InStat index according to the match outcome (win, draw and loss) for total sample and for specific playing positions. ** p<0.01; * p<0.05

Values of InStat index were higher for the players who played in teams that have been qualified from group stage of Champions league (CD=306, FB=323, CM=308, WM=327, FW=296) when compared to those who did not (CD=277, FB=272, CM=264, WM=278, FW=268). Significant association between InStat index and achievement of the teams observed as a qualification for knock-out phase are evidenced for total sample (F-test=59.6), CD (F-test=8.33), FB (F-test=32.06), CM (F-test=21.58), WM (F-test=9.13) (all p<0.01) (Figure 3).

In general, the highest InStat index was found among players who played on teams that finished as first ranked in the UCL group stage, followed by players who played on 2nd- and 3rd-ranked teams (315, 308 and 279, respectively). The lowest InStat index was found for players who played in bottom-ranked teams (266). Observing playing positions, the results indicated that FB, CM and FW with the highest values of the InStat index were first ranked, while CD and WM with the highest InStat indices were second ranked at the end of the UCL group stage (Table 3)

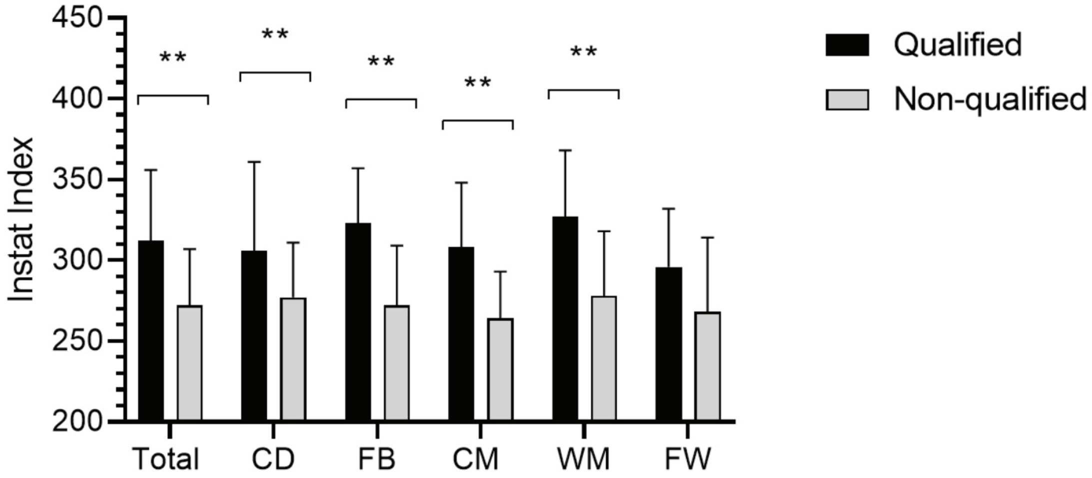


Figure 3. Differences in the players' InStat index according to the qualification of their teams from the group stage of UCL. ** - indicates significant post-hoc differences at p<0.01

InStat index was significantly correlated (all p<0.01) with total points in the group for total sample (r=0.46) and specifically for CD (r=0.33), FB (r=0.59), CM (r=0.54) and FW (r=0.49). Correlation between InStat index and total points in the group was 0.41, but did not reach level of statistical significance (p=0.10)

Table 3. Descriptive statistics and differences of InStat Index in relations to final position in the group stage UCL (data are given as Means ± Standard deviations)

	Placement				ANOVA		
	1st	2nd	3rd	4th	F-test	p	η^2
Total sample (n=244)	315±48 [3, 4]	308±40 [3, 4]	279±37 [1, 2]	266±33 [1, 2]	21.64	0.01	0.21
Central defenders (n=79)	301±77	310±29 [4]	290±38	267±28 [2]	3.92	0.01	0.13
Fullbacks (n=65)	334±31 [3, 4]	311±34 [4]	274±30 [1]	270±43 [1, 2]	11.73	0.01	0.36
Central midfielders (n=55)	312±33 [3, 4]	303±46 [4]	268±28 [1]	259±32 [1, 2]	7.38	0.01	0.3
Wide midfielders (n=28)	316±12	366±94	281±46	273±32	4.03	0.02	0.33
Forwards (n=17)	313±22	280±43	286±66	254±19	1.56	0.25	0.26

Superscripted numbers indicate significant post-hoc differences in InStat index ([1]significantly different from first position, [2]significantly different from second position, [3]significantly different from third position, [4]significantly different from forth position)

Discussion

The main objective of this study was to identify associations between the technical performances of football players, and achievement of their teams, in the most elite football competition in the world – the UCL. The results revealed that technical performances evaluated by the InStat index were associated with: (i) match outcome; (ii) qualification from the group stage of the UCL; (iii) final ranking in the group stage of the UCL; and (iv) total group points. Specifically, criterion-related validity indicated higher players' InStat index when: (i) teams won the match; (ii) teams were qualified into the knockout phase; (iii) teams achieved better placement on the table; and (iv) teams earned more group points. Therefore, our initial hypothesis can be accepted.

Playing positions and InStat index

Football players at different playing positions require different technical abilities (Konefał et al., 2019b). The InStat index is a relatively new tool that provides a unique measure for evaluating position-specific technical performance (i.e., abilities) in football. Previous works demonstrated that InStat index in general cannot be compared across playing positions (Modric et al., 2019; Modric et al., 2020). In detail, Modric et al., in their two recent studies, did not indicate differences in the InStat index for different playing positions in the Croatian National Championship. In support, our results did not show significant differences in the InStat index among UCL players playing at different positions (F test=0.57, p>0.05). Therefore, the lack of differences among playing positions in InStat index indicates that this index might be observed as an applicable measure of position-specific technical performance in top-elite football.

Next, it must be emphasized that InStat index is not comparable across the different competitions due to the specificity of the algorithm, which includes the level of competition as one of the factors in the calculation (please see Methods section for details). For example, the equal technical performance in the UCL, and in some national-level competition will not be rated with the same values simply because higher performance-level of UCL logically implies better opponent. In other words, since the UCL is the most prestigious club football competition in the world (Lago-Peñas et al., 2011), the technical performances of the players from the UCL will be additionally pondered, which will consequently result in higher values of InStat index for UCL performances. Therefore, technical performances evaluated by InStat index are exclusively comparable within the same competition.

DOI 10.26773/mjssm.220901

Match outcome and InStat index

A previous study performed in the Croatian National Championship demonstrated that the InStat index was related to the final match outcome and consequently should be considered a valid measure of final team achievement at that competitive-level (Modric et al., 2019). In brief, the authors indicated higher values of the InStat index when winning for all playing positions, and these findings actually confirmed the criterion validity of the InStat index in the evaluation of final match achievement (observed as criterion variable) in Croatian professional football. However, to confirm applicability in the UCL the validity of the InStat index should be verified utilizing data observed from the matches played in the UCL.

To the best of our knowledge, this study is the first in which the InStat index was validated in the UCL, and the results indicated the highest values of the InStat Index when teams won matches, followed by lower values when teams played to draws, and the lowest InStat values when teams lost matches. This trend is particularly evident for FB, WM, FW and CD (large to moderate effect sizes). Although the association between the InStat index and team achievement did not reach the required statistical significance for CM (p=0.06), the equal trend of results (i.e., better InStat index for won matches) was also evident for this position. Altogether, results supported previous considerations that technical performance are important determinant for achieving positive match outcome in elite football competitions (Konefał et al., 2018). Specifically, the fact that higher technical performance contributed to winning matches in the UCL was the first phase in confirmation of the criterion-validity of the InStat index in the evaluation of achievement in the UCL.

Achievement in the group stage of UCL

To additionally evaluate the criterion-related validity of the InStat index, we observed players' InStat index in relation to their team achievement in the group stage of UCL. Our results consistently indicated higher values of the InStat index for the players of the teams that were qualified from the group-stage UCL than for their peers who played for teams that did not qualify. Basically, these findings indicate that (i) technical performance is a highly important discriminator between successful and unsuccessful teams (Lago-Peñas et al., 2010; Castellano et al., 2012; Zhou et al., 2018), (ii) InStat index should be considered as valid measure of technical performance in football of most advantageous level.

In the third phase, we validated InStat index with regard to final position of the team in UCL group. Specifically, results indicated strong association between InStat index and the final position of the team Specifically, the InStat index was highest among players that played on teams that finished as first ranked in the UCL group stage, followed by players who played on 2nd-and 3rd-ranked teams (315, 308 and 279, respectively). The lowest InStat index was found in players who played on bottom-ranked teams (i.e., 4th position in the group) (Table 4). These findings once again demonstrated that higher technical performance contributes to greater achievement in football (Rampinini et al., 2009; Konefał et al., 2018).

However, it should be noted here that extended analysis of the InStat index according to the different playing positions revealed that CDs and WMs from the first ranked teams did not achieve the highest InStat index. In detail, the highest InStat index was achieved by CDs and WMs from the teams that finished in the second positions in the UCL group stage. Since this issue was not evident when observing a larger sample (i.e., total sample), the authors believe that these results were influenced by a limited number of observations when players were divided into smaller groups (i.e., according to the playing positions), limiting the possibility of reaching appropriate statistical significance of correlations (Huck, 2011). Also, it is possible that technical performances of some other playing positions, and not CDs and WMs are more important in achieving the success in UCL, but it should be studied in more details in future studies.

All of the previously discussed findings of proper criterion-related validity of the observed measurement tool can be additionally supported by analysing associations between the InStat index and total group points at the end of the group stage of the UCL (Table 5). In particular, our results showed moderate correlations between the InStat index and total group points for the total sample (r=0.46), and specifically for each playing position (r=0.33–0.59). It should certainly be emphasized that only for WMs was the numerical value of the correlation not statistically significant (p=0.10). Since the correlation coefficient for this group is still reasonably high (r=0.41), these findings indicate the existence of a relationship between players' technical performance (i.e., evaluated by the InStat index) and the achievement of their teams defined by total group points.

Collectively, the results from our study demonstrated that achieving greater technical performance enables: (i) more points to be earned, (ii) higher final ranking at the end of the group stage in the UCL, which altogether result in qualification to the knockout stage and promotion of teams to the 16 best in Europe. These findings actually support the previous idea that overall technical and tactical effectiveness likely has a large impact on results and a team's final league ranking in football (Carling, 2013; Asian Clemente et al., 2019), but also point to proper criterion related validity of the InStat index in the evaluation team-achievement in the UCL.

Limitations and Strengths

This study did not analyse all of the matches from the group stage of the UCL. Specifically, only 20 randomly selected matches were observed. Additionally, because of methodological reasons, only players who played whole matches were included in analysis. This limitation reduced the number of observations when the total sample was divided according to playing positions, which could have affected the results obtained for the InStat index. Further, the team indicators of the number of goals conceded and scored were not analysed, nor was the goal difference achieved toward the criterion for differences between teams' success rates. On the other hand, this study included matches and players involved in the most prestigious football competition in the world and provided information on validity of the specific and widely used measurement tool for monitoring technical performances of football players. Additionally, since the evaluated tool was clearly related to match outcomes and to success of the teams, this study demonstrated that InStat index parameters can be important discriminators between successful and unsuccessful teams. Furthermore, the position-specific approach from this study enabled insight into the individual technical performances of top-elite football players, specifically for each playing position.

Conclusion

The findings from this study confirmed that the InStat index is a valid discriminator of differences between successful and unsuccessful teams. Specifically, criterion-related validity indicated higher technical performance of the players (i.e., higher InStat index) when their teams: (i) won matches; (ii) qualified into the knockout; (iii) achieved a higher position on the table; and (iv) earned more points in the group phase of the UCL. Furthermore, the results from our study supported previous studies reporting that technical performance is an important discriminator between successful and unsuccessful teams.

Since position-specific analysis of the InStat index did not indicate differences among playing positions, this index might be observed to be an applicable measure of position-specific technical performance in top-level football. Simply stated, higher numerical values of the InStat index indicate better technical performance. This fact will enable football practitioners to monitor the technical performances of top-elite football players without addressing a large amount of data.

This study provided data about the validity and applicability of the observed measurement tool in the UCL, which is known to be the most prestigious football competition in the world. However, since the InStat index is derived on the basis of specific parameters and specifically scored for different competitive levels, further analyses are needed to validate this measurement tool in other competitions and competitive levels.

Acknowledgements

Support of the Croatian Science Foundation is gratefully acknowledged (grant number DOK-2020-01-9298). Authors are particularly grateful to InStat Limited, Limerick, Republic of Ireland for providing the data used in the study.

References

Aquino, R., Carling, C., Palucci Vieira, L., Martins, G., Jabor, G., Machado, J., & Puggina, E. (2018). Influence of situational variables, team formation, and playing position on match running performance and social network analysis in brazilian professional soccer players. *J Strength Cond Res.*

Asian Clemente, J. A., Requena, B., Jukic, I., Nayler, J., Hernández, A. S., & Carling, C. (2019). Is physical performance a differentiating element between more or less successful football teams? *Sports, 7*(10), 216.

Butterworth, A., O'Donoghue, P., & Cropley, B. (2013). Performance profiling in sports coaching: A review. *International Journal of Performance Analysis in Sport, 13*(3), 572-593.

Carling, C. (2013). Interpreting physical performance in professional soccer match-play: should we be more pragmatic in our approach? *Sports medicine, 43*(8), 655-663.

Castellano, J., Casamichana, D., & Lago, C. (2012). The use of match statistics that discriminate between successful and unsuccessful soccer teams. *Journal of Human Kinetics, 31*, 137-147.

De Albuquerque Freire, L., Brito, M. A., Muñoz, P. M., Pérez, D. I. V., Kohler, H. C., Aedo-Muñoz, E. A., . . . Znazen, H. (2022). Match Running Performance of Brazilian Professional Soccer Players according to Tournament Types. *Montenegrin Journal of Sports Science and Medicine, 11*(1), 53-58.

Ferguson, C. J. (2016). An effect size primer: A guide for clinicians and researchers.

Hoppe, M., Slomka, M., Baumgart, C., Weber, H., & Freiwald, J. (2015). Match running performance and success across a season in German Bundesliga soccer teams. *International journal of sports medicine, 36*(07), 563-566.

Huck, S. W. (2011). *Reading Statistics and Research*: Pearson Education.

Konefał, M., Chmura, P., Zacharko, M., Chmura, J., Rokita, A., & Andrzejewski, M. (2018). Match outcome vs match status and frequency of selected technical activities of soccer players during UEFA Euro 2016. *International Journal of Performance Analysis in Sport, 18*(4), 568-581.

Konefał, M., Chmura, P., Zając, T., Chmura, J., Kowalczuk, E., & Andrzejewski, M. (2019a). Evolution of technical activity in various playing positions, in relation to match outcomes in professional soccer. *Biology of sport, 36*(2), 181.

Konefał, M., Chmura, P., Zając, T., Chmura, J., Kowalczuk, E., & Andrzejewski, M. (2019b). A new approach to the analysis of pitch-positions in professional soccer. *Journal of Human Kinetics, 66*, 143.

Lago-Peñas, C., & Lago-Ballesteros, J. (2011). Game location and team quality effects on performance profiles in professional soccer. *Journal of sports science & medicine, 10*(3), 465.

Lago-Peñas, C., Lago-Ballesteros, J., Dellal, A., & Gómez, M. (2010). Game-related statistics that discriminated winning, drawing and losing teams from the Spanish soccer league. *Journal of sports science & medicine, 9*(2), 288.

Lago-Peñas, C., Lago-Ballesteros, J., & Rey, E. (2011). Differences in performance indicators between winning and losing teams in the UEFA Champions League. *Journal of Human Kinetics, 27*, 135-146.

Lepschy, H., Wäsche, H., & Woll, A. (2018). How to be successful in football: a systematic review. *The Open Sports Sciences Journal, 11*(1).

Liu, H., Gómez, M.-A., Gonçalves, B., & Sampaio, J. (2016). Technical performance and match-to-match variation in elite football teams. *Journal of sports sciences, 34*(6), 509-518.

Liu, H., Yi, Q., Giménez, J.-V., Gómez, M.-A., & Lago-Peñas, C. (2015). Performance profiles of football teams in the UEFA Champions League considering situational efficiency. *International Journal of Performance Analysis in Sport, 15*(1), 371-390.

Memmert, D., Lemmink, K. A., & Sampaio, J. (2017). Current approaches to tactical performance analyses in soccer using position data. *Sports medicine, 47*(1), 1-10.

Modric, T., Versic, S., & Sekulic, D. (2020). Aerobic fitness and game performance indicators in professional football players; playing position specifics and associations. *Heliyon, 6*(11), e05427.

Modric, T., Versic, S., & Sekulic, D. (2021). Relations of the Weekly External Training Load Indicators and Running Performances in Professional Soccer Matches. *Sport Mont, 19*(1), 31-37.

Modric, T., Versic, S., Sekulic, D., & Liposek, S. (2019). Analysis of the Association between Running Performance and Game Performance Indicators in Professional Soccer

 DOI 10.26773/mjssm.220901

Players. *International journal of environmental research and public health, 16*(20), 4032.

Pappalardo, L., & Cintia, P. (2018). Quantifying the relation between performance and success in soccer. *Advances in Complex Systems, 21*(03n04), 1750014.

Rampinini, E., Impellizzeri, F. M., Castagna, C., Coutts, A. J., & Wisløff, U. (2009). Technical performance during soccer matches of the Italian Serie A league: Effect of fatigue and competitive level. *Journal of science and medicine in sport, 12*(1), 227-233.

Ribeiro, J., Silva, P., Duarte, R., Davids, K., & Garganta, J. (2017). Team sports performance analysed through the lens of social network theory: implications for research and practice. *Sports medicine, 47*(9), 1689-1696.

Sarmento, H., Clemente, F. M., Araújo, D., Davids, K., McRobert, A., & Figueiredo, A. (2018). What performance analysts need to know about research trends in association football (2012–2016): A systematic review. *Sports medicine, 48*(4), 799-836.

Travassos, B., Davids, K., Araújo, D., & Esteves, T. P. (2013). Performance analysis in team sports: Advances from an Ecological Dynamics approach. *International Journal of Performance Analysis in Sport, 13*(1), 83-95.

Yi, Q., Jia, H., Liu, H., & Gómez, M. Á. (2018). Technical demands of different playing positions in the UEFA Champions League. *International Journal of Performance Analysis in Sport, 18*(6), 926-937.

Zhou, C., Zhang, S., Lorenzo Calvo, A., & Cui, Y. (2018). Chinese soccer association super league, 2012–2017: key performance indicators in balance games. *International Journal of Performance Analysis in Sport, 18*(4), 645-656.

OPEN ACCESS

REVIEW PAPER

Genetic Variants that Influence Performance on the Wingate Anaerobic Test: A Systematic Review

Arkaitz Castañeda-Babarro[1], Paula Etayo-Urtasun[1], Patxi Leon-Guereño[1]

Affiliations: [1]Health, Physical Activity and Sports Science Laboratory, Department of Physical Activity and Sports, Faculty of Education and Sport, University of Deusto, Bizkaia, Spain

Correspondence: A. Castañeda-Babarro, University of Deusto, Faculty of Education and Sport, Avenida de las Universidades 24, 48007, Bilbao, Bizkaia, Spain. E-mail: arkaitz.castaneda@deusto.es

Abstract

Anaerobic performance is decisive in many sports. The Wingate Anaerobic Test (WAnT) is the most widely used test for the assessment of anaerobic performance to date. Performance in this test is influenced by many variables, including genetics. The aim of this review is to analyze the genes related to WAnT performance. A detailed search of four databases (Pubmed, Scopus, Web of Science and Cochrane Library) was conducted until February 2022. This literature search was implemented according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement. Nine eligible studies were selected from the 153 records identified. 3 articles for the ACTN3 gene, 2 for AMPD, one combined ACTN3 and AMPD, 1 article each for PPARA, UCP2 and MCT1. The genes ACTN3 and AMPD seem to report contradictory literature regarding its influence on WAnT peak power (PP), mean power and fatigue index. The MCT1 gene seems to have no influence, and the PPARA and UCP2 genes seem to have a positive relationship with PP.

Keywords: *polymorphism, gene, performance, power, supramaximal*

@MJSSMontenegro
GENETIC VARIANTS THAT INFLUENCE PERFORMANCE
http://mjssm.me/?sekcija=article&artid=237

Cite this article: Castañeda-Babarro, A., Etayo-Urtasun, P.,& Leon-Guereño, P. (2022). Genetic Variants that Influence Performance on the Wingate Anaerobic Test: A Systematic Review. *Montenegrin Journal of Sports Science and Medicine*, 11 (2), 13–19. https://doi.org/10.26773/mjssm.220902

Introduction

The vast majority of sports require high intensity stimuli such as jumps or sprints (Baker & Davies, 2002), which are often decisive in the final performance. For this reason, it is very important to be able to measure anaerobic power. Different tests have been designed for this purpose, such as cycling with the Wingate Anaerobic Test (WAnT) (Capostagno et al., 2016), 20-45 seconds linear sprints in running (Krops et al., 2017) or Counter Movement Jump or Squat Jump in jumping (Wen et al., 2018). However, the most commonly used protocol for assessing anaerobic metabolism is the WAnT, which is considered the gold-standard of anaerobic testing (Bertuzzi et al., 2015; Driss & Vandewalle, 2013; Madrid et al., 2013; Minahan et al., 2007). The WAnT requires pedalling with the lower or upper limbs for 30 seconds, at maximum speed and against a constant resistance (7.5% of the participant's body mass). The most important information we can obtain from the test is (Hopkins et al. 2001): peak power (PP): The highest level of power reached during the test is usually within the first 10 seconds if the test is performed correctly; mean power (MP): The average power reached during 30 seconds; and fatigue index (FI): it represents the loss of power experienced from the moment in which the maximum power is reached and the end of the test or, in other words, FI is the rate of decrease in power during the test, expressed as a percentage of the maximum power (Castañeda-Babarro, 2021).

Received: 02 May 2022 | Accepted after revision: 9 June 2022 | Early access publication date: 20 June 2022 | Final publication date: 1 September 2022

© 2022 by the author(s). License MSA, Podgorica, Montenegro. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY).

Conflict of interest: None declared.

There are many variables that can affect performance in WAnT. On the one hand, certain external variables may affect outcomes, such as listening to music during the test (Castañeda-Babarro et al., 2020), the resistance used in the cycle-ergometer (Hermina, 1999; Richmond et al., 2011), the warm-up carried out (Burnley & Doust, 2005; Ramierz et al., 2007) or carrying out the test with or without cleats (LaVoie et al., 1984).

On the other hand, internal variables can also influence the results achieved. It has been reported that in anaerobic tests such as the vertical jump genetic variables can play an important role in the final performance (Ostojić & Stojanović, 2010). Muniesa et al. (2016) observed how the ACE gene showed significant improvements with respect to the DD genotype in the Sargent test and the sprint speed test, while in the ACTN3 gene, the RR variable obtained improvement results with respect to the RX and XX variables in jumping and the Sargent test. Similarly, the ACTN3 and ACE genes have been related to sprint and power performance in elite athletes (Eynon et al., 2016).

In this sense, internal variables such as genetics also condition the final result of WAnT (Bondareva et al., 2017). Hanson et al. (2010) concluded that the ACTN3 genotype did not affect power output recorded in active but untrained men and young boys in the United States, whereas Atanasov et al. (2015) observed a predominance of the ACTN3 and AMPD1 genotypes in elite and sub-elite athletes compared to subjects with low levels of physical activity. In addition, Petr et al. (2014) saw how PPARA polymorphism was linked to greater power values among elite hockey players. In this sense, there are several studies related to the ACTN3 R577X polymorphism with conflicting findings. Whereas Norman et al. (2009) did not find any difference among the general population with regard to the performance of subjects with different genotypes, Kikuchi et al. (2014) reported differences in the performance of subjects (athletes) with different genotypes. Finally, Kikuchi et al. (2017) studied the influence of different genotypes of MCT1 T1470A polymorphism on WAnT performance, comparing national and international wrestlers with other less trained subjects, and found differences related to different genetic options.

Therefore, the main purpose of this systematic review was to analyze the association between genetic variants and different performance indicators in WAnT, such as. PP, MP and FI.

Methods

Literature searching strategies

The current publication is a systematic review of the genetic variants that influence performance on the WAnT. The research was conducted according to Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009; Stewart et al., 2015). A systematic search was conducted on PubMed/MEDLINE, Web of Science (WOS), Cochrane library and Scopus database. Appropriate bibliographic support was ensured with these databases, and the search was completed without being limited to any specific years, results being included until 7 February 2022. Combinations of the following keywords were used as search terms: ("Wingate MeSH" OR "Supramaximal anaerobic test MeSH") AND (Polimorphism OR Gen OR Genetic OR SNP). After conducting the initial search, the reference lists of the retrieved articles were then screened for other articles that were relevant to the topic as described by Greenhalgh and Peacock (2005). Articles were first screened by title and abstract, followed by a full-text review of all articles considered relevant.

Inclusion and exclusion criteria

To define the inclusion criteria, the PICOS model was used (O'Connor et al., 2008): P (Population): "female athletes or physically active women", I (Intervention): "wingate, C (Comparison): "same experimental condition with and placebo", O (Outcome): "physical and/or athletic performance measures" and S (study design): "random or double-blind and random design".

No filters were applied to level, gender, race or age (with participants over the age of 18 years). Inclusion criteria were: (I) There is a comparison between the WAnT results made in an identical way by the subjects; (II) Studied the effect of a genetic variable on the outcome obtained in WAnT; (III) Studies on a variety of genetic variables were accepted; (IV) studies with variations of the original WAnT protocol, assuming that it was applied to all participants in the same way; (V) only studies in which WAnT was applied to the lower body; cycling (VI) even if no PP, MP or FI data was provided.

The exclusion criteria listed below were also applied to the experimental protocols attached to the research: (I) studies that tested anaerobic metabolism but not with WAnT; (II) studies which used different outcomes other than PP, MP and FI obtained by the WAnT; (III) articles that do not relate WAnT with genetic variables; (IV) studies conducted on injured participants or on those suffering from medical conditions, injuries or drugs and (V) unpublished studies in PubMed/MEDLINE, WOS, Cochrane library or Scopus.

Study selection and data extraction

Once the inclusion/exclusion criteria were applied to each article, the following data were extracted: source of the study (author/s and year of publication); sample population (number of participants, sex and age), sample size, indicating the level of physical activity and sport discipline; intervention (test); parameters analyzed as a measure of physical/sport performance; and conclusion, the results of the effect of the gene/polymorphism on the parameters analyzed in the population. Finally, the final results of the interventions using a spreadsheet (Microsoft Inc, Seattle, WA, U.S.A) were extracted.

In addition, the snowball strategy was applied to review the reference sections of all the highlighted studies which returned relevant articles in the field of snowball strategy implementation (Palinkas et al., 2015). According to the information included in the full texts, the inclusion and exclusion criteria were applied in order to select the articles that could be included in this systematic review.

Outcome variables

The literature was examined for the effects of genetic variables on WAnT performance using the following outcome variables: PP, MP, and FI.

Quality assessment and risk of bias

To determine the quality of the evidence, the authors reviewed the considered articles and provided PEDro (Physiotherapy Evidence Database) scores for each article. Only studies with PEDro scores of 4 or higher were included in the systematic review. According to Maher et al. (2003), the PEDro scale is an 11-item scale designed for rating methodological quality of randomized control trials. Each satisfied item (except for item 1) contributes one point to the total PEDro

DOI 10.26773/mjssm.220902

score (0–10 points). The PEDro scores were extracted from the PEDro database. If a study had not been entered into the database and scored, it was reviewed and scored by an experienced PEDro rater.

Results

Main search

Of the 153 articles that were identified through the literature search, only nine studies fulfilled all the inclusion criteria for this systematic review (Figure 1). Firstly, 45 studies were removed because they were duplicates. Of the remaining 108 articles, a total of 98 studies were removed because their abstracts were not related to the objective of the review (92), did not make a comparison of the results in the WAnT (5) and because one article was only a correction of the last name of an author of a valid article. Of the 10 full-text articles assessed for eligibility, 1 further paper was disregarded because after reading the whole article, it was concluded that it was unrelated to the genes that influence performance on the Wingate Test. Thus, the current systematic review included

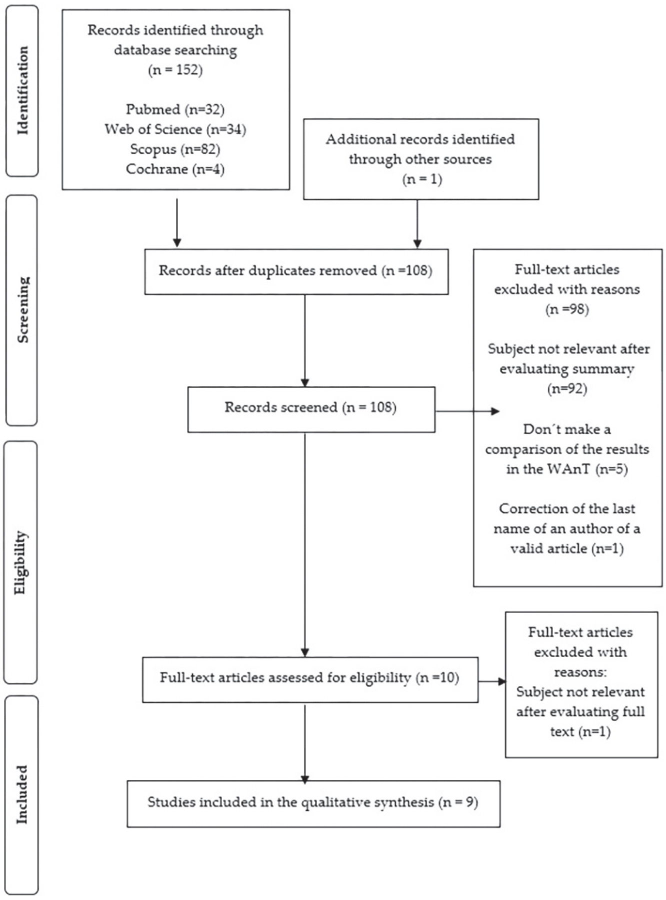


Figure 1. Flow chart of study selection

Table 1. Quality Assessment with the PEDro Scale

Article	Items by number on the PEDro Scale											Total score
	1	2	3	4	5	6	7	8	9	10	11	
Hanson et al. (2010)	Y	N	N	N	Y	Y	Y	Y	Y	Y	Y	7
Atanasov et al. (2015)	Y	N	N	Y	Y	Y	Y	Y	N	Y	Y	7
Fischer et al. (2007)	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	8
Petr et al. (2015)	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	8
Norman et al. (2001)	Y	N	Y	N	Y	N	N	Y	Y	Y	Y	6
Norman et al. (2009)	Y	N	Y	Y	Y	N	N	Y	Y	Y	Y	7
Kikuchi et al. (2014)	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	8
Bondareva et al. (2018)	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	6
Kikuchi et al. (2017)	Y	N	Y	N	Y	Y	Y	Y	Y	Y	Y	8

Note. N: criterion not fulfilled; Y: criterion fulfilled; 1: eligibility criteria were specified; 2: subjects were randomly allocated to groups or to a treatment order; 3: allocation was concealed; 4: the groups were similar at baseline; 5: all subjects were blinded; 6: all therapists were blinded; 7: all assessors were blinded; 8: measures of at least one key outcome were obtained from over 85% of the subjects who were initially allocated to groups; 9: intention-to-treat analysis was performed on all subjects who received the treatment or control condition as allocated; 10: the results of between-group statistical comparisons are reported for at least one key outcome; 11: the study provides both point measures and measures of variability for at least one key outcome; total score: each satisfied item (except the first) contributes 1 point to the total score, yielding a PEDro scale score that can range from 0 to 10.

nine studies (Atanasov et al., 2015; Bondareva et al., 2018; Fischer et al., 2007; Hanson et al., 2010; Kikuchi et al., 2017; Kikuchi et al., 2014; Norman et al., 2009; Norman et al., 2001; Petr et al., 2014).

Quality assessment of the experiments

The nine studies obtained a high-quality methodology score (PEDro score ≥5/10), with a mean score of 7.2, according to the PEDro scale (Table 1).

Genetic variables related to performance in WAnT

The characteristics of the participants and the characteristics of the protocols used in the different studies are shown in Tables 2 and 3. There were a total of 1791 participants included in the selected studies, of which at least 264 were women (the gender of some of the groups, such as the control, is not specified).

Table 2. Studies Included in the Systematic Review: Features of those Taking Part and of the Relevant Interventions

Variables	Classification	Articles
Level of participants	Not physically active	1 study (Bondareva et al., 2018)
	Physically active	3 studies (Fischer et al., 2007; Hanson et al., 2010; Norman et al., 2001)
	Athletes	4 studies (Bondareva et al., 2018; Kikuchi et al., 2017; Kikuchi et al., 2014; Norman et al., 2009)
	Elite or Sub Elite	2 studies (Atanasov et al., 2015; Petr et al., 2014)
Age of participants	18-25	2 studies (Atanasov et al., 2015; Kikuchi et al., 2014)
	18-35	4 studies (Hanson et al., 2010; Norman et al., 2009; Norman et al., 2001; Petr et al., 2014)
	18-45	1 study (Fischer et al., 2007)
	Not specified	2 studies (Bondareva et al., 2018; Kikuchi et al., 2017)
Resistance applied during the WAnT	7,5% of body weight	7 studies (Atanasov et al., 2015; Fischer et al., 2007; Hanson et al., 2010; Kikuchi et al., 2014; Kikuchi et al., 2017; Norman et al., 2001; Norman et al., 2009)
	0.091kg·kg^{-1} body mass	1 study (Petr et al., 2014)
	100 g/kg^{-1} (for men)	1 study (Bondareva et al., 2018)
Analized parameters during the WAnT	PP	8 studies (Atanasov et al., 2015; Bondareva et al., 2018; Fischer et al., 2007; Hanson et al., 2010; Kikuchi et al., 2014; Kikuchi et al., 2017; Norman et al., 2001; Norman et al., 2009; Petr et al., 2014)
	Mean power	6 studies (Atanasov et al., 2015; Fischer et al., 2007; Hanson et al., 2010; Kikuchi et al., 2017; Kikuchi et al., 2014; Norman et al., 2009; Norman et al., 2001)
	FI	1 study (Fischer et al., 2007; Hanson et al., 2010; Norman et al., 2009)
Way to obtain genetic material	Buccal cells	1 study (Bondareva et al., 2018; Hanson et al., 2010; Kikuchi et al., 2014)
	Blood	1 study (Atanasov et al., 2015; Fischer et al., 2007; Norman et al., 2009)
	Saliva	1 study (Kikuchi et al., 2017; Petr et al., 2014)
	Muscle biopsy and blood extraction	1 study (Norman et al., 2001)
Genes analyzed	ACTN3 R577X	3 studies (Atanasov et al., 2015; Hanson et al., 2010; Kikuchi et al., 2014; Norman et al., 2009)
	AMPD	2 studies (Atanasov et al., 2015; Fischer et al., 2007; Norman et al., 2001)
	PPARA	1 study (Petr et al., 2014)
	UCP2	1 study (Bondareva et al., 2018)
	MCT1	1 study (Kikuchi et al., 2017)

Note. WAnT: Wingate Anaerobic Test; PP: Peak power, FI: Fatigue index.

Discussion

A summary of the effects of different genes on WAnT performance constituted the chief aim of this systematic review. The main results indicate that while ACTN3 and AMPA have a contradictory influence (except PP in the ACTN3 gene), the MCT1 gene seems to have no influence, and the PPARA and UCP2 genes may have a positive relationship with PP. Regarding the number of articles found, it seems that the most studied polymorphisms have been ACTN3 and AMPD (ACTN3 n=3, AMPD n=2 and the two polymorphisms at the same time n=1).

According to the results, it can be observed that ACTN3 has been related to sports activities that require polymorphism, power and strength (Atanasov et al., 2015; Kikuchi et al., 2014), especially the R alleles (Atanasov et al., 2015), since ACTN3 is a protein that serves to stabilize the contraction of fast fibres. However, in explosive and anaerobic activities like jumping there is a contradictory literature. There are some studies that found a positive relationship between the R allele of this gene and performance (Massidda et al., 2014; Pimenta et al., 2013). However, the study by Ginevičienė et al. (2011) concluded that the X allele has a positive relationship with performance, whereas others do not find any relationship (Garatachea et al., 2014; Massidda et al., 2012). It has also been observed that this gene does not influence the muscle power obtained in a WAnT after an intense session (Hanson et al., 2010) and that the gene does not condition muscle strength or sprint performance of trained women and men again obtained by a WAnT (Norman et al., 2009). Regarding WAnT, the influence of the ACTN3 gene is contradictory for both PP and MP,

DOI 10.26773/mjssm.220902

whereas for FI there do not seem to be any studies to support its influence on WAnT performance. Until now it seemed that the gene was related to muscle power, but some research calls into question the positive influence of this gene (Hanson et al., 2010; Norman et al., 2009). However, some studies such as those by Atanasov et al. (2015) or Kikuchi et al. (2014) observed positive relationships. The differences in performance obtained in the anaerobic test may depend on the composition of the muscle fibres in the samples analysed, the type of training performed and the intensity and frequency (Norman et al., 2009) ultimately, to a large extent, depending on the subject. Furthermore, it should be noted that the experiments conducted focus exclusively on one test.

The AMPD1 gene regulates the cellular energy metabolism in high intensity sport activities (Atanasov et al., 2015). The AMPD1 deficiency of skeletal muscle leads to poor sport performance, a feeling of premature fatigue and a slowing of muscle contraction speed. Nevertheless, it can be argued that AMPD1 gene does not have a solid literature on its effect on the WAnT. Some sources of information also about this gene indicate that between genotypes of the AMPD1 gene, in terms of performance, there are no significant differences (Fischer et al., 2007; Norman et al., 2001), even if others say otherwise (Atanasov et al., 2015). Those contradictions may be due to the number and type of samples collected. It is not easy to gather large numbers of people who lack the gene when analysing AMPD1 deficiency, as only 2 percent of the Caucasian population develops it (Fischer et al., 2007). It should be noted that although in some cases no significant influence has been obtained in the WAnT between the ACTN3 and AMPD1 genotypes, it has been observed that the combination of both specific genes influences performance (PP) (Atanasov et al., 2015). Although there is only one research that studied the influence of this gene in WAnT on the IF variable, it appears that DMPA may have an influence on the ability to maintain "anaerobic fatigue" or anaerobic capacity (Fischer et al., 2007).

There is only one study included in this review that studied the relationship between the PPARA gene and WAnT performance, so the conclusions that can be drawn in this regard are limited. However, this gene is responsible for: fatty acid assimilation and oxidation, glucose and lipid metabolism, left ventricular growth and the regulation of the expression of genes involved in body weight control (Ahmetov & Fedotovskaya, 2015). Considering that this gene has previously been linked to performance in other anaerobic tests such as jumping (Ahmetov et al., 2013), and that the only article included in this review is along the same lines (Petr et al., 2014), it can be suggested that it may indeed have an influence on PP in this type of tests.

Regarding the UCP2 gene, it has been linked to weight acquisition and performance in sports requiring aerobic competition (Bondareva et al., 2018). In addition, it appears in most of the organs and tissues of the body, as well as in skeletal muscle. The Val/ala 55 allele of the UCP2 gene has been observed to be related to aerobic capacities and Val/ala 55 times with sports that require explosiveness (Bondareva et al., 2018). As with the previous gene, although we must be aware of the limitations of the small number of studies conducted on this gene and with this test, in view of what has been analyzed, it can be stated that the Val/ala55 polymorphism of this gene has a positive influence on the PP of the WAnT.

As for the MCT1 gene T170A, the expression of this gene increases with high intensity interval training, thus achieving lactate clearance and better regulation of muscle pH (Kikuchi et al., 2017). It can be said that the MCT1 gene T1704 appears to have no influence on the WAnT (PP and MP) and is not genotype dependent. Given its relation to lactate metabolism, it would have made sense to assess FI in the tests performed, as this value is more related to glycolytic metabolism than PP (Serresse et al., 1988).

Finally, it is necessary to take into account some limitations that condition the work. On the one hand, it is important to consider the limitations that the low number of articles found with some genes entails when drawing conclusions. On the other hand, of the three data that WAnT can report, such as PP, MP and FI, they were not measured in all the articles, limiting the study or the corresponding relationship with the gene investigated. In the case of FI, which is not found in all the included studies, it can provide valuable information on the subject's ability to withstand fatigue and relating it to genetics could also be of great interest. It is important to underline that we should not only take into account studies that use WAnT for the evaluation of anaerobic metabolism and its relationship with some genes, as there are many other tests. However, we must give the importance it deserves to a test considered as the gold standard and probably the most widely used in the scientific literature.

Conclusions

Based on the results obtained from this systematic review, the ACTN3 and AMPD1 genes seem to report contradictory literature regarding their influence on PP, MP and FI values of WAnT. The MCT1 gene appears to have no influence, and the PPARA and UCP2 genes appear to have a positive relationship with PP. Thus, this review shows the importance of genetics in one of the most important anaerobic tests. This is of great interest, as it could facilitate talent detection or even predict a subject's future anaerobic performance. However, few articles were found, so more research is needed in order to obtain more conclusive results. Furthermore, the importance of environmental and behavioral factors, as well as epigenetic variables, cannot be rejected, so the results should be interpreted with caution.

Ethical Approval Information

No Ethical Approval was necessary to present this review.

Funding

This research received no external funding, given that it is a systematic review.

References

Ahmetov, I. I., & Fedotovskaya, O. N. (2015). Chapter six-current progress in sports genomics. *Advances in Clinical Chemistry*, *70*, 247–314. https://doi.org/10.1016/bs.acc.2015.03.003

Ahmetov, I. I., Gavrilov, D. N., Astratenkova, I. V., Druzhevskaya, A. M., Malinin, A. V., Romanova, E. E., & Rogozkin, V. A. (2013). The association of ACE, ACTN3 and PPARA gene variants with strength phenotypes in middle school-age children. *The Journal of Physiological Sciences*, *63*(1), 79–85. https://doi.org/10.1007/s12576-012-0233-8

Atanasov, P., Djarova, T., Kalinski, M., Petrov, L., Kaneva, R., Mugandani, S., Watson, G., & Jemni, M. (2015). ACTN3 and AMPD1 polymorphism and genotype combinations in bulgarian athletes performing wingate test. *Journal of Sports Science*, *3*, 1–10. https://doi.org/10.17265/2332-7839/2015.01.001

Baker, J. S., & Davies, B. (2002). High intensity exercise assessment: Relationships between laboratory and field measures of performance. *Journal of Science and Medicine in Sport*, *5*(4), 341–347. https://doi.org/10.1016/S1440-2440(02)80022-6

Bertuzzi, R., Kiss, M. A. P. D. M., Damasceno, M., Oliveira, R., & Lima-Silva, A. E. (2015). Association between anaerobic components of the maximal accumulated oxygen deficit and 30-second wingate test. *Brazilian Journal of Medical and Biological Research*, *48*(3), 261–266. https://doi.org/10.1590/1414-431X20144043

Bondareva, E. A., Parfenteva, O. I., Kozlov, A. V., Zhuravleva, U. S., Kosyakova, E. V., Karelina, V. V., Ketlerova, E. S., & Son'kin, V. D. (2018). The Ala/Val polymorphism of the UCP2 gene is reciprocally associated with aerobic and anaerobic performance in athletes. *Human Physiology*, *44*, 673–678. https://doi.org/10.1134/S036211971806004X

Burnley, M., Doust J.H., & Jones, A. M. (2005). Effects of prior warm-up regime on severe cycling performance. *Medicine and Science in Sports and Exercise*, *37*(5), 838-845. https://doi.org/10.1249/01.mss.0000162617.18250.77

Capostagno, B., Lambert, M. I., & Lamberts, R. P. (2016). A systematic review of submaximal cycle tests to predict, monitor, and optimize cycling performance. *International Journal of Sports Physiology and Performance*, *11*(6), 707–714. https://doi.org/10.1123/ijspp.2016-0174

Castañeda-Babarro, A. (2021). The Wingate Anaerobic Test, a narrative review of the protocol variables that affect the results obtained. *Applied Sciences, 11*(16), 7417. https://doi.org/10.3390/app11167417

Castañeda-Babarro, A., Marqués-Jiménez, D., Calleja-González, J., Viribay, A., León-Guereño, P., & Mielgo-Ayuso, J. (2020). Effect of listening to music on Wingate Anaerobic Test performance. A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health*, *17*(12), 4564. https://doi.org/10.3390/ijerph17124564

Driss, T., & Vandewalle, H. (2013). The measurement of maximal (anaerobic) power output on a cycle ergometer: A critical review. *BioMed Research International*. https://doi.org/10.1155/2013/589361

Eynon, N., Hanson, E. D., Lucia, A., Houweling, P. J., Garton, F., North, K. N., & Bishop, D. J. (2013). Genes for elite power and sprint performance: ACTN3 leads the way. *Sports Medicine*, *43*(9), 803-817. https://doi.org/10.1007/s40279-013-0059-4

Fischer, H., Esbjörnsson, M., Sabina, R. L., Strömberg, A., Peyrard-Janvid, M., & Norman, B. (2007). AMP deaminase deficiency is associated with lower sprint cycling performance in healthy subjects. *Journal of Applied Physiology*, *103*(1), 315–322. https://doi.org/10.1152/japplphysiol.00185.2007

Garatachea, N., Verde, Z., Santos-Lozano, A., Yvert, T., Rodriguez-Romo, G., Sarasa, F. J., & Lucia, A. (2014). ACTN3 R577X polymorphism and explosive leg-muscle power in elite basketball players. *International Journal of Sports Physiology & Performance*, *9*(2), 226-232. https://doi.org/10.1123/ijspp.2012-0331

Ginevičienė, V., Pranckevičienė, E., Milašius, K., & Kučinskas, V. (2011). Gene variants related to the power performance of the Lithuanian athletes. *Central European Journal of Biology*, *6*, 48–57. https://doi.org/10.2478/s11535-010-0102-5

Greenhalgh, T., & Peacock, R. (2005). Effectiveness and efficiency of search methods in systematic reviews of complex evidence: audit of primary sources. *British Medical Journal.*, *331*(7524), 1064–1065. https://doi.org/10.1136/bmj.38636.593461.68

Hanson, E. D., Ludlow, A. T., Sheaff, A. K., Park, J., & Roth, S. M. (2010). ACTN3 genotype does not influence muscle power. *International Journal of Sports Medicine*, *31*(11), 834–838. https://doi.org/10.1055/s-0030-1263116

Hermina, W. (1999). *The Effects of Different Resistances on Peak Power during the Wingate Anaerobic Test.* [A Thesis]. The Oregon State University.

Hopkins, W. G., Schabort, E. J., & Hawley, J. A. (2001). Reliability of power in physical performance tests. *Sports Medicine, 31*, 211–234. https://doi.org/10.2165/00007256-200131030-00005

Kikuchi, N., Fuku, N., Matsumoto, R., Matsumoto, S., Murakami, H., Miyachi, M., & Nakazato, K. (2017). The association between MCT1 T1470A polymorphism and power-oriented athletic performance. *International Journal of Sports Medicine*, *38*(1), 76–80. https://doi.org/10.1055/s-0042-117113

Kikuchi, N., Nakazato, K., Min, S. K., Ueda, D., & Igawa S. (2014). The ACTN3 R577X polymorphism is associated with muscle power in male Japanese athletes. *Journal of Strength and Conditioning Research*, *28*(7), 1783–1789. https://doi.org/10.1519/jsc.0000000000000338

Krops, L. A., Albada, T., Van Der Woude, L. H. V., Hijmans, J. M., & Dekker, R. (2017). Anaerobic exercise testing in rehabilitation: A systematic review of available tests and protocols. *Journal of Rehabilitation Medicine*, *49*(4), 289–303. https://doi.org/10.2340/16501977-2213

LaVoie, N., Dallaire, J., Brayne, S., & Barret, D. (1984). Anaerobic testing using the Wingate and Evans-Quinney protocols with and without toe stirrups. *Canadian Journal of Applied Sport Sciences*, *9*(1), 1–5.

Madrid, B., Pardono, E., Farias, D. L., Asano, R. Y., Silva, R. J. S., & Simões, H. G. (2013). Reprodutibilidade do teste anaeróbio de Wingate em ciclistas. *Motricidade*, *9*(4), 40–46. https://doi.org/10.6063/motricidade.9(4).1130

Maher, C. G., Sherrington, C., Herbert, R. D., Moseley, A. M., & Elkins, M. (2003). Reliability of the PEDro scale for rating quality of randomized controlled trials. *Physical Therapy, 83*(8), 713–721.

Massidda, M., Corrias, L., Ibba, G., Scorcu, M., Vona, G., & Calò, C. M. (2012). Genetic markers and explosive leg-muscle strength in elite Italian soccer players. *The Journal of Sports Medicine and Physical Fitness*, *52*(3), 328–334.

Massidda, M., Scorcu, M., & Calò, C. M. (2014). New genetic model for predicting phenotype traits in sports. *International Journal of Sports Physiology and Performance*, *9*(3), 554–560. https://doi.org/10.1123/ijspp.2012-0339

Minahan, C., Chia, M., & Inbar, O. (2007). Does power indicate capacity? 30-S wingate anaerobic test vs. maximal accumulated O2 deficit. *International Journal of Sports Medicine*, *28*(10), 836–843. https://doi.

 DOI 10.26773/mjssm.220902

org/10.1055/s-2007-964976

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., Altman, D., Antes, G., Atkins, D., Barbour, V., Barrowman, N., & Berlin, J. A. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Medicine, 6*(7). https://doi.org/10.1371/journal.pmed.1000097

Muniesa, C. A., Kouvatsi, A., Massidda, M., Calò, C. M., Garton, F., Houweling, P. J.,… Eynon, N. (2016). ACTN3 R577X and ACE I/D gene variants influence performance in elite sprinters: a multi-cohort study. *BMC Genomics*, *17*(285). https://doi.org/10.1186/s12864-016-2462-3

Norman, B., Esbjörnsson, M., Rundqvist, H., Osterlund, T., von Walden, F., & Tesch, P. A. (2009). Strength, power, fiber types, and mRNA expression in trained men and women with different ACTN3 R577X genotypes. *Journal of Applied Physiology*, *106*(3), 959–965. https://doi.org/10.1152/japplphysiol.91435.2008

Norman, B., Sabina, R. L., & Jansson, E. (2001). Regulation of skeletal muscle ATP catabolism by AMPD1 genotype during sprint exercise in asymptomatic subjects. *Journal of Applied Physiology*, *91*(1), 258–264. https://doi.org/10.1152/jappl.2001.91.1.258

O'Connor, D., Green, S., & Higgins, J. P. T. (2008). Defining the review question and developing criteria for including studies. In J. P. T. Higgins & S. Green (Eds.), Cochrane Handbook for Systematic Reviews of Interventions (pp. 81-94). The Cochrane Collaboration.

Ostojić, S. M., Stojanović, M., & Ahmetović, Z. (2010). Vertical jump as a tool in assessment of muscular power and anaerobic performance. *Medicinski Pregled*, *63*(5–6), 371–375. https://doi.org/10.2298/mpns1006371o

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health.*, *42*(5), 533–544. https://doi.org/10.1007/s10488-013-0528-y

Petr, M., Stastny, P., Pecha, O., Šteffl, M., Šeda, O., & Kohlíkova, E. (2014). PPARA intron polymorphism associated with power performance in 30-s anaerobic Wingate Test. *PLoS One*, *9*(9). https://doi.org/10.1371/journal.pone.0107171

Pimenta, E. M., Coelho, D. B., Veneroso, C. E., Coelho, E. J. B., Cruz, I. R., Morandi, R. F., & Fernández, J. A. D. P. (2013). Effect of ACTN3 gene on strength and endurance in soccer players. *The Journal of Strength & Conditioning Research.*, *27*(12), 3286–3292. https://doi.org/10.1519/jsc.0b013e3182915e66

Ramierz, E. B., Williford, H. N., & Olson, M. S. (2007). Effects of a static stretching versus conventional warm-up on power output during Wingate cycle performance. *Medicine & Science in Sports & Exercise*, *39*(5). https://doi.org/10.1249/01.mss.0000274384.13923.06

Richmond, S. R., Whitman, S. A., Acree, L. S., Olson, B. D., Carper, M. J., & Godard, M. P. (2011). Power output in trained male and female cyclists during the wingate test with increasing flywheel resistance. *Journal of Exercise Physiology*, *14*(5), 46–53.

Serresse, O., Lortie, G., Bouchard, C., & Boulay, M. R. (1988). Estimation of the contribution of the various energy systems during maximal work of short duration. *International Journal of Sports Medicine*, *9*(6), 456–460. https://doi.org/10.1055/s-2007-1025051

Stewart, L. A., Clarke, M., Rovers, M. M., Riley, R. D., Simmonds, M., Stewart, G., & Tierney, J. F. (2015). Preferred Reporting Items for a Systematic Review and Meta-analysis of individual participant data. *Journal of the American Medical Association*, *313*(16), 1657-1665. https://doi.org/10.1001/jama.2015.3656

Wen, N., Dalbo, V. J., Burgos, B., Pyne, D. B., & Scanlan, A. T. (2018). Power testing in basketball: Current practice and future recommendations. *Journal of Strength and Conditioning Research*, *32*(9), 2677–2691. https://doi.org/10.1519/jsc.0000000000002459

ORIGINAL SCIENTIFIC PAPER

Four-week whole-body vibration training and its effects on strength, power and sprint performance in young basketball players - a randomized control trial

Erol Kovacevic[1], Ensar Abazovic[1], Nedim Covic[1], Armin H. Paravlic[2,3,4]

Affiliations: [1]Faculty of Sport and Physical Education, University of Sarajevo, Sarajevo, Bosnia and Herzegovina, [2]Faculty of Sport, University of Ljubljana, Ljubljana, Slovenia, [3]Science and Research Centre Koper, Institute for Kinesiology Research, Koper, Slovenia, [4]Faculty of Sports Studies, Masaryk University, Brno, Czech Republic

Correspondence: Armin H. Paravlic, PhD, Faculty of Sport, University of Ljubljana, Ljubljana, Slovenia, Science and Research Centre Koper, Institute for Kinesiology Research, Slovenia, Faculty of Sports Studies, Masaryk University, Brno, Czech Republic, Tel.: +386 68 948 557.
E-mail: armin.paravlic@hotmail.com

Abstract

We aimed to investigate whether the addition of whole-body vibration (WBV) to resistance training (RT) will be more beneficial in improving lower limbs muscle strength, power and sprinting performance than RT alone in young basketball players. We recruited 30 young basketball players to participate in four weeks of training and assessments. They were randomized into the WBV resistance training group (VRTG, n=15) and a conventional resistance training group (RTG, n=15), performed 3 times per week. At the beginning and end of the four weeks a back squat one-repetition maximum (1RMBS), Countermovement jump (CMJ), Squat jump (SJ), 10 meters (10m) and 20 meters sprint (20m) were performed. We found that: a) VRTG when added to RT can induce greater improvements in 1RMBS (percentage difference [PD], 8.4%, $p < 0.001$), CMJ (PD = 4.7%, $p = 0.001$) and SJ (PD = 1.6, $p = 0.02$) than RT alone. In contrary, significant time*group interactions were found for sprint times at 10m ($p=0.08$, $F=3.2$) and 20m ($p=0.17$, $F=1.93$). An additional 4-week WBV resistance training program proved effective in improving lower limb power and strength in young basketball players. When performed on a vibration platform (with accurate and constant vibration stimulus parameters), the resistance exercises were superior to their conventional forms and resulted in additional gains on measures of muscle power and strength, while sprint performance remained unchanged.

Keywords: *vibration training, countermovement jump, squat jump, barbell squat, neuromuscular performance, conditioning, muscle strength, athletic performance*

@MJSSMontenegro
VIBRATION TRAINING EFFECTS IN BASKETBALL PLAYERS
http://mjssm.me/?sekcija=article&artid=238

Cite this article: Kovacevic, E., Abazovic E., Covic N., & Paravlic A.H. (2022). Four-week whole-body vibration training and its effects on strength, power and sprint performance in young basketball players – a randomized control trial. *Montenegrin Journal of Sports Science and Medicine*, 11 (2), 21–27. https://doi.org/10.26773/mjssm.220903

Received: 19 April 2022 | Accepted after revision: 18 June 2022 | Early access publication date: 20 June 2022 | Final publication date: 1 September 2022

© 2022 by the author(s). License MSA, Podgorica, Montenegro. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY).

Conflict of interest: None declared.

Introduction

Lately, a modern training technology development increased the total number of available training methods used to enhance athletic performance. One of these is whole-body vibration (WBV) training which includes an additional mechanical stimulus to musculotendinous structures characterized by oscillatory motion determined by its amplitude, frequency, and magnitude (Cardinale & Bosco, 2003; Osawa, Oguma, & Ishii, 2013).

It has been shown that this type of stimuli increases overall training intensity through enhanced neuromuscular excitability and tonic vibration reflex (Luo, McNamara, & Moran, 2005). Additionally, the oscillatory motion affects the whole body, including both agonist and antagonist muscle groups, adding to the overall muscle performance enhancement (Nordlund & Thorstensson, 2007).

Numerous studies showed that WBV can cause a significant positive short- (Dallas, Kirialanis, & Mellos, 2014) and long-term (Hartard et al., 2022) effects on strength, power and sprinting abilities. Previously published meta-analyses showed greater long-term WBV training effects on muscle strength and power than without WBV (Osawa et al., 2013) with vertical platforms eliciting larger effects as compared to oscillating platforms (Marín & Rhea, 2010). These long-term effects are accompanied by greater gains in muscle mass and an enhancement in muscle contraction properties (Nordlund & Thorstensson, 2007).

However, come conflicting data can be found in previous studies conducted over short period (up to four weeks in duration). For example, Dolny and Reyes (2008) stated WBV alone will provide limited or no benefit in improving muscle strength and/or jumping performance compared with similar exercise training without WBV in young athletes. In contrary, Colson, Pensini, Espinosa, Garrandes, and Legros (2010) found that 4-week of WBV training in young basketball players improves solely isometric strength with small improvements in squat jump (SJ) performance but no significant effects in lower limb dynamic explosive performance involving stretch-shortening cycle actions like countermovement or drop jumps as well as 30-second rebound jumps or sprint running performance. However, latter authors used unloaded static exercise as a training stimulus, which might have a training specific effect as showed elsewhere.

The WBV volume ranges from 15-75 sec per set, while the intensity depends on the type, frequency and amplitude of the vibration applied. WBV modalities with both low frequency and amplitude can improve flexibility and balance (Despina et al., 2014), while high frequency and amplitude showed potential to augment strength, power and sprinting performance (Alam, Khan, & Farooq, 2018; Osawa et al., 2013). To our knowledge, the present study differs from previously published (Colson et al., 2010; Mahieu et al., 2006; Pérez-Turpin et al., 2014) in terms of the resistance exercises intensity used in both WBV and resistance intervention and the comparison of its effects on strength, power and sprinting performance in young basketball players. Thus, we aimed to evaluate a 4-week WBV loaded resistance training program effects and compare them with same resistance training without WBV. The assumption that resistance training with added whole-body vibration will provide greater improvements in strength, power and sprinting performance seems justified.

Materials and methods

Study design

The study was a randomized controlled trial including young basketball players. Screening of players was done using questionnaires filled individually indicating eligibility data based on following criteria: 1) minimum 2-year of resistance training experience, 2) at least 5 training sessions per week, and 3) free of any neurological problems and lower extremity injuries in the past two years before study begun. In total, 36 players were assessed for eligibility criteria of whom six players did not meet the criteria. Testing was performed at the baseline and after four weeks of intervention. Players were randomly assigned to two training groups using a computer-based system (Research Randomizer, https://randomizer.org/). The staff involved did not influence the randomization procedure. The subjects were randomized 1:1 to the WBV resistance training group (VRTG, n=15) or conventional resistance training group (RTG, n=15). Players not receiving their assigned intervention or being absent ~10% from the intervention were excluded from the study. Overall, two subjects from both VRTG and RTG were excluded (Figure 1). Both groups performed intensity and volume matched resistance training with additional WBV in the VRTG group. The players were minors so legal representative/parental consent was obtained prior to inclusion. The

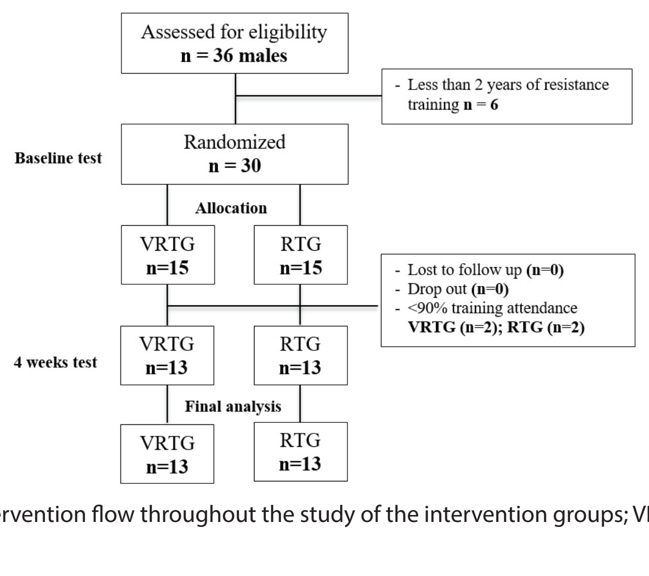


Figure 1. Intervention flow throughout the study of the intervention groups; VRTG and RTG

DOI 10.26773/mjssm.220903

study was carried out in accordance with the ethical standards of the 1964 Helsinki Declaration and approved by the University Ethics Committee.

Participants

In the conceptualization phase of the study, we conducted a power analysis using the G*Power . Based on previous studies with similar design we expected to find small to medium effects between baseline and final evaluation between VRTG and RTG groups (0.30) (Rhea & Kenn, 2009) with power of 0.90 and α = 0.05, two-tiled, which calculated a sample size of 26 participants in total. Therefore, thirty young male basketball players were included in the study. After completing the study, the final number for the analysis was n=13 in both groups. Except for a body height ($p<0.001$), there were no differences between groups for the participants' demographic characteristic at the baseline. (Table 1). All players were members of the local club and were participating in basketball training and competitions for 2-4 years.

Table 1. Baseline characteristics of subjects randomized to resistance training with vibration group (VRTG) or resistance training group (RTG).

	VRTG (n=13)	RTG (n=13)
Age (years)	15.1±0.8	15.1±0.7
Heigh (cm)	188.1±5.5	194.8±6.1**
Weight (kg)	79.5±10.0	85.5±9.5
BMI (kg/m²)	22.5±2.6	22.5±1.6

**Significantly different from VRTG $p<0.001$

Training intervention

Both groups performed intervention in a local fitness facility using the same equipment. Training sessions were supervised by the investigators and two experienced strength and conditioning coaches. All players attended 12 resistance training sessions lasting 55 minutes on average. Training protocol included 3-5 sets and 5-8 reps at 80-90 RM % of the following exercises: 1) dynamic back squat, 2) alternative lounge, 3) deadlift and 4) donkey calf raise (with partner similar in weight). Training session consisted of a 7-8 min warm-up, resistance exercise routine as presented in Table 2 and 7-8-min cooldown (stretching exercises). Inter-set and inter-exercise rest intervals were set to one and three minutes, respectively.

VRTG group performed all sessions standing on a vertical oscillatory vibration platform (Pro Evolution 2.7, Powrx Gmbh, D) with 35 Hz frequency and 4mm peak-to-peak displacement. According to the formula, the acceleration amounted to 7.6 G.

Table 2. Prescribed training interventions

Week	Training sessions	Sets	Reps.	Exercises	Intensity	Vibration duration per exercise for VRTG	Training vibration duration
1	3	3	8	1. back squat, 2. alternate lounge 3. deadlift 4. donkey calf raises	80% 1RM Partner*	32″ (35Hz, 4 mm)	8′
2	3	4	6	1. back squat, 2. alternate lounge 3. deadlift 4. donkey calf raises	85% 1RM Partner*	24″ (35Hz, 4 mm)	8′
3	3	5	5	1. back squat, 2. alternate lounge 3. deadlift 4. donkey calf raises	90% 1RM Partner*	20″ (35Hz, 4 mm)	8′20″
4	3	3	8	1. back squat, 2. alternate lounge 3. deadlift 4. donkey calf raises	80-90% 1RM Partner*	32″ (35Hz, 4 mm)	8′

* A partner of approximately the same body weight; Recovery time between sets was 60″and exercises was 180″

Measuring procedures

To evaluate the strength, power and speed, a back squat one-repetition maximum (1RMBS), Countermovement jump (CMJ), Squat jump (SJ), 10 meters (10m) and 20 meters sprint (20m) were evaluated at baseline and after 4 weeks. All measurements were performed early in the morning by experienced Sports Institute personnel. Players performed a standardized general 8–10-minute warm-up routine consisting of a 5-minute treadmill run at 6-10 km/h followed by three to five minutes of rest prior to assessment.

1RM back squat (1RMBS)

The maximal strength was measured using 1RM back squat test protocol. The expected/estimated 1RM value was used as a reference. The lower squat position was set at 90 degrees of knee flexion, measuring from the upright standing position (180°). After the first 5-10 reps with an unloaded barbell, participants completed 5-10 reps at 50%, 3-5 reps at 75% and 1-3 reps at 90% of the estimated 1RM with 3-5 minutes rest between sets. Further 5kg weight increment with 3-5 minutes rest and 1RM determination was conducted when the player failed to complete the lift.

Countermovement jump (CMJ) and Squat jump (SJ)

Subjects were asked to perform CMJ and SJ measured using Optojump^{TM} photoelectric cells (Microgate, Bolzano, Italy). Each player performed three consecutive trials parted with one minute for recovery and the best result was used for further analysis. A standardized warm-up including 3-5 jumps at approximately 50% effort, followed by 3-5 minutes of rest, was conducted before the assessment.

Sprint on 10 meters (10m) and 20 meters (20m)

Two 20m sprints were performed and recorded to the nearest 0.01 second by using portable electronic timing gates (Speedtrap II, Brower Timing Systems, Draper, UT, USA) set 1 m high and 1 m apart at 0, 10 and 20 meters. All sprints were executed indoors on a basketball court from a standing start with the dominant foot to the front at a line 30 cm from the first gate to prevent false timer triggering. Once the participants were set, they started at their own volition.

Statistical analysis

Statistical analysis was performed using SPSS statistical software (version 27.0, IBM Inc, Chicago, USA). All data are presented in tables and charts as mean±SD. Descriptive statistics were used to summarize individual characteristics and all outcome measures. Normality was confirmed using the Shapiro-Wilk's test, while homogeneity of variances was tested using Levene's test for all variables. Coefficients of variation (CV%) were calculated as the percentage of standard deviation between test-retest results and mean values for 1RMBS, CMJ, SJ, 10m and 20m. Threshold of CV%<5 indicated low result variability. Intraclass coefficient (ICC) determined the test-retest reliability for CMJ, SJ 10m and 20m with ICC<0.5, between 0.5 and 0.75, between 0.75 and 0.9, and >0.90 were indicative of poor, moderate, good, and excellent reliability (Koo & Li, 2016). Baseline differences were examined using an independent sample t-test. Further on, inter and intra-group differences were analyzed by 2-way repeated-measures ANOVA (group*time). In the case of significant effects were found for group, or time, or 2-way interactions, post hoc comparisons with Bonferroni corrections were applied to address significant PRE-to-POST differences for each variable independently. The magnitude of change (ES) between baseline and 4 weeks of intervention was expressed using Cohens' d effect size and rated as Trivial (ES<0.2), Small (ES<0.50), Moderate (ES<0.80) and large (ES<0.79) . The level of statistical significance was set at p<0.05.

Results

There were no significant differences between VRTG and RTG at baseline measures except for body height where RTG subjects were taller compared to VRTG (Table 1 and 4, Fig. 2). Within-subjects variability was low (CV%<5) for all the tests conducted, while test-retest reliability was rated as excellent for $1RM_{BS}$, CMJ, SJ, 10- and 20-meter sprint times with ICC ranging from 0.902 – 0.981 (Table 3).

Significant time*group interaction was found for 1RMBS (p<0.001, F=21.07). Pairwise comparisons revealed an increase (p<0.001) of 37% (31.7±8.84 kg, Large) and 28.6% (24.0±6.94 kg, Large) over 4 weeks for VRTG and RTG, resulting in an 8.4±32.1% greater weight lifted in VRTG. (Table 4; Fig. 2 a) and b)).

Significant time*group interactions were observed for CMJ (p=0.025, F=11.37) and SJ (p=0.039, F=10.29). Over 4 weeks CMJ and SJ was increased by 8.4% (3.01±2.4 cm; p=0.001, t=4.512; Small) and 3.0% (1.14±3.75 cm; p=0.02, F=2.14; Small) in VRTG, while non-significant increase of 2.7% (1.04±2.92 cm; p=0.22, t=1.22; Trivial) and 1.4% (0.5±2.96 cm; p=0.57, t=0.59; Trivial) were noted in RTG, respectively (Table 4; Fig. 2 a) and b)).

No significant time*group interactions were found for sprint times at 10m (p=0.08, F=3.2) and 20m (p=0.17, F=1.93). Pairwise comparisons showed that after 4 weeks times on 10 and 20 meters were lowered by 2.8 % (0.06±0.08 sec, p=0.03, t=2.57; Moderate) and 1.8% (0.06±0.1 sec, p=0.04, t=2.32; Small) in VRTG, with corresponding changes of 3.4% (0.08±0.07; p=0.004, t=3.58; Moderate) and 2.7 (0.1±0.1; p=0.006, t=3.29; Moderate) for RTG (Table 4; Fig. 2 a) and b)).

Table 3. Coefficients of variation (CV%) and intraclass correlation coefficients (ICC) for squat ($1RM_{BS}$), countermovement jump (CMJ), squat jump (SJ), 10 meters sprint time (10m) and 20 meters sprint time (20m).

	$1RM_{BS}$	CMJ	SJ	10m	20m
CV%	3.8%	4.4%	4.4%	2.6%	2.0%
ICC	0.902	0.981	0.964	0.965	0.912
ICC rating	Excellent	Excellent	Excellent	Excellent	Excellent

Table 4. Squat one repetition maximum ($1RM_{BS}$), countermovement jump (CMJ), squat jump (SJ), 10 meters (10m) and 20 meters (20m) sprint time in young basketball players at baseline and after 4 weeks of additional resistance training with vibration (VRTG) and resistance training (RTG).

	VRTG (n=13)				RTG (n=13)			
	Baseline	4 weeks	ES	Δ%	Baseline	4 weeks	ES	Δ%
$1RM_{BS}$ (kg)[a]	85.8±17.9	117.50±23.6**	Large	37.0%	84.03±18.04	108.07±16.44**	Large	28.6%
CMJ (cm)[a]	40.40±5.92	43.41±6.59**	Small	7.4%	38.58±6.03	39.62±6.90	Trivial	2.7%
SJ (cm)[a]	37.44±5.22	38.58±5.75**	Small	3.0%	36.55±4.83	37.05±5.55	Trivial	1.4%
10m (s)	2.13±0.1	2.07±0.07**	Moderate	-2.8%	2.16±0.12	2.08±0.08**	Moderate	-3.4%
20m (s)	3.46±0.14	3.40±0.12**	Small	-1.8%	3.51±0.17	3.41±0.14**	Moderate	-2.7%

Values are presented as Mean±SD; ** Significantly different from baseline p<0.001; [a] Significant group*time interaction p<0.001; ES – Magnitude of effect based on Cohen d effect size

DOI 10.26773/mjssm.220903

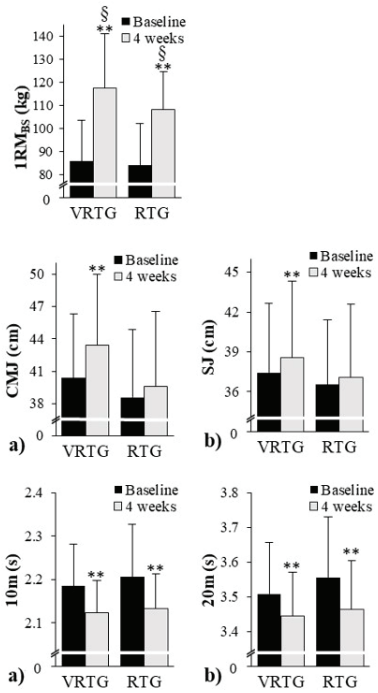


Figure 2. Difference in squat one repetition maximum weight (1RMBS), a) countermovement jump (CMJ) and b) squat jump (SJ) and sprint times at a) 10 meters (10m) and b) 20 meters (20m) for young basketball players in the Vibration resistance training group (VRTG) and Resistance training group (RTG) at baseline and after 4 weeks. ** p<0.001; § time*group interaction p<0.001

Discussion

The present study demonstrated that a short-term resistance training applied over a 4-week period with added WBV develops muscle strength and power more effectively, and sprinting abilities equally well compared to resistance training alone. The main findings were that additional WBV resulted in a significant pre-post improvement in jumping performance measured by CMJ and SJ, which was not observed after resistance training alone. Furthermore, back squat 1RM increased after both training interventions with higher relative improvement after WBV indicating that additional performance impact is primarily caused due to added WBV. Changes and comparisons in sprinting performance were inconclusive with slight improvements after both interventions.

Since resistance exercise stimulus is induced by workload intensity, its variations as well as its duration and frequency (Kraemer & Ratamess, 2004), it seemed reasonable to hypothesize that additional WBV, which involves forces that might exaggerate resistance training stimulus, would have a larger potential for performance improvement in trained athletes. Although both interventions significantly improved strength performance, our primary hypothesis was confirmed by showing the relative enhancement in 1RMBS were for 8.4% higher in the VRTG than RTG after 4-week intervention period. Previous investigations (Colson et al., 2010; Dallas et al., 2014; Mahieu et al., 2006; Pérez-Turpin et al., 2014) have also shown marked lower limb 1RM strength increase after short and long-term WBV. Further on, Rønnestad (2004) found 24.2% and 32.4% in both non- and WBV group, respectively, which complies with our study results. Additionally, in their systematic review, Nordlund and Thorstensson (2007) reported changes in muscle strength performance in the WBV groups ranging from -0.9% to 24.4%. The observed increase in strength performance regardless of additional WBV stimulus might be caused by subjects' relatively low baseline physical fitness since the testing was performed before the preparation period. Also, some of the players had poor technique in performing basic strength exercises which explains the fact that several players improved 1RMBS by nearly 50% just by learning proper techniques. Such individual improvement was notably higher in 3 participants in VRTG, hypothetically indicating that WBV might enhance motor learning development (Fereydounnia & Shadmehr, 2020).

It is evident that differences in training interventions notably emphasized the diversity of the magnitudes on the strength performance impact. Some studies compared acute effects of WBV and resistance training using bodyweight exercises (Dallas et al., 2014) while others used traditional strength training (Pérez-Turpin et al., 2014) or performed strength exercises using the fixed machine to avoid balance and problems related to exercise technique (Rønnestad, 2004). On the other side, the magnitude of the WBV training effects primarily depended on the vibration training methodology and, the magnitude of the external load applied(Marín & Rhea, 2010). Differences in WBV frequency mainly ranged from 25 Hz (Özsu, Ertan, Simsek, Özçaldiran, & Kurt, 2018), 30-40Hz (Delecluse, Roelants, Diels, Koninckx, & Verschueren, 2005; Pérez-Turpin et al., 2014) and up to 50Hz (Adams et al., 2009) with unloaded static and dynamic exercises while amplitudes ranged from 1.7 to 2.5mm for up to 4mm with relatively similar training gains after the interventions. Özsu et al. (2018) concluded that WBV, when combined with dynamic squatting in well-trained athletes by using similar amplitude and frequency as in current study (i.e., 4mm and 40Hz), enhances neuromuscular activation to greater extent than resistance training alone resulting in higher muscle strength output. Other studies suggested that greatest effect is obtained by using combination of a high amplitude and the frequency (<4mm and 50Hz) (Adams et al., 2009). It still remains inconclusive how to optimise and apply WBV parameters concerning athletes age, experience, gender, type of exercise, body position and health status to maximise the muscle activation and strength gains (Hartard et al., 2022).

The present study found that both CMJ (4.7%) and SJ (1.6%) were significantly higher in WBV than RTG following the intervention. Similar findings were reported in the previous studies (Colson et al., 2010; Dallas et al., 2014; Fernandez-Rio, Terrados, Fernandez-Garcia, & Suman, 2010; Pérez-Turpin et al., 2014). After 4 weeks of training, the CMJ and SJ height increased by 7.4% and 3.0% in VRTG, whereas the level of improvement was roughly the same as that found in the studies with a similar intervention regimes that lasted for up to 6 weeks (Pérez-Turpin et al., 2014), 12 weeks (Delecluse et al., 2005) and in longer (Torvinen et al., 2002) from 1% (Owen, 2004) to 12% (Bosco et al., 1998) for CMJ and 3.4% (Fernandez-Rio et al., 2010) to 17.9% (Mester, Kleinöder, & Yue, 2006) for SJ. By the best of the authors knowledge, only two studies (Mahieu et al., 2006; Pérez-Turpin et al., 2014) compared resistance training with and without added WBV similar to our study. Latter authors found that additional WBV had cumulative effect of 3-12% on jumping performance in volleyball, beach volleyball players and young skiers (Mahieu et al., 2006; Pérez-Turpin et al., 2014). These results indicate that 4-week WBV resistance training improves jump height regardless of the jumping regime considering the type of muscle actions such as purely concentric (Pérez-Turpin et al., 2014) or combination of both the eccentric and concentric (Mahieu et al., 2006). In contrast, in study of Delecluse et al. (2005) five weeks of additional vibration training protocol did not provide any auxiliary improvements compared to the resistance training in sprint athletes. However, subjects were experienced and well-trained athletes, suggesting that implementation of the short-term WBV training to ongoing training regime of well-trained athletes cannot provide added benefits to their power capacities.

To our knowledge, this is the first study that evaluated WBV resistance training effects on sprint performance in junior basketball players. Players improved significantly sprint time from baseline by 1.8% to 3.4%. Although 10m and 20 m sprint performance significantly improved in both groups, between-group interaction effects difference was not found, suggesting that the WBV has no surplus effect over resistance training on sprint performance. The results of this study showed that WBV training caused a decrease in sprint time by 2.8% at 10m and 1.8% at 20m which suggests that the WBV effect on sprint time between 10 and 20m, considering the results, is due to a significantly better result in the initial 10m sprint. Similar results were found by Giorgos and Elias (2007) with 3% at 20m and 4.3% at 10m in the physically active population. Only three studies (Cochrane, Legg, & Hooker, 2004; Giorgos & Elias, 2007; Owen, 2004) found long-term WBV training effects on sprint time at 5 to 60m to be up to 4.3%.

A large number of previously conducted studies (Bosco et al., 1998; Delecluse, Roelants, & Verschueren, 2003; Giorgos & Elias, 2007; Mester et al., 2006; Osawa et al., 2013; Torvinen et al., 2002; Torvinen et al., 2003) found significantly greater WBV effects compared to standard and/or placebo group subjects. Additionally, differences in WBV application methodologies among recent studies, population characteristics, and the duration of the experimental process may be a key factor in explaining the differences in the magnitude of the effects observed. Undoubtedly, based on the differences between the WBV and non-WBV training effects, this study proved the net effects of short-term vibration stimulus as more beneficial gains in strength and power of lower extremities than conventional training were found. The observed strength and power gains are more likely to be related to neural adaptation in contrast to the physiological or hormonal long-term responses (Pérez-Turpin et al., 2014). Additionally, the neural adaptations and gains of WBV were uniform likewise in the resistance training, including the augmented rate of motor unit firing and synchronization, inhibition of antagonist as well as contraction of synergist muscles (Bosco et al., 1998; Torvinen et al., 2003).

Finally, we should mention the limitations of the current study. Firstly, the players, as well as the investigators were not blinded to their assigned intervention which might compromise the results. Secondly, the passive control group was not included in the present investigation to indicate the level of performance changes due to basketball training alone.

Further research should investigate the prolonged effects of WBV application. In addition, to determine the optimal training stimulus of WBV, prior and post-application effects on power, strength, speed, flexibility and injuries during follow-up should be examined. Also, further studies aimed to investigate the muscle structure and endocrine system response to WBV in relation to the specific age of young athletes are warranted.

Conclusion

An additional 4-week WBV resistance training program proved effective in improving lower limb power and strength in young basketball players. When performed on a vibration platform (with accurate and constant vibration stimulus parameters), the resistance exercises were superior to their conventional forms and resulted in additional gains on measures of muscle power and strength, while sprint performance remained unchanged. The additional training effects of WBV were probably caused by the neural adaptation to vibration stimuli, although it should emphasize effects from potential load increase of mechanical oscillation source, muscle hypertrophy and hormonal response to WBV. Thus, to investigate this question a well-designed original study is warranted.

Acknowledgements

The authors would like to thank the participants enrolled in the study.

Funding

No external funding was received for this study.

Availability of data and material

The data that support the findings of this study are available on reasonable request from the corresponding author.

References

Adams, J. B., Edwards, D., Serviette, D., Bedient, A. M., Huntsman, E., Jacobs, K. A., . . . Signorile, J. F. (2009). Optimal frequency, displacement, duration, and recovery patterns to maximize power output following acute whole-body vibration. *The Journal of Strength & Conditioning Research, 23*(1), 237-245.

Alam, M. M., Khan, A. A., & Farooq, M. (2018). Effect of

 DOI 10.26773/mjssm.220903

whole-body vibration on neuromuscular performance: A literature review. *Work, 59*(4), 571-583.

Bosco, C., Cardinale, M., Tsarpela, O., Colli, R., Tihanyi, J., Von Duvillard, S., & Viru, A. (1998). The influence of whole body vibration on the mechanical behaviour of skeletal muscle. *Biol Sport, 153*, 157-164.

Cardinale, M., & Bosco, C. (2003). The use of vibration as an exercise intervention. *Exercise and sport sciences reviews, 31*(1), 3-7.

Cochrane, D. J., Legg, S. J., & Hooker, M. J. (2004). The short-term effect of whole-body vibration training on vertical jump, sprint, and agility performance. *The Journal of Strength & Conditioning Research, 18*(4), 828-832.

Colson, S. S., Pensini, M., Espinosa, J., Garrandes, F., & Legros, P. (2010). Whole-body vibration training effects on the physical performance of basketball players. *The Journal of Strength & Conditioning Research, 24*(4), 999-1006.

Dallas, G., Kirialanis, P., & Mellos, V. (2014). The acute effect of whole body vibration training on flexibility and explosive strength of young gymnasts. *Biology of sport, 31*(3), 233.

Delecluse, C., Roelants, M., Diels, R., Koninckx, E., & Verschueren, S. (2005). Effects of whole body vibration training on muscle strength and sprint performance in sprint-trained athletes. *International journal of sports medicine, 26*(08), 662-668.

Delecluse, C., Roelants, M., & Verschueren, S. (2003). Strength increase after whole-body vibration compared with resistance training. *Medicine and science in sports and exercise, 35*(6), 1033-1041.

Despina, T., George, D., George, T., Sotiris, P., George, K., Maria, R., & Stavros, K. (2014). Short-term effect of whole-body vibration training on balance, flexibility and lower limb explosive strength in elite rhythmic gymnasts. *Human movement science, 33*, 149-158.

Dolny, D. G., & Reyes, G. F. C. (2008). Whole body vibration exercise: training and benefits. *Current sports medicine reports, 7*(3), 152-157.

Fereydounnia, S., & Shadmehr, A. (2020). Efficacy of whole body vibration on neurocognitive parameters in women with and without lumbar hyper-lordosis. *Journal of Bodywork and Movement Therapies, 24*(1), 182-189.

Fernandez-Rio, J., Terrados, N., Fernandez-Garcia, B., & Suman, O. E. (2010). Effects of vibration training on force production in female basketball players. *The Journal of Strength & Conditioning Research, 24*(5), 1373-1380.

Giorgos, P., & Elias, Z. (2007). Effects of whole-body vibration training on sprint running kinematics and explosive strength performance. *Journal of sports science & medicine, 6*(1), 44.

Hartard, M., Seiler, A., Spitzenpfeil, P., Engel, L., Hartard, D., Fenneni, M. A., & Ben Saad, H. (2022). Sex-specific response to whole-body vibration training: a randomized controlled trial. *Biology of sport, 39*(1).

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of chiropractic medicine, 15*(2), 155-163.

Kraemer, W. J., & Ratamess, N. A. (2004). Fundamentals of resistance training: progression and exercise prescription. *Medicine & science in sports & exercise, 36*(4), 674-688.

Luo, J., McNamara, B., & Moran, K. (2005). The use of vibration training to enhance muscle strength and power. *Sports medicine, 35*(1), 23-41.

Mahieu, N. N., Witvrouw, E., Van de Voorde, D., Michilsens, D., Arbyn, V., & Van den Broecke, W. (2006). Improving strength and postural control in young skiers: whole-body vibration versus equivalent resistance training. *Journal of athletic training, 41*(3), 286.

Marín, P. J., & Rhea, M. R. (2010). Effects of vibration training on muscle strength: a meta-analysis. *The Journal of Strength & Conditioning Research, 24*(2), 548-556.

Mester, J., Kleinöder, H., & Yue, Z. (2006). Vibration training: benefits and risks. *Journal of biomechanics, 39*(6), 1056-1065.

Nordlund, M., & Thorstensson, A. (2007). Strength training effects of whole-body vibration? *Scandinavian journal of medicine & science in sports, 17*(1), 12-17.

Osawa, Y., Oguma, Y., & Ishii, N. (2013). The effects of whole-body vibration on muscle strength and power: a meta-analysis. *J Musculoskelet Neuronal Interact, 13*(3), 380-390.

Owen, G. J. (2004). *The influence of whole body vibration on knee extensor stiffness and functional performance.* Auckland University of Technology.

Özsu, İ., Ertan, H., Simsek, D., Özçaldiran, B., & Kurt, C. (2018). The Effects of Whole Body Vibration Treatments on Lower Body Muscular Activity in Well-Trained Athletes from Different Sports Branches. *Journal of Education and Training Studies, 6*(n9a), 43-55.

Pérez-Turpin, J. A., Zmijewski, P., Jimenez-Olmedo, J. M., Jové-Tossi, M., Martínez-Carbonell, A., Suárez-Llorca, C., & Andreu-Cabrera, E. (2014). Effects of whole body vibration on strength and jumping performance in volleyball and beach volleyball players. *Biology of sport, 31*(3), 239.

Rhea, M. R., & Kenn, J. G. (2009). The effect of acute applications of whole-body vibration on the iTonic platform on subsequent lower-body power output during the back squat. *The Journal of Strength & Conditioning Research, 23*(1), 58-61.

Rønnestad, B. R. (2004). Comparing the performance-enhancing effects of squats on a vibration platform with conventional squats in recreationally resistance-trained men. *The Journal of Strength & Conditioning Research, 18*(4), 839-845.

Torvinen, S., Kannus, P., Sievanen, H., Jarvinen, T. A., Pasanen, M., Kontulainen, S., . . . Vuori, I. (2002). Effect of four-month vertical whole body vibration on performance and balance. *Medicine and science in sports and exercise, 34*(9), 1523-1528.

Torvinen, S., Kannus, P., Sievänen, H., Järvinen, T. A., Pasanen, M., Kontulainen, S., . . . Järvinen, M. (2003). Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: a randomized controlled study. *Journal of bone and mineral research, 18*(5), 876-884.

ORIGINAL SCIENTIFIC PAPER

The influence of a specific high intensity circuit training during physical education classes in children's physical activity and body composition markers

Daniel A Marinho[1,2], Henrique P Neiva[1,2], Luis Marques[1], Vitor P Lopes[2,3], Jorge E Morais[2,3]

Affiliations: [1]University of Beira Interior, Covilhã, Portugal, [2]Research Centre in Sports, Health and Human Development (CIDESD), Covilhã, Portugal, [3]Instituto Politécnico de Bragança, Bragança, Portugal

Correspondence: Jorge E Morais, Department of Sport Sciences, Instituto Politécnico de Bragança, Campus Sta. Apolónia, Apartado 1101, 5301-856, Bragança, Portugal. Email: morais.jorgestrela@gmail.com

Abstract

Physical activity plays a paramount role on children growth and schools emerged as a key setting for promoting physical activity during childhood. The aim of this study was to verify the effects of a high intensity circuit training performed during regular physical education classes at schools. One hundred and five children aged 11–14 years (71 boys and 34 girls) were evaluated. The participants were split into a control group (boys: N = 47; girls: N = 16) and an experimental group (boys: N = 24; girls: N = 18). Besides the normal physical education classes, the experimental group also performed a high intensity circuit training for eight weeks, twice a week, at the beginning of the lesson. A pre- post-test was performed. Cardiorespiratory (20 m shuttle run test) and a set of strength variables were evaluated. Percentage of fat mass was used as a somatic indicator. The 20 m shuttle run test presented a significant time effect, but not a time X sex, time X group, and time X weight status interactions. Conversely, the strength variables presented a significant time X group interaction (significant differences between groups). Percentage of fat mass presented a significant time effect, but not a significant time X group interaction. Data showed that adding a high intensity circuit training to physical education classes would result in a significant increase in muscular fitness performance in children, but cardiorespiratory fitness may not present the same magnitude of improvement. High intensity circuit training programs (performed during regular physical education classes at schools) seem to present a positive and significant effect in physical fitness parameters as well as reducing the percentage of fat mass.

Keywords: *children, physical activity, extra-school programs, strength, fitness*

@MJSSMontenegro
HIGH INTENSTY TRAINING IN PHYSICAL EDUCATION CLASSES
http://mjssm.me/?sekcija=article&artid=239

Cite this article: Marinho D.A., Neiva H.P., Marques L., Lopes V.P., & Morais J.E. (2022). The influence of a specific high intensity circuit training during physical education classes in children's physical activity and body composition markers. *Montenegrin Journal of Sports Science and Medicine*, 11 (2), 29–36. https://doi.org/10.26773/mjssm.220904

Received: 02 April 2022 | Accepted after revision: 06 June 2022 | Early access publication date: 01 July 2022 | Final publication date: 1 September 2022

© 2022 by the author(s). License MSA, Podgorica, Montenegro. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY).

Conflict of interest: None declared.

Introduction

It is worldwide known that physical activity plays a paramount role on children growth (García-Hermoso et al., 2020). The level of physical activity presents a strong relationship with the development of motor skills (Loprinzi et al., 2015). Literature has suggested that increased motor stimulation during childhood would lead to children's development of fundamental motor skills acquisition (Balaban, 2018; Loprinzi et al., 2015). Indeed, the regular physical stimulation would provide new opportunities for enhancement of motor, perceptual, cognitive, and social skills (Adolph, 2019). Moreover, physical activity during childhood contributes to health and quality of life status (Larsen et al., 2018a). For instance, it was reported that children who perform physical activity are more likely to achieve musculoskeletal changes getting beneficial consequences for long-term osteogenic health (Larsen et al., 2018a,b). Therefore, it is recognized that physical activity in children plays a key-role on promoting long-term healthy lifestyle habits and preventing diseases (Donnelly et al., 2016).

Curiously, and despite all motor skills and health benefits, it seems that physical activity among children and adolescents have been declining or considered insufficient worldwide (Guthold et al., 2020). Moreover, it has been estimated that most of school-aged children and youth worldwide do not reach recommendations, specifically regarding the minimum of 60 minutes of moderate to vigorous physical activity per day (Sallis et al., 2016). This decline in physical activity values were believed to happen mostly during adolescence, however, studies found that it starts in early ages (Basterfield et al., 2011). The most known causes that could explain this phenomenon may be related to environmental context and resources and social influences (Sember et al., 2018). For instance, there are evidence suggesting that parental encouragement may affect the patterns of physical activity in children (Bradley et al., 2011). Moreover, it seems that transition into adolescence seems especially relevant among rural children, girls and those who are overweight or obese (Corder et al., 2015). In this context, schools (specifically physical education classes) emerged as a key setting for promoting physical activity during childhood (García-Hermoso et al., 2020; Sember et al., 2018).

Indeed, children are exposed to vigorous physical activity mainly in school-based classes (Drummy et al., 2016). Therefore, physical education classes at school can be seen and used to promote health-related and an active lifestyle by ensuring moderate to vigorous activities or exercises (Delgado-Floody et al., 2019). A wide range of interventions have been developed to increase quality and quantity of physical activity interventions in children at school (Larsen et al., 2018a,b). For instance, different cardiorespiratory and/or resistance training strategies (e.g., bodyweight exercises, suspension training, plyometric training, small-sided games, circuit training) implemented during physical education classes in children aged 8–10 years caused favorable training responses on muscular fitness, cardiorespiratory fitness, body composition, motor performance skills, mental health, well-being, and even motivation for physical activity (Larsen et al., 2018a,b). Specifically, it was shown that high intensity training programs (with low volume intervention) promoted meaningful improvements in variables related to cardiometabolic risk, namely triglycerides and waist circumference, in 14 years children (Weston et al., 2016). Moreover, restrictions or the impossibility of attending school (such as the COVID-19 pandemic), promote a meaningful decline on children's physical activity (Yomoda & Kurita, 2021). Thus, it seems that school environment may be considered of paramount importance for maintaining children's levels of physical activity.

However, most of the times, the requirements of the school curriculum do not allow increasing frequency or duration of physical educations classes. Thus, additional strategies should be studied to understand the most effective way to increase youths' levels of physical activity in children. Although several high intensity interval trainings were assessed before (Larsen et al., 2018a,b), it is not known if this type of activity can be effective to improve children and youth health and physical fitness, implemented in short sessions, during physical education classes. Therefore, the aim of this study was to verify the effects of a high intensity circuit training (HICT) performed during regular physical education classes at schools. It was hypothesized that the HICT would promote positive and significant effects in physical fitness parameters (i.e., cardiorespiratory fitness and strength) as well as in reducing health-related parameters (i.e., % of fat mass).

Methods

Participants

One hundred and five children aged 11–14 years old (71 boys: 11.63 ± 0.90 years; and 34 girls: 11.50 ± 0.61 years) were evaluated. The participants were split into two groups: (1) control group (CG: 47 boys and 16 girls with 11.64 ± 0.87 and 11.69 ± 0.70 years, respectively); (2) experimental group (EG: 24 boys and 18 girls with 11.63 ± 0.97 and 11.33 ± 0.49 years, respectively). Parents or guardians signed an informed consent form. All procedures were in accordance with the Declaration of Helsinki regarding human research, and the University Ethics Board approved the research design.

Design and Procedures

Based on the school's guidelines, a typical physical education class was lectured twice per week with a 60 minute duration. Within this physical education class, the EG also performed a HICT during the initial 20 minutes of the class for eight weeks. Thus, the EG performed the HICT during 20 minutes and the typical physical education class in the remaining 40 minutes. The CG performed a typical physical education class during 60 minutes. The HICT program's are commonly used by teachers in their physical education classes and coaches in many sports (Alves et al., 2021; Klika & Jordan, 2013). This typically includes exercises using body weight which are executed in a circuit fashion-way aiming to enhance neuromuscular structure and function (Engel et al., 2019). Table 1 shows the exercises included in the additional HICT program (EG), purpose, time of exercise and time of rest between drills. Ten exercises were included and performed twice by each participant, making a total of 20 minutes of exercise. Participants (both CG and EG groups) were instructed not to participate in any other physical activity besides the ones implemented in their school.

Fat mass (FAT, in %) was measured by bioimpedance with body composition digital scale (Omron BF511, Japan). The same instrument was also used to measure body mass (BM, in kg). The height (H, in cm) was measured as the distance be-

 DOI 10.26773/mjssm.220904

Table 1. Exercises included in the high intensity circuit training (HICT) program, purpose, time of execution and rest.

		Exercise and rest time		
Exercise description	Purpose	Week 1 – 2	Week 3 – 5	Week 6 – 8
Jump to box	Lower-limbs strength			
Chest press	Upper-limbs strength			
Squat clean press	Lower-limbs and abdominal strength			
Jefferson curls	Lower-limbs flexibility			
Jumping jacks	Aerobic	30 s drill – 30 s rest	40 s drill – 20 s rest	45 s drill – 15 s rest
In and out squat	Lower-limbs strength			
Mountain climbers	Upper-limbs and abdominal strength			
Sit ups	Abdominal strength			
Shoulder rotation	Upper-limbs flexibility			
Side shuffle	Aerobic			

tween the vertex to the floor with a digital stadiometer (SECA, 213, Germany). The body mass index (BMI, in $kg{\cdot}m^{-2}$) was calculated as BMI = body mass / height^2. Age- and sex-specific cut-offs suggested by the International Obesity Task Force (IOTF) were used to classify weight status (Cole et al., 2007).

Physical fitness was assessed with two main components from the Fitnessgram test battery (Plowman & Meredith, 2013), specifically cardiorespiratory fitness and strength. The 20 m shuttle run test (20 m SRT, in number of laps) was used to assess the cardiorespiratory fitness. This is a non-invasive test that presents a strong relationship with maximal oxygen uptake ($VO_{2máx}$) and it can be applied in children with different weight status (Nevill et al., 2020). It is characterized by running between two lines set 20 m apart at a pace dictated by a sound beep emitting tones at appropriate intervals. Velocity was 8.5 $km{\cdot}h^{-1}$ for the first minute, and it was increased by 0.5 $km{\cdot}h^{-1}$ every minute thereafter as reported elsewhere (Nevill et al., 2020). The test scores achieved by the participant was the number of shuttles (20 m) completed before the subject either withdrew voluntarily from the test or failed to be within 3 meters of the end lines on two consecutive tones (Paradisis et al., 2014).

Strength assessment included: (i) curl-up (CU, in number of repetitions); ii) push-up (PU, in number of repetitions); (iii) standing long jump (SLJ, in cm), and; (iv) vertical jump (VJ, in cm). For the CU, the participants were instructed to lay on their back, knees bent at approximately 140 degrees, feet flat on the floor, legs slightly apart, arms straight and parallel to the trunk with palms of hands resting on the mat. With the heels in contact with the mat, he/she curls up, then curls back down until their head touches the mat. Movement was controlled by a sound system at the cadence of 20 curl-ups per minute (1 curl-up every 3 seconds). The test finishes until he/she reached exhaustion or 75 curls (Plowman & Meredith, 2013). For the PU, participants were asked to touch with hands and toes on the floor, the body and legs in a straight line, feet slightly apart, the arms at shoulder width apart, extended and at a right angle to the body (Plowman & Meredith, 2013). Boys performed the PU by keeping the back and knees straight, he/she lowers the body until there is a 90º angle at the elbows, with the upper arms parallel to the floor. Girls performed the PU as boys but with knees standing on the ground. The push-up movement was controlled as described previously (cadence of 20 reps per minute). The test finishes until he/she can do no more in such rhythm, has not done the last three in rhythm, or has reached the target number of push-ups (Plowman & Meredith, 2013).

The SLJ test consists of reaching the maximum distance in length, aiming to assess the explosive strength of the lower limbs. The students were asked to stand behind a line that marks the starting point with both feet shoulder-width apart. Starting from standing position, in continuous movement, the students were instructed to flex the knees, pull the arms back and jump in length as far as possible, landing with both feet parallel. The evaluator should be placed across the jump zone and record distance (measuring tape, RossCraft, Canada). Distances are measured from the starting point to the heel. Two trials were attempted, and the best value was recorded (Plowman & Meredith, 2013). The VJ was analyzed as the highest distance in height. Students were instructed to stand on a contact mat (Ergojump Digitime 1000, Digitest, Jyvaskyla, Finland), with both feet shoulder-width apart, knee angle between 90º to 120º, both hands on the waist throughout the exercise, and afterwards to perform an explosive extension of the legs (without any countermovement) (Acero et al., 2011). Two repetitions were performed, and the best trial was selected for further analysis.

Statistical analyses

Normality, and homoscedasticity assumptions were tested beforehand with the Kolmogorov-Smirnov, and Levene tests, respectively. The mean plus one standard deviation, and the relative difference (Δ, in %) were calculated as descriptive statistics. Cohen's d was selected as standardized effect size, and interpreted as: (i) small effect size $0 \leq |d| \leq 0.2$; (ii) medium effect size if $0.2 < |d| \leq 0.5$ and; (iii) large effect size if $|d| > 0.5$ (Cohen, 1988).

Hierarchical linear modeling (HLM) was used to test when there was significant changes between pre and post-test and when these changes were significant different between boys and girls and between experimental and control group Maximum likelihood estimation was calculated with HLM7 software.

Results

Figure 1 and Table 2 present the descriptive data and the relative difference and effect size comparison for each group (i.e., control – CG, and experimental – EG) by sex, respectively. Overall, the participants in the EG (boys and girls) showed an improvement in all variables related to physical fitness. Boys presented the highest improvement in the CU test, and girls in the PU test. The % FAT and BMI presented a large decrease in both sexes (i.e., improvement) (Table 2).

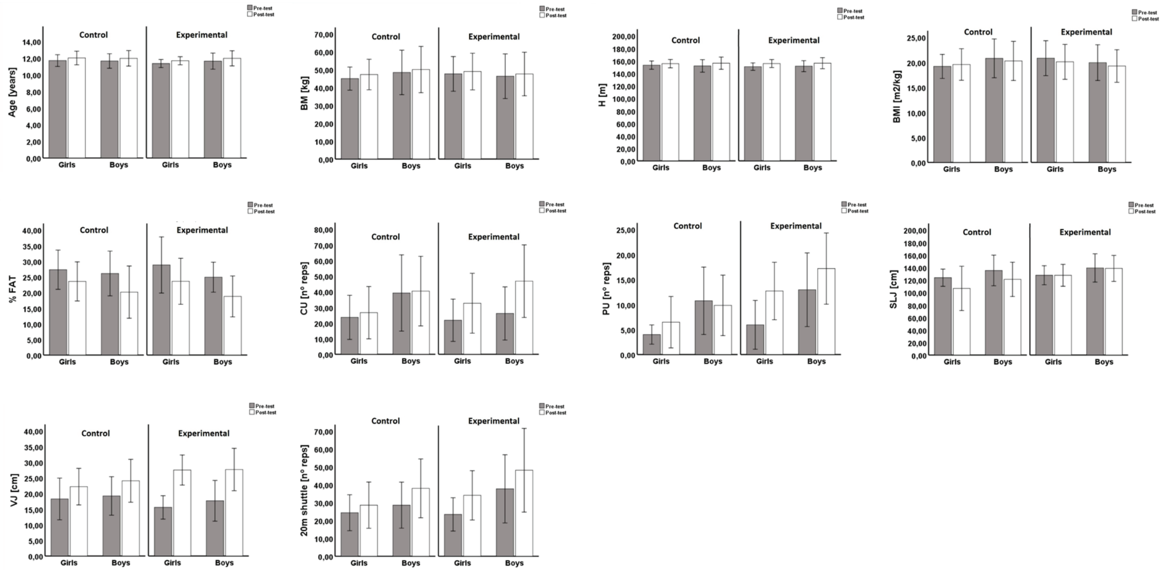


Figure 1. Descriptive statistics (mean ± one standard deviation) for the control and experimental group by sex.

Table 2. Effect size comparison for the control and experimental group by sex.

	Control group		Experimental group	
	Boys (N = 47)	Girls (N = 16)	Boys (N = 24)	Girls (N = 18)
	Δ (d)	Δ (d)	Δ (d)	Δ (d)
Age [years]	2.75 (0.36)	2.65 (0.41)	2.84 (0.35)	3.00 (0.69)
BM [kg]	3.32 (0.13)	5.11 (0.30)	2.65 (0.10)	2.79 (0.13)
% FAT [%]	-22.66 (0.76)	-13.57 (0.59)	-24.96 (1.09)	-18.15 (0.64)
H [cm]	2.88 (0.44)	1.51 (0.35)	3.16 (0.54)	3.24 (0.79)
BMI [kg·m^{-1}]	-2.50 (0.13)	1.93 (0.13)	-3.41 (0.20)	-3.54 (0.21)
CU [nº of reps]	3.03 (0.05)	12.70 (0.19)	79.07 (1.01)	50.00 (0.66)
PU [nº of reps]	-8.47 (0.14)	61.60 (0.58)	32.58 (0.48)	118.89 (1.23)
SLJ [cm]	-8.40 (0.47)	-9.35 (0.58)	-0.54 (0.03)	-0.08 (0.01)
VJ [cm]	25.25 (0.74)	21.59 (0.63)	56.59 (1.50)	76.74 (2.76)
20 m shuttle [nº of reps]	32.77 (0.63)	17.43 (0.37)	27.60 (0.49)	45.52 (0.91)

BM – body mass; % FAT – percentage of fat mass; H – height; BMI – body mass index; CU – curl up's; PU – push-up's; SLJ – standing long jump; VJ – vertical jump; Δ – relative difference in %; d – Cohen's d (effect size index).

Participants in the CG presented mixed findings. For boys, the highest improvement was observed in the 20 m shuttle. However, a small decrease was observed in the PU, and a large decrease in the SLJ. Girls presented the highest and large improvement in the PU. As well boys, girls also presented a large decrease in the SLJ. Both sexes presented a large decrease (i.e., improvement) in the % FAT, and BMI (Table 2).

Table 3 presents the variation of each physical fitness variable modelled with HLM. The 20 m shuttle run test presented a significant sex effect and weight status at baseline (pre-training). A significant time effect was also observed. A non-significant time X sex, time X group, and time X weight status interactions were observed. Conversely, the variables related to strength assessments presented a significant time X group interaction (i.e., significant differences between the CG and EG). The % FAT presented a significant time effect, but not a significant time X group interaction. (Table 3).

Table 3. Parameters estimates for fixed effects of the final model computed for each variable with standard errors (SE) and 95% confidence intervals (95CI).

Parameter	Estimate (SE)	95CI	p-value
20 m shuttle run test (nº of reps)			
Intercept (pretest)	25.72 (2.32)	21.17 to 30.27	<0.001
Sex (girls)	8.98 (2.40)	4.28 to 13.68	<0.001
Group (experimental)	6.18 (2.73)	0.83 to 11.53	0.026
Weight status (O/Ob)	-13.35 (2.33)	-17.92 to -8.78	<0.001
Time	7.12 (1.70)	3.79 to 10.45	<0.001

(continued on next page)

DOI 10.26773/mjssm.220904

(continued from previous page)

Parameter	Estimate (SE)	95CI	p-value
Time*Sex (girls)		N.S.	
Time*Group (experimental)		N.S.	
Time*Weight status (O/Ob)		N.S.	
Curl Up			
Intercept (pretest)	29.13 (3.50)	22.27 to 35.99	<0.001
Sex (girls)	10.36 (3.45)	3.60 to 17.12	0.003
Group (experimental)	-4.58 (3.80)	-12.03 to 2.87	0.015
Weight status (O/Ob)		N.S.	
Time		N.S.	
Time*Sex (girls)		N.S.	
Time*Group (experimental)	15.56 (3.06)	9.56 to 21.56	<0.001
Time*Weight status (O/Ob)		N.S.	
Push Up			
Intercept (pretest)	4.41 (0.90)	2.65 to 6.17	<0.001
Sex (girls)	6.85 (1.05)	4.79 to 8.91	<0.001
Group (experimental)		N.S.	
Weight status (O/Ob)		N.S.	
Time	3.10 (1.04)	1.06 to 5.14	0.004
Time*Sex (girls)	-3.03 (1.07)	-5.13 to -0.93	0.006
Time*Group (experimental)	4.81 (1.16)	2.54 to 7.08	<0.001
Time*Weight status (O/Ob)	-2.41 (1.07)	-4.51 to -0.31	0.027
Standing long jump			
Intercept (pretest)	128.68 (3.58)	121.66 to 135.70	<0.001
Sex (girls)	10.50 (3.68)	3.29 to 17.71	0.005
Group (experimental)		N.S.	
Weight status (O/Ob)	-12.28 (3.83)	-19.79 to -4.77	0.002
Time	-11.17 (3.79)	-18.60 to -3.74	0.004
Time*Sex (girls)		N.S.	
Time*Group (experimental)	10.89 (4.16)	2.74 to 19.04	0.010
Time*Weight status (O/Ob)		N.S.	
Vertical jump			
Intercept (pretest)	19.01 (1.27)	16.52 to 21.50	<0.001
Sex (girls)		N.S.	
Group (experimental)		N.S.	
Weight status (O/Ob)	-3.21 (1.18)	-5.52 to -0.90	0.007
Time	5.70 (1.13)	3.49 to 7.91	<0.001
Time*Sex (girls)		N.S.	
Time*Group (experimental)	6.23 (1.07)	4.13 to 8.33	<0.001
Time*Weight status (O/Ob)		N.S.	
% Fat mass			
Intercept (pretest)	24.71 (1.01)	22.73 to 26.69	<0.001
Sex (girls)	-2.54 (1.04)	-4.58 to -0.50	0.016
Group (experimental)		N.S.	
Weight status (O/Ob)	9.68 (1.04)	7.64 to 11.72	<0.001
Time	-4.40 (0.78)	-5.93 to -2.87	<0.001
Time*Sex (girls)		N.S.	
Time*Group (experimental)		N.S.	
Time*Weight status (O/Ob)		N.S.	

Notes: O/Ob = overweight/obese. N.S. – non-significant.

Discussion

The purpose of this study was to verify the effects of including a short duration HICT (for eight weeks) into the regular physical education classes at schools. A significant sex effect was verified for all variables (except for the VJ), i.e., boys presented better scores than girls. Overall, the results showed significant improvements in cardiorespiratory fitness in both groups (i.e., CG and EG). Muscular fitness (except the curl-up), and fat mass presented a similar trend. However, our hypothesis was only partially confirmed because the HICT caused significant gains (i.e., a time X group interaction) in the muscular fitness variables (curl-up, push-up, standing long jump and vertical jump) by the EG, but not in the cardiorespiratory fitness and fat mass (somatic feature).

Previous studies aimed to understand the effects of implementing high-intensity training programs in children, trying to achieve the health benefits of physical activity but in a shorter time than traditional training methods (Larsen et al., 2018a,b). The use of circuit training as a strategy for implementing high-intensity training has shown to be effective. It was found that 10 months of intense exercise, 3 x 40 min per week of small-sided ball games or circuit training decreased diastolic blood pressure and elicited cardiac adaptations, bone mineralization, jump performance and postural balance, suggesting improving cardiovascular and musculoskeletal health in 8–10 year-old children (Larsen et al., 2018a,b). Still, these training programs were time-consuming and shorter duration sessions could be implemented instead. A pioneering study examining 8–10 min of high-intensity interval training embedded within physical education class (3 times per week) for eight weeks was found to improved cardiorespiratory fitness and body composition in adolescents boys and girls aged between 15 to 16 years (Costigan et al., 2015).

Our data indicated that children of both sexes tended to significantly improve muscular fitness over time. However, those who underwent a HICT (i.e., EG) presented higher and significant improvements. This specific HICT was composed by a set of muscular, flexibility, and aerobic drills. However, most of the drills (60%) were muscular based. Literature reports that HICT's are prone to improve muscular strength in children aged 11.6 ± 0.2 years on average (Engel et al., 2019). The authors indicated that power and strength training (with similar drills as the one used by us) have a positive impact on functional strength as well as on jumping and sprinting performance in children (Engel et al., 2019). Moreover, in children aged between 10 and 12 years, Mayorga-Vega et al. (2013) also verified significant improvements in muscular strength parameters (and different drills were used) after a HICT performed for eight weeks (twice per week). Indeed, it was claimed that adaptations in neuromuscular structure and function, and improvements in intra- and inter-muscular coordination are responsible for the sharp increases in functional strength after high-intensity training (Granacher et al., 2011). In the present study, a HICT performed for eight weeks (twice per week) was enough to elicit such improvements in most of the muscular fitness variables. The exception was found in SLJ, which was maintained from pre to post-intervention in EG. Nonetheless, it should be highlighted that EG prevented SLJ values from being decreased as happened in CG.

Studies indicated that HICT can be prone on improving the cardiorespiratory fitness of children (Seo et al., 2021; Weiss et al., 2015). Indeed, our data indicate that the 20 m shuttle run test significantly improved over time for boys and girls. However, non-significant time X group interaction was observed. That is, the EG group did not improve largely over time than the CG. As aforementioned, most studies about this topic indicated that HICT (or other similar training programs) elicit cardiorespiratory fitness in children (Cvetković et al., 2018; Seo et al., 2021). Nonetheless, such studies employed the training program for more than eight weeks (i.e., this study's timeframe). For instance, Cvetković et al. (2018) employed a high intensity interval training that lasted 12 weeks, two times per week, and it was complemantary to the physical education classes. Others, employed a training program during eight months, two times per week during 45 minutes per session in addition to regular physical educations classes (Weiss et al., 2015). S Thus, one can argue that the duration of the program can be determinant to achieve positive and significant results on cardiorespiratory fitness variables. Like our results, Engel et al. (2019) also noted that cardiorespiratory fitness was not significantly enhanced after a HICT with an intervention period of four weeks. The authors claimed that the short duration of the HICT (6.0 ± 1.5min) combined with the short intervention period were the main reasoning for not eliciting sufficient stimulus to enhance cardiorespiratory fitness. On the other hand, Mayorga-Vega et al. (2013) observed a significant improvement in the cardiorespiratory fitness variable over an eight-week training but with 50-minute sessions. Therefore, one can argue that HICT's that include drills more related to functional strength are more prone to elicit muscular strength rather than cardiorespiratory fitness.

The percentage of fat mass (as a somatic marker) showed a similar trend to the 20 m shuttle run test. That is, a significant improvement over time was observed in boys and girls but not a significant time X group interaction (i.e., it was not verified larger effects by the EG in comparison to the CG). Studies that used the % of fat mass as a body composition marker based on HICT (Seo et al., 2021), high-intensity interval training or even moderate-intensity continuous training (Dias et al., 2018) indicated that all types of training programs were effective on decreasing the % of fat mass in children. Nonetheless, it was claimed that the effect of exercise training on body fat was larger whenever the amount of time performing such programs was higher (Atlantis et al., 2006). Despite non-significant differences over time between groups (i.e., EG and CG) the EG did show larger improvements in the % of fat mass (i.e., decrease over time) in comparison to CG. Additionally, the weight status indicated a significant difference in most of the variables assessed (except for the curl- and push-up). This highlights that children who are most likely to be overweighted or obese present more difficulties in performing such physical fitness drills. This can be extrapolated for daily basis tasks. Thus, extra training programs to the normal school program can play a positive and meaningful key role in schoolchildren physical fitness and overall life quality (Larsen et al., 2018a,b).

The school environment is suggested to be fundamental for interventions that support children in meeting the recommended level of physical activity (García-Hermoso et al., 2020; Sember et al., 2018). This would lead to a better quality of life regarding social, psychological, and nutritional factors (Seo et al., 2021). Therefore, the investigation tried to further understand the effects of different resistance and/or cardiorespiratory training programs to boost activity levels and reduce sedentary behavior during childhood (Larsen et al., 2018a,b).

 DOI 10.26773/mjssm.220904

Most of the times, physical education classes are not enough to meet the needed quantity/intensity of physical activity. Thus, time-efficient methods must be developed as an alternative or even as complementary programs that should be applied at the school context. As suggested, our findings support this by using a short-duration 20 min HICT as a complement of physical education classes. These results showed that adding this kind of HICT to physical education classes would result in a significant increase in muscular fitness performance in children aged 11–14 years old, but not in cardiorespiratory fitness. Nonetheless, it should be highlighted that increasing the amount of time performing the HICT with the same drills could be enough to also improve cardiorespiratory fitness. As main limitation it can be considered the control of the extra physical activitiy besides the one implemented in their school. Nonetheless, parents and teachers were instructed to control and monitor this absence.

Conclusion

Main findings indicate that a HICT program performed during regular physical education classes at schools presented a positive and significant effect in physical fitness parameters, as well as reducing the % of fat mass which is a quality-of-life marker. Implementing this kind of high intensity programs complementary to the school-based program is a must for enhancing children physical fitness and hence their life quality. Future studies should rely on comparing high intensity training programs based on different drills to understand the kind of effect that each type of program/drill has on each pre-established outcome.

Acknowledgments

This work is supported by national funds (FCT - Portuguese Foundation for Science and Technology) under the project UIDB/DTP/04045/2020.

References

Acero, R. M., Fernández-del Olmo, M., Sánchez, J. A., Otero, X. L., Aguado, X., & Rodríguez, F. A. (2011). Reliability of squat and countermovement jump tests in children 6 to 8 years of age. *Pediatric Exercise Science*, 23(1), 151-160. doi: 10.1123/pes.23.1.151.

Adolph, K. E. (2019). An ecological approach to learning in (not and) development. *Human Development*, 63(3-4), 180-201. doi.org/10.1159/000503823.

Alves, A. R., Dias, R., Neiva, H. P., Marinho, D. A., Marques, M. C., Sousa, A. C., Loureiro, V., & Loureiro, N. (2021). High-Intensity interval training upon cognitive and psychological outcomes in youth: A systematic review. *International Journal of Environmental Research and Public Health*, 18(10), 5344. doi: 10.3390/ijerph18105344.

Atlantis, E., Barnes, E. H., & Singh, M. A. (2006). Efficacy of exercise for treating overweight in children and adolescents: a systematic review. *International Journal of Obesity*, 30(7), 1027-1040. doi: 10.1038/sj.ijo.0803286.

Balaban, V. (2018). The relationship between objectively measured physical activity and fundamental motor skills in 8 to 11 years old children from the Czech Republic. *Montenegrin Journal of Sports Science and Medicine*, 7(2), 11-16. doi: 10.26773/mjssm.180902.

Basterfield, L., Adamson, A. J., Frary, J. K., Parkinson, K. N., Pearce, M. S., Reilly, J. J., & Gateshead Millennium Study Core Team. (2011). Longitudinal study of physical activity and sedentary behavior in children. *Pediatrics*, 127(1), 24-30. doi: 10.1542/peds.2010-1935.

Bradley, R. H., McRitchie, S., Houts, R. M., Nader, P., & O'brien, M. (2011). Parenting and the decline of physical activity from age 9 to 15. *International Journal of Behavioral Nutrition and Physical Activity*, 8(1), 1-10. doi.org/10.1186/1479-5868-8-33.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Lawrence Earlbaum Associates.

Cole, T. J., Flegal, K. M., Nicholls, D., & Jackson, A. A. (2007). Body mass index cut offs to define thinness in children and adolescents: international survey. *BMJ*, 335(7612), 194. doi.org/10.1136/bmj.39238.399444.55.

Corder, K., Sharp, S. J., Atkin, A. J., Griffin, S. J., Jones, A. P., Ekelund, U., & van Sluijs, E. M. (2015). Change in objectively measured physical activity during the transition to adolescence. *British Journal of Sports Medicine*, 49(11), 730-736. doi: 10.1136/bjsports-2013-093190.

Costigan, S. A., Eather, N., Plotnikoff, R. C., Taaffe, D. R., Pollock, E., Kennedy, S. G., & Lubans, D. R. (2015). Preliminary efficacy and feasibility of embedding high intensity interval training into the school day: a pilot randomized controlled trial. *Preventive Medicine Reports*, 2, 973-979. doi: 10.1016/j.pmedr.2015.11.001.

Cvetković, N., Stojanović, E., Stojiljković, N., Nikolić, D., Scanlan, A. T., & Milanović, Z. (2018). Exercise training in overweight and obese children: Recreational football and high-intensity interval training provide similar benefits to physical fitness. *Scandinavian Journal of Medicine & Science in Sports*, 28, 18-32. doi: 10.1111/sms.13241.

Delgado-Floody, P., Latorre-Román, P., Jerez-Mayorga, D., Caamaño-Navarrete, F., & García-Pinillos, F. (2019). Feasibility of incorporating high-intensity interval training into physical education programs to improve body composition and cardiorespiratory capacity of overweight and obese children: A systematic review. *Journal of Exercise Science and Fitness*, 17(2), 35-40. doi: 10.1016/j.jesf.2018.11.003.

Dias, K. A., Ingul, C. B., Tjønna, A. E., Keating, S. E., Gomersall, S. R., Follestad, T., Hosseini, M.S., Hollekim-Strand, S. M., Ro, T. B., Haram, M., Huuse, E. M., Davies, P. S. W., Cain, P. A.,Leong, G. M., & Coombes, J. S. (2018). Effect of high-intensity interval training on fitness, fat mass and cardiometabolic biomarkers in children with obesity: a randomised controlled trial. *Sports Medicine*, 48(3), 733-746. doi: 10.1007/s40279-017-0777-0.

Donnelly, J. E., Hillman, C. H., Castelli, D., Etnier, J. L., Lee, S., Tomporowski, P., Lambourne, K., & Szabo-Reed, A. N. (2016). Physical activity, fitness, cognitive function, and academic achievement in children: a systematic review. *Medicine and Science in Sports and Exercise*, 48(6), 1197. doi: 10.1249/MSS.0000000000000901.

Drummy, C., Murtagh, E. M., McKee, D. P., Breslin, G., Davison, G. W., & Murphy, M. H. (2016). The effect of a classroom activity break on physical activity levels and adiposity in primary school children. *Journal of Paediatrics and Child Health*, 52(7), 745-749. doi: 10.1111/jpc.13182.

Engel, F. A., Wagner, M. O., Schelhorn, F., Deubert, F., Leutzsch, S., Stolz, A., & Sperlich, B. (2019). Classroom-based micro-sessions of functional high-intensity circuit training enhances functional strength but not cardiorespiratory fitness in school children—a feasibility study. *Frontiers in*

Public Health, 291. doi: 10.3389/fpubh.2019.00291.

García-Hermoso, A., Alonso-Martínez, A. M., Ramírez-Vélez, R., Pérez-Sousa, M. Á., Ramírez-Campillo, R., & Izquierdo, M. (2020). Association of physical education with improvement of health-related physical fitness outcomes and fundamental motor skills among youths: a systematic review and meta-analysis. *JAMA Pediatrics*, 174(6), 200223-200223. doi: 10.1001/jamapediatrics.2020.0223.

Granacher, U., Goesele, A., Roggo, K., Wischer, T., Fischer, S., Zuerny, C., Gollhofer, A., & Kriemler, S. (2011). Effects and mechanisms of strength training in children. *International Journal of Sports Medicine*, 32(05), 357-364. doi: 10.1055/s-0031-1271677.

Guthold, R., Stevens, G. A., Riley, L. M., & Bull, F. C. (2020). Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1· 6 million participants. *The Lancet Child & Adolescent Health*, 4(1), 23-35. doi: 10.1016/S2352-4642(19)30323-2.

Klika, B., & Jordan, C. (2013). High-intensity circuit training using body weight: Maximum results with minimal investment. *ACSM's Health & Fitness Journal*, 17(3), 8-13. doi: 10.1249/FIT.0b013e31828cb1e8

Larsen, M. N., Nielsen, C. M., Helge, E. W., Madsen, M., Manniche, V., Hansen, L., Hansen, P. R., Bangsbo, J., & Krustrup, P. (2018a). Positive effects on bone mineralisation and muscular fitness after 10 months of intense school-based physical training for children aged 8–10 years: the FIT FIRST randomised controlled trial. *British Journal of Sports Medicine*, 52(4), 254-260. doi: 10.1136/bjsports-2016-096219.

Larsen, M. N., Nielsen, C. M., Madsen, M., Manniche, V., Hansen, L., Bangsbo, J., Krustrup, P., & Hansen, P. R. (2018b). Cardiovascular adaptations after 10 months of intense school-based physical training for 8-to 10-year-old children. *Scandinavian Journal of Medicine and Science in Sports*, 28, 33-41. doi: 10.1111/sms.13253.

Loprinzi, P. D., Davis, R. E., & Fu, Y. C. (2015). Early motor skill competence as a mediator of child and adult physical activity. *Preventive Medicine Reports*, 2, 833-838. doi: 10.1016/j.pmedr.2015.09.015.

Mayorga-Vega, D., Viciana, J., & Cocca, A. (2013). Effects of a circuit training program on muscular and cardiovascular endurance and their maintenance in schoolchildren. *Journal of Human Kinetics*, 37, 153. doi: 10.2478/hukin-2013-0036.

Nevill, A. M., Duncan, M. J., & Sandercock, G. (2020). Modeling the dose–response rate/associations between VO2max and self-reported Physical Activity Questionnaire in children and adolescents. *Journal of Sport and Health Science*, 9(1), 90-95. doi.org/10.1016/j.jshs.2019.05.001.

Nyberg, G. A., Nordenfelt, A. M., Ekelund, U., & Marcus, C. (2009). Physical activity patterns measured by accelerometry in 6-to 10-yr-old children. *Medicine and Science in Sports and Exercise*, 41(10), 1842-1848. doi: 10.1249/MSS.0b013e3181a48ee6.

Paradisis, G. P., Zacharogiannis, E., Mandila, D., Smirtiotou, A., Argeitaki, P., & Cooke, C. B. (2014). Multi-stage 20-m shuttle run fitness test, maximal oxygen uptake and velocity at maximal oxygen uptake. *Journal of Human Kinetics*, 41, 81-87. doi: 10.2478/hukin-2014-0035.

Plowman, S. A., & Meredith, M. D. (2013). *Fitnessgram/Activitygram reference guide*. Dallas, Texas: The Cooper Institute.

Sallis, J. F., Bull, F., Guthold, R., Heath, G. W., Inoue, S., Kelly, P., Oyeyemi, A. L., Perez, L. G., Richards, J., Hallal, P. C., & Lancet Physical Activity Series 2 Executive Committee. (2016). Progress in physical activity over the Olympic quadrennium. *The Lancet*, 388(10051), 1325-1336. doi: 10.1016/S0140-6736(16)30581-5.

Sember, V., Morrison, S. A., Jurak, G., Kovac, M., & Starc, G. (2018). Differences in physical activity and academic performance between urban and rural schoolchildren in Slovenia. *Montenegrin Journal of Sports Science and Medicine*, 7(1), 67-72. doi: 10.26773/mjssm.180309.

Seo, Y. G., Lim, H., Kim, Y., Ju, Y. S., Choi, Y. J., Lee, H. J., Jang, H. B., Park, S. I., & Park, K. H. (2021). Effects of circuit training or a nutritional intervention on body mass index and other cardiometabolic outcomes in children and adolescents with overweight or obesity. *PLoS ONE*, 16(1), 0245875. doi: 10.1371/journal.pone.0245875.

Weiss, M. R., Phillips, A. C., & Kipp, L. E. (2015). Effectiveness of a school-based fitness program on youths' physical and psychosocial health outcomes. *Pediatric Exercise Science*, 27(4). doi: 10.1123/pes.2015-0011.

Weston, K. L., Azevedo, L. B., Bock, S., Weston, M., George, K. P., & Batterham, A. M. (2016). Effect of novel, school-based high-intensity interval training (HIT) on cardiometabolic health in adolescents: project FFAB (fun fast activity blasts)-an exploratory controlled before-and-after trial. *PLoS One*, 11(8), e0159116. doi: 10.1371/journal.pone.0159116.

Yomoda, K., & Kurita, S. (2021). Influence of social distancing during the COVID-19 pandemic on physical activity in children: A scoping review of the literature. *Journal of Exercise Science & Fitness*, 19(3), 195-203. doi.org/10.1016/j.jesf.2021.04.002.

ORIGINAL SCIENTIFIC PAPER

The Difference Between Winners and Losers in Balanced Handball Games in the Final 10 Minutes

Sveinn Þorgeirsson[1,2], Miguel Pic[3], Demetrio Lozano[4], Olafur Sigurgeirsson[5], Damir Sekulic[2], Jose M. Saavedra[1]

Affiliations: [1]Physical Activity, Physical Education, Sport and Health Research Centre, Sports Science Department, School of Social Sciences, Reykjavik University, Reykjavik, Iceland, [2]Faculty of Kinesiology, University of Split, Split, Croatia, [3]Institute of Sport, Tourism, and Service, South Ural State University, Chelyabinsk, Russia; Motor Action Research Group (GIAM), [4]Health Sciences Faculty, VALORA Research Group, Universidad San Jorge, Zaragoza, Spain, [5]HBStatz Company, Reykjavik, Iceland

Correspondence: S. Þorgeirsson, Reykjavik University, Physical Activity, Physical Education, Sport and Health Research Centre, School of Social, Sciences Sports Science Department, Menntavegur 1, 102 Reykjavík, Iceland. E-mail: sveinntho@ru.is

Abstract

The objectives of this study are to analyze handball game-related statistics in balanced games (0-2 goal difference at minute 50) in the final 10 minutes regarding the final outcome of winning or losing. i) Analyse statistical differences between winners and losers in male and female top Icelandic handball leagues and ii) calculate a discriminating model for performance variables for both male and female top Icelandic handball leagues. The game-related statistics from the final 10 minutes of 127 games from two seasons (85 male and 42 female) with a goal difference of two or fewer at minute 50 were analyzed. The internal consistency and reliability ranged from good to excellent for the games of both sexes. Differences between winning or losing for each sex were determined using the unpaired t-test or Mann-Whitney U test, and Cohens d for effect sizes was calculated. The results for males include four variables with large effect sizes and six with significant differences. The discriminatory model selected technical fouls and goalkeeper blocked shots from 9 m to classify 40.4% correctly (Wilks' lambda 0.005, and canonical correlation of 0.997). For females, findings align with previous research underscoring the importance of 9 m shots at goal at this level. However, they differ somewhat from full game statistics at the elite level with no difference in red cards and 7 m shots. Coaches should pay particular attention in tactical preparation to shots outside 9 m – both offensively and defensively in balanced games in the final 10 minutes.

Keywords: *Performance, notational analysis, discriminatory analysis, league, amateur*

@MJSSMontenegro
THE DIFFERENCE BETWEEN WINNERS AND LOSERS IN THE FINAL 10 MINUTES
http://mjssm.me/?sekcija=article&artid=240

Cite this article: Þorgeirsson, S., Pic, M., Lozano, D., Sigurgeirsson, O., Sekulic, D., & Jose Saavedra, J.M. (2022) The Difference Between Winners and Losers in Balanced Handball Games in the Final 10 Minutes. *Montenegrin Journal of Sports Science and Medicine*, 11 (2), 37–43. https://doi.org/10.26773/mjssm.220905

Introduction

In recent years, the literature on performance analysis in handball has grown with emerging technologies and more detailed game-related statistics. However, gameplay can only be partially described by the static outcome statistics (what) as the processes behind each play (how) are dynamic. Most performance analyses rely on standard performance indicators such as number of attacks, offensive efficiency, shots, shots efficiency, goalkeepers' efficiency, the average number of suspensions, and statistics according to playing positions and

Received: 03 April 2022 | Accepted after revision: 23 June 2022 | Early access publication date: 01 August 2022 | Final publication date: 1 September 2022

© 2022 by the author(s). License MSA, Podgorica, Montenegro. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY).

Conflict of interest: None declared.

event locations on the court (Ferrari et al., 2019).

Several papers on the differences between winners and losers have recently been published. One recent article identified discriminatory variables for winners in the female's World Championships from 2007 to 2017, grouping games into clusters by the final outcome. Defensive variables (stolen balls, blocked throws, and goalkeeper's efficiency indicators) contributed more to balanced games than attack variables. Also, a higher number of technical faults were associated with lower chances of winning (de Paula et al., 2020). Another paper on male play from four past Olympic Games indicated winners perform better in total shot efficiency and from 9 m, assists, and goalkeeper blocked shots in fast breaks than losing teams. Additionally, a model correctly classified 82% of the games using only four variables of shots, goalkeeper-blocked shots, technical fouls, and the number of attacks (Saavedra et al., 2017a). With similar methods, discriminatory models have been constructed for the domestic league level in Iceland for male and female play, providing insight into a topic with minimal previous research. Using five variables (shots, goalkeeper blocked saves [GB saves], steals, technical fouls, GB 7 m saves), 84% of games were correctly classified between winners and losers. Though only shots and GB saves were enough to classify 87% correctly for females (Þorgeirsson et al., 2022).

Only a few studies have examined balanced games (de Paula et al., 2020; Pic, 2018) or concentrated on the final minutes (Debanne et al., 2018; Lozano et al., 2016) or both (Prieto et al., 2015) in handball. A more extensive literature on these critical last minutes of playing time exists in other sports such as basketball (Gómez et al., 2018). The handball coach plays an active role in the game by managing the on-field players and tactics at any moment. The coach can directly impact the game with time-outs (Gutiérrez-Aguilar et al., 2016), player´s on-court time (Büchel et al., 2019) and moderate defensive tactics, thinking about the effects of fouls (Fasold & Redlich, 2018; Laxdal & Ivarsson, 2022), and exclusions (Prieto et al., 2015). Therefore, coaches need to know if the final minutes in balanced matches represent a different situation from the rest of the game to make better decisions in the match. Furthermore, a previous review study has suggested comparing winning teams to losing teams during an entire season to understand the most crucial performance indicators during specific game periods (Ferrari et al., 2019). In line with that, the primary purpose of this research is to analyze handball game-related statistics in balanced games (0-2 goal difference at minute 50) in the final 10 minutes regarding the final outcome of winning or losing. i) Analyse statistical differences between winners and losers in male and female top Icelandic handball leagues and ii) calculate a discriminating model for performance variables for both male and female top Icelandic handball leagues.

Methods

Participants

A total of 127 handball games (85 male and 42 female) from the top Icelandic league spanning two seasons (2018-2019 and 2019-2020) were analyzed with game-related statistics. The data set included only games in goal-scoring balance at minute 50 with a goal difference of two or fewer. Matches resulting in a draw (n= 26 male and 8 female) were also excluded as the statistics from the last 10 minutes were analyzed by the final game outcome of winning or losing. In the top Icelandic league, 12 teams compete in the top male leagues (out of three), and females have eight teams in the top league (out of two). The majority of senior teams (male and female) have players 18 years and older, however, coaches do include youth aged players in their teams. The full dataset is available online at https://hbstatz.is/ (a collaboration between the Icelandic Handball Federation and HBStatz company).

Procedures

During handball games, trained observers entered the game-related statistics on a computer using a specifically designed application named HBStatz written in VB.net PHP and SQL code. The data was then extracted from the database for further processing in Excel and subject to error checks by one of the authors [SÞ] to detect possible errors before importing it into the statistical analysis software. Authors extracted the information used in the study from sources available in the public domain on a website (male league: [https://hbstatz.is/OlisDeildKarlaLeikir2018.php, https://hbstatz.is/OlisDeildKarlaLeikir2019.php] and female league: [https://hbstatz.is/OlisDeildKvennaLeikir2018.php, https://hbstatz.is/OlisDeildKvennaLeikir2019.php] and therefore no participant informed consent was needed. This method of obtaining data has been commonly used in performance analysis in team sports, such as handball (Calin, 2010; Meletakos et al., 2011; Yamada et al., 2011; Pollard & Gomez, 2012). In this study, game outcome of winning or losing is the dependent variable, and the independent variables are listed in table 1.

Table 1. Definitions of the game-related statistics.

Variable	Definition
Shots	Percentage of converted shots relative to the number of shots made.
6 m shots	Percentage of converted shots at 6 m relative to the number of shots made. The shot is from a zone outside the 45° angle from the left and the right.
7 m shots	Percentage of penalties (7 m) converted relative to the number of penalties taken.
9 m shots	Percentage of converted shots at 9 m relative to the number of shots made. The shot is from a backcourt player either (a) over or through the defence, or (b) after a breakthrough but with a defensive player in front.
Wing shots	Percentage of converted shots from the wing area relative to the number of shots made. The shot is from a zone within the 45° angle from the left and the right without a defence player in front.
Fast-break shots	Percentage of shots converted in a fast-break situation (rapid switch from defense to attack without the defense organized) relative to the number of shots made in this situation.
Breakthrough shots	Percentage of shots converted in a breakthrough situation relative to the number of shots made in this situation (a) from a backcourt player after breakthrough in the 9 m zone without a defence player in front, (b) from the pivot after a 1:1 situation, (c) from the left or right back after a breakthrough of a 1:1 situation.

(continued on next page)

 DOI 10.26773/mjssm.220905

(continued from previous page)

Variable	Definition
Yellow cards	Yellow cards received by each player and/or coaching staff member.
Red cards	Red cards received by each player and/or coaching staff member.
2-min exclusions	2-minute suspension received by each player and/or coaching staff member.
Assists	Number of passes from one offensive player to another leading directly to a goal scored.
Technical fouls	Number of turnovers made by the offensive team where the ball is awarded to the defence due to a foul in the offence.
Steals	Number of turnovers in favor of the defence due to actions of anticipation and snatching the ball.
GB saves	Percentage of shots stopped relative to the number of shots made by the attackers.
GB 6 m saves	Percentage of 6 m shots stopped relative to the number of shots made by the attackers.
GB 7 m saves	Percentage of penalties (7 m) stopped relative to the number of penalties taken by the attackers.
GB 9 m saves	Percentage of 9 m shots stopped relative to the number of shots made by the attackers.
GB wing saves	Percentage of shots stopped in the wing area relative to the number of shots made by the attackers.
GB fast-break saves	Percentage of shots stopped in fast-break situations relative to the number of shots made by the attackers.
GB breakthrough saves	Percentage of shots stopped in breakthrough situations relative to the number of shots made by the attackers.

The data was validated with the use of an ad hoc observational instrument (Anguera, 2003; Anguera, Camerino, Castañer, Sánchez-Algarra & Onwuegbuzie, 2017) and LINCE software package (Gabín, Camerino, Anguera & Castañer, 2012). Four subgroups were created for the organization of the variables; (i) shots (shots, 6 m shots, 7 m shots, 9 m shots, wing shots, fast-break shots, breakthrough shots); (ii) fouls (yellow card, red card, 2-minutes exclusions); (iii) goalkeeper-blocked (goalkeeper-blocked 6 m shots, 7 m shots, 9 m shots, wing shots, fast-break shots, and breakthrough shots) and (iv) other variables (assists, technical fouls, blocks, steals).

Table 2. Intra- and inter-observer internal consistency (Cronbach's alpha – α) and reliability (intra-class correlation coefficient – ICC, and Cohen's kappa – κ).

	Men						Female					
	Intra-observer			Inter-observer			Intra-observer			Inter-observer		
Variable Group	α	ICC	κ	α	ICC	κ	α	ICC	κ	α	ICC	κ
Shots	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Cards and exclusions	1.000	1.000	1.000	0.876	0.866	0.816	1.000	1.000	1.000	0.657	0.657	0.621
Goalkeeper-blocked	0.976	0.976	0.961	0.837	0.837	0.832	0.816	0.816	0.8	0.816	0.816	0.8
Other variables	0.882	0.882	0.784	0.69	0.69	0.731	0.976	0.976	0.965	0.781	0.781	0.619
Mean	0.965	0.965	0.928	0.851	0.848	0.845	0.948	0.948	0.988	0.814	0.814	0.747

Statistical analysis

Descriptive statistics (mean and standard deviation) were calculated for game-related statistics by game outcome (winning and losing teams) and by sex. The reliability of data was determined using Cohen's kappa (κ) values and Cronbach's alpha (α) for internal consistency and intra-class correlation coefficients (ICC). Four games were chosen by random, analyzed (two females and two males), and calculated for intra-observer internal consistency and reliability (at two different times) and inter-observer internal consistency and reliability (to compare the observation record with the one obtained from the official website). The cut-off points between 0 and 1 (Peterson, & Kim, 2013), were: for α (internal consistency) <0.50 unacceptable, 0.51-0.60 poor, 0-61-0.70 questionable, 0.71-0.80 acceptable, 0.81-0.90 good, and ≥0.91 excellent (George, & Mallery, 2003); for ICC (reliability) ≤0.50 poor, 0.51-0.75 moderate, 0.76-0.90 good, and ≥0.91 excellent (Koo & Li, 2016); and for κ (reliability) <0.01 no agreement, 0.01–0.20 poor, 0.21–0.40 discrete/regular, 0.41–0.60 moderate, 0.61–0.80 good, and 0.81–1.00 very good (Landis & Koch, 1977). Table 2 lists the internal consistency and reliability results of the intra-observer and inter-observer mean. For males, the intra-observer results are very good (κ) and excellent (α and ICC), and the inter-observer values are good (α and ICC) and very good (κ). For females, intra-observer results are very good (κ) and excellent (α and ICC), and inter-observer results are good (α, ICC, and κ).

Kolmogorov-Smirnov test was used to determine the normality of each variable. Differences between winning and losing teams in the male and female top league were calculated with a parametric (unpaired t-test) or non-parametric (Mann-Whitney U) test, according to whether the variable was normally distributed or not. The effect sizes (ES) interval of >0.2 small, >0.5 moderate and >0.8 large were used to interpret the differences calculated according to recommendations (Cohen, 1988). The authors performed a discriminant analysis with a sample-splitting method depending on the game outcome (winning and losing teams) for both males and females. Wilks' lambda (λ) measures the deviations within each group relative to the total deviations. That criterion was used to determine whether or not a variable is discriminatory. The sample-splitting method initially included the variable that best minimized the value of λ under the provision that the value of F was greater than a specific critical value (F = 3.84, "include"). From that point on, the method combined the variables pairwise. The new variable was selected if λ was greater than the value of the input F. Before introducing a variable, an attempt to eliminate those that had already been selected was made, as long as the increase in the minimized λ was below a critical threshold (F = 2.71, “remove”). The canonical correlation index (λ) was calculated (deviations of the between-group discriminant scores relative to the total deviations), and the percentage of correctly classified games (winning and losing teams). A p-value <0.05 was considered to be statistically significant. The statistical analysis was performed with the software package SPSS version 27.0 (Version 27.0; IBM, Armonk, NY, USA).

Results

Table 3 compares means of game-related statistics for males during the last 10 minutes of balanced games by game outcome (winning and losing) with standard deviations using a non-parametric test (Mann-Whitney) with p values and effect sizes. Ten variables in total showed significant differences (alpha level <0.05) depending on the game outcome. Four variables had large effect sizes using Cohen’s d > 0.80. In order of decreasing effect sizes these variables were: shots (d = 1.114) , GB 9 m saves (d = 1.100), 9 m shots (d = 0.875) and GB saves (d = 0.827).

Table 3. Basic descriptors (mean and standard deviation), Mann-Whitney U test (non-parametric test), p-value, and the effect size of the differences (Cohen’s d) for each variable according to the game outcome in males.

Variable	Winners	Losers	U	*p*	ES
Shots (%) [a]	68.20 ± 17.01	49.12 ± 17.22	1565.00	<0.001	1.114
6 m shots (%) [a]	77.16 ± 36.81	73.91 ± 40.62	1220.00	0.855	0.084
7 m shots (%) [a]	72.36 ± 41.77	80.16 ± 38.12	775.00	0.325	0.195
9 m shots (%) [a]	57.16 ± 32.89	31.13 ± 26.24	1819.00	<0.001	0.875
Wing shots (%) [a]	70.43 ± 37.98	44.45 ± 39.98	1217.00	<0.001	0.666
Fast-break shots (%) [a]	78.86 ± 35.75	66.18 ± 45.78	608.00	0.256	0.309
Breakthrough shots (%) [a]	72.27 ± 37.48	69.29 ± 40.92	1129.50	0.811	0.076
Yellow cards (n)	0.04 ± 0.19	0.12 ± 0.32	3315.00	0.044	0.304
Red cards (n)	0.14 ± 0.35	0.19 ± 0.45	3515.50	0.628	0.124
2-min exclusions (min)	1.22 ± 1.45	1.88 ± 1.91	2958.50	0.028	0.389
Assists (n)	2.01 ± 1.34	1.32 ± 1.05	2543.00	<0.001	0.573
Technical fouls (n)	1.13 ± 1.10	1.69 ± 1.401	2805.50	0.009	0.714
Steals (n)	0.71 ± 0.94	0.44 ± 0.63	3174.50	0.119	0.337
GB saves (%) [b]	23.38 ± 15.83	38.13 ± 18.77	2066.00	<0.001	0.827
GB 6 m saves (%) [b]	17.65 ± 32.56	20.93 ± 36.75	1072.00	0.813	0.094
GB 7 m saves (%) [b]	24.58 ± 40.65	11.11 ± 30.91	648.50	0.072	0.373
GB 9 m saves (%) [b]	29.86 ± 32.45	55.10 ± 36.00	1952.00	<0.001	1.100
GB wing saves (%) [b]	23.22 ± 36.93	46.43 ± 42.05	1203.50	0.002	0.587
GB fast-break saves (%) [b]	16.13 ± 35.09	20.94 ± 37.99	550.5	0.870	0.039
GB breakthrough saves (%) [b]	22.88 ± 35.41	25.00 ± 38.11	1040.50	0.846	0.614

[a] number of shots converted/number of shots; [b] number of shots saved/number of shots; GB = goalkeeper-blocked, ES = effect size.

Table 4 compares means of game-related statistics for females during the last 10 minutes of balanced games by game outcome (winning and losing) with standard deviations using parametric (t-test) and non-parametric test (Mann-Whitney) with p values and effect sizes. Six variables showed significant differences (alpha level <0.05) depending on the game outcome. Four variables showed large effect sizes (Cohen’s d>0.80) between winning and losing teams. In order of decreasing effect sizes the variables were; shots (d = 1.414), GB saves (d = 1.330), 9 m shots (d = 0.933) and GB 9 m saves (d = 0.923).

Table 4. Basic descriptors (mean and standard deviation), unpaired-sample t-test (parametric test), Mann-Whitney U test (non-parametric test), p-value, and the effect size of the differences (Cohen’s d) for each variable according to the game outcome in female.

Variable	Winners	Losers	t	U	p	ES
Shots (%) [a]	62.34 ± 17.58	37.94 ± 16.92	7.268		<0.001	1.414
6 m shots (%) [a]	79.32 ± 34.08	76.66 ± 41.69		2549.00	0.872	0.070
7 m shots (%) [a]	70.59 ± 43.51	69.44 ± 42.49		149.50	0.893	0.027
9 m shots (%) [a]	53.06 ± 27.25	27.66 ± 27.14		367.50	<0.001	0.933
Wing shots (%) [a]	40.33 ± 38.77	38.23 ± 41.58		381.50	0.754	0.052
Fast-break shots (%) [a]	82.84 ± 35.41	54.76 ± 45.96		39.00	0.120	0.684
Breakthrough shots (%) [a]	75.60 ± 36.14	64.63 ± 40.30		209.50	0.294	0.287
Yellow cards (n)	0.10 ± 0.30	0.10 ± 0.30		882.00	1.000	0
Red cards (n)	0.00 ± 0.00	0.00 ± 0.00		882.00	1.000	0

(continued on next page)

 DOI 10.26773/mjssm.220905

(continued from previous page)

Variable	Winners	Losers	t	U	p	ES
2-min exclusions (min)	0.67 ± 0.95	1.14 ± 1.48		716.00	0.182	0.402
Assists (n)	2.01 ± 1.45	1.32 ± 1.05		539.50	0.004	0.600
Technical fouls (n)	1.57 ± 1.35	2.31 ± 1.72		631.50	0.048	0.497
Steals (n)	0.71 ± 0.94	0.44 ± 0.63		574.00	0.005	0.592
GB saves (%) [b]	24.99 ± 15.52	50.43 ± 22.15	-5.385		<0.001	1.330
GB 6 m saves (%) [b]	16.36 ± 32.89	23.33 ± 41.69		195.00	0.799	0.186
GB 7 m saves (%) [b]	16.67 ± 36.19	26.47 ± 39.99		109.50	0.389	0.257
GB 9 m saves (%) [b]	60.03 ±32.36	32.08 ± 28.02		376.00	<0.001	0.923
GB wing saves (%) [b]	45.08 ± 43.84	53.97 ± 44.12		283.50	0.477	0.202
GB fast-break saves (%) [b]	5.95 ± 22.63	4.17 ± 17.39		880.00	0.968	0.088
GB breakthroughs saves (%) [b]	20.37 ± 33.76	31.48 ± 41.58		210.00	0.378	0.293

[a] number of shots converted/number of shots; [b] number of shots saved/number of shots; GB = goalkeeper-blocked, ES = effect size.

Table 5 shows the results of discriminant analysis (Wilks' lambda, the canonical correlation index, and the percentage of teams correctly classified) for the game outcome by sex during the final 10 minutes in balanced games. The male's predictive model correctly classified 40.4% of games using two selected variables: technical fouls and GB 9 m saves. The dataset did not allow the female's predictive model to be constructed due to too many excluded variables in the stepwise discriminative model.

Table 5. Discriminant analysis models by the game outcome (winning and losing teams) in male and female, giving the percentage correctly classified, Wilks' lambda, canonical correlation index, and variables included in the model by order of selection.

	Men	Female
Percentage correctly classified	40.4	n.a.
Wilks' lambda	0.005	
Canonical correlation index	0.997	
Variables selected	Technical fouls, GB 9 m saves	

GB = goalkeeper-blocked.

Discussion

This study aimed to analyze i) differences and ii) discriminatory variables in game-related statistics between winners and losers in the Icelandic top handball league in balanced games during the final 10 minutes. As expected, the main findings suggest that winners have better shot efficiency and GB saves. Furthermore, shot efficiency from 9 m was significantly better amongst winners than losers, as were GB saves from 9 m. Interestingly, the discriminatory model consisted only of technical fouls and goalkeeper blocked shots from 9 m (classifying 40.4% of games correctly). The model for the female league was impossible to construct due to excluded variables in the stepwise discriminatory model. This study brings value to the current handball performance analysis literature as it is the first to take a closer look at the game-related statistics (20 variables) during an exciting period of the games for the players, coaches and spectators of the sport.

Previous research into the final minutes of handball have been studied (Debanne et al., 2018; Lozano et al., 2016), and the concept of balanced games explored (de Paula et al., 2020; Pic, 2018). One recent study investigated the same game-related statistics on a whole season basis at the domestic league level (Þorgeirsson et al., 2022), rather than the more commonly researched elite level (Saavedra et al., 2017a). In those two papers, the methodology is the same as used in this present work, and thus offers better opportunities to compare this study's results to both whole game outcomes and different competition levels.

Differences between winners and losers for males were found in ten of the 20 analysed variables, of which shots (d = 1.114), GB 9 m saves (d = 1.100), GB saves (d = 0.827) and 9 m shots (d = 0.875) returned large effect sizes. This is in line with findings from recent work on the same league (Þorgeirsson et al., 2022), which found shot efficiency, GB saves and 9 m shots to differ between winners and losers. Compared to results from four past Olympic Games, they have 9 m shots in common but differ on GB fast-break saves, and assists found at the elite level (Saavedra et al., 2017b). There are several possible explanations why the 9 m shot is so important. First, tactically, it could be wise to direct the opponent into the relatively lower chance shot from outside 9 m with a more passive approach than allowing close range shots from 6 m, the wings, or breakthrough opportunities. Second, as the match draws to an end, the defense might take a more passive stance closer to the 6 m line to avoid receiving a 2-minute suspension or 7 m penalty throw. The third is the rotation of outfield players between defense and offense. In a recent study on the elite level, the absolute on-court time for back-court players is less than for wing players (Büchel et al., 2019), giving back-court players more time to recover during matches.

For differences between winners and losers for female league teams, six variables emerge as being significantly different, whereby four of them (shots d = 1.414, GB saves d = 1.330, 9 m shots d = 0.933, and GB 9 m saves d = 0.923) showed large effect sizes. These results are comparable to male variables and highlight the role of goalkeepers and shots from

9 m during the final minutes in balanced games. Previous research on international-level whole game females has indicated that red cards and assists differ between winners and losers (Saavedra et al., 2018). Red cards did not appear in this limited data set and were therefore not calculated. Still, they could be considered to be likely to be a meaningful event at the domestic level as well as elite level. Assists also appear significant (with moderate effect size d = 0.600) in the last ten minutes of balanced domestic games, as was the result at the elite level (Saavedra et al., 2018). Unlike findings investigating balanced games at the elite level, assists were more important in unbalanced games (de Paula et al., 2020). Generally, these results from the final minutes of balanced games share similar characteristics with full game statistics – as observed before in shots, GB saves, and GB 9 m saves, all with large effect size and assists. However, 7 m shots were not identified in this work as before during whole games (Þorgeirsson et al., 2022). There are two reasons for this, first, it is possible that too few 7 m throw events were observed in this study to produce a statistically significant difference. Second, although the efficiency is very similar, the number of 7 m throws awarded might differ between winners and losers and thus affecting the final outcome. Similar to males, the 9 m shots, whether blocked or a goal, seem to be the variable to consider during the final minutes of balanced games for females.

A discriminatory model for males was constructed (Wilks' lambda 0.005 and canonical correlation of 0.997) and interestingly selected only two variables with 40.4% correct classification. Technical fouls and GB 9 m saves emerged from this model, just as those two variables had been selected in a whole game analysis model for a domestic league before, in addition to shots, GB shots, steals, and GB 7 m saves (Þorgeirsson et al., 2022). The results can be compared to the international elite level, where technical fouls also appear with shots, GB saves, and the number of attacks (not analyzed here) (Saavedra et al., 2017a). The fact that technical fouls is the first variable selected in the model should not surprise coaches at the top level or readers of scientific papers about performance analysis at the elite level (Saavedra et al., 2017b).

Unfortunately, after an exploratory analysis, it was impossible to construct a discriminatory model for females based on the dataset assembled from two seasons. It was limited to only games balanced at minute 50 with a goal difference of two or fewer. However, it would have been expected to find shots and GB saves to classify games correctly, as was the case with full games for an entire season (Þorgeirsson et al., 2022). Also, technical fouls, which have been shown to damage teams' chances of winning (de Paula et al., 2020), with steals and GB fast-break saves, have been previously identified in such models at the elite level (Saavedra et al., 2018).

This study has several limitations: i) the sample consists of top domestic leagues and is therefore only representative of that competition level. ii) The nature of the data is static, and with only 10 minutes included for analysis, the sample consists of relatively few events, although comprised of two seasons. iii) The standard situational variables available for this study do not provide details for precise analysis. iv) The cut-off point at 50 minutes could have excluded games that minutes later became balanced (less than a two-goal difference) or included games that were about to become unbalanced for the remainder of the game. At a nuanced level, the most balanced games being excluded from the analysis because they resulted in a draw. The results of this study underline the importance of incorporating process-related data to understand the effects of individual variables on the handball goal-scoring dynamics. Future research must include efforts to better understand the processes behind the outcome statistics covered in this work. They should also consider adding the number of each statistical event into the analysis to understand the weight of each variable better in the context of the final outcome. In conclusion, coaches preparing their teams for the final minutes of balanced games should consider a special tactical preparation for the shots made from outside 9 m when breaking through defenses is challenging, defensively (GB saves) and offensively (shots).

Acknowledgements

The authors wish to thank Garðar Örn Arnarsson creative director from Stöð 2 television network for assisting in preparing the recordings of the handball games for the validation process.

References

Anguera, M. T. (2003). Observational Methods (General). In R. Fernandez- Ballesteros (ed.), Encyclopedia of Psychological Assessment (Vol. 2, pp. 632-637). London: Sage.

Anguera, M. T., Camerino, O., Castañer, M., Sánchez-Algarra, P. & Onwuegbuzie, A. J. (2017). The specificity of observational studies in physical activity and sports sciences: Moving forward in mixed methods research and proposals for achieving quantitative and qualitative symmetry. Frontiers in Psychology, 8, 2196. doi: 10.3389/fpsyg.2017.02196

Büchel, D., Jakobsmeyer, R., Döring, M., Adams, M., Rückert, U., & Baumeister, J. (2019). Effect of playing position and time on-court on activity profiles in german elite team handball. International Journal of Performance Analysis in Sport, 19(5), 832–844. https://doi.org/10.1080/24748668.2019.1663071

Calin, R. (2010). The analysis of the efficiency of using fast breaks in female handball during the World Championship in China, 2009. Science, Movement and Health, 2: 594-599. https://www.analefefs.ro/anale-fefs/2010/issue-2-supplement/pe-autori/44.pdf

Cohen, J. (1988). Statistical power analysis for the behavioral sciences. Routledge Academic.

de Paula, L. V., Costa, F. E., Ferreira, R. M., Menezes, R. P., Werneck, F. Z., Coelho, E. F., & Greco, P. J. (2020). Analysis of discriminatory game variables between winners and losers in women's handball world championships from 2007 to 2017. Kinesiology, 52(1), 54–63. https://doi.org/10.26582/k.52.1.6

Debanne, T., Laffaye, G., & Trouilloud, D. (2018). Motivational orientations and performance in penalty throws during elite male team handball games. Scandinavian Journal of Medicine & Science in Sports, 28(3), 1288–1294. https://doi.org/10.1111/sms.12995

Fasold, F., & Redlich, D. (2018). Foul or no Foul? Effects of Permitted Fouls on the Defence Performance in Team Handball. Journal of Human Kinetics, 63(1), 53–59. https://doi.org/10.2478/hukin-2018-0006

Ferrari, W. R., Sarmento, H., & Vaz, V. (2019). Match Analysis in Handball: A Systematic Review. Montenegrin Journal

 DOI 10.26773/mjssm.220905

of Sports Science and Medicine, 8(2), 63–76. https://doi.org/10.26773/mjssm.190909

Gabín, B., Camerino, O., Anguera, M. T. & Castañer, M. (2012). Lince: Multiplatform sport analysis software. Procedia-Social and Behavioral Sciences, 46, 4692–4694. doi: 10.1016/j.sbspro.2012.06.320

George, D. & Mallery, P. (2003). SPSS for Windows step by step: A simple guide and reference. 11.0 update (4th ed.). Boston: Allyn & Bacon.

Gómez, M.-Á., Avugos, S., Oñoro, M.-Á., Lorenzo, A., & Bar-Eli, M. (2018). Shaq is not Alone: Free-Throws in the Final Moments of a Basketball Game. Journal of Human Kinetics, 62, 135–144. https://doi.org/10.1515/hukin-2017-0165

Gutiérrez-Aguilar, Ó., Montoya-Fernández, M., Fernández-Romero, J. J., & Saavedra-García, A. M. (2016). Analysis of time-out use in handball and its influence on the game performance. International Journal of Performance Analysis in Sport, 16(1), 1–11. https://doi.org/10.1080/24748668.2016.11868866

Koo, T. K. & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. Journal of Chiropractic Medicine, 15(2), 155-163. https://doi.org/10.1016/j.jcm.2016.02.012

Landis, J. R. & Koch, G. G. (1977). The measurement of observer agreement for categorical data. Biometrics, 33(1), 159–174. https://doi.org/10.2307/2529310

Laxdal, A., & Ivarsson, A. (2022). Breaking up the play: The relationship between legal stops and winning in team handball. International Journal of Sports Science & Coaching, 17479541211070788. https://doi.org/10.1177/17479541211070787

Lozano, D., Camerino, O., & Hileno, R. (2016). Analysis of the offensive tactical behavior in critical moments of game in the high performance in handball: A study Mixed Methods. Cuadernos de Psicología del Deporte, 16(1), 151–159.

Meletakos, P., Vagenas, G., Bayios, I. (2011). A multivariate assessment of offensive performance indicators in Men's Handball: Trends and differences in the World Championships. International Journal of Performance Analysis in Sport, 11(2), 284–294. https://doi.org/10.1080/24748668.2011.11868548

Peterson, R. A. & Kim, Y. (2013). On the relationship between coefficient alpha and composite reliability. Journal of Applied Psychology, 98(1), 194-198. doi: 10.1037/a0030767

Pic, M. (2018). Performance and Home Advantage in Handball. Journal of Human Kinetics, 63(1), 61–71. https://doi.org/10.2478/hukin-2018-0007

Prieto, J., Gómez, M.-Á., & Sampaio, J. (2015). Players' exclusions effects on elite handball teams' scoring performance during close games. International Journal of Performance Analysis in Sport, 15(3), 983–996. https://doi.org/10.1080/24748668.2015.11868845

Saavedra, J. M. (2018). Handball Research: State of the Art. Journal of Human Kinetics, 63(1), 5–8. https://doi.org/10.2478/hukin-2018-0001

Saavedra, J. M., Þorgeirsson, S., Kristjánsdóttir, H., Chang, M., & Halldórsson, K. (2017a). Handball game-related statistics in men at Olympic Games (2004-2016): Differences and discriminatory power. Retos, 32(2), 260–263.

Saavedra, J. M., Þorgeirsson, S., Kristjánsdóttir, H., Chang, M., & Halldórsson, K. (2017b). Handball game-related statistics in men at Olympic Games (2004-2016): Differences and discriminatory power. 4.

Yamada, E., Aida, H. & Nakagawa, A. (2011). Notational analysis of shooting play in the middle area by world-class player and Japanese elite players in woman's handball. International Journal of Sport and Health Science, 9, 15-25. https://doi.org/10.5432/ijshs.20100028

Þorgeirsson, S., Pic, M., Lozano, D., Sigurgeirsson, O., Sekulic, D., & Saavedra, J. M. (2022). Gender-based differences in game-related statistics between winning and losing teams in an amateur handball league. Acta Gymnica, 52. https://doi.org/10.5507/ag.2022.001

REVIEW ARTICLE

Can complex contrast training interventions improve aerobic endurance, maximal strength, and repeated sprint ability in soccer players? A systematic review and meta-analysis

Rohit K. Thapa[1], Pushpendra Narvariya[1], Anthony Weldon[2,3], Kaushik Talukdar[4,5], Rodrigo Ramirez-Campillo[6]

Affiliations: [1]School of Physical Education and Sports, Rashtriya Raksha University, Gandhinagar, India, [2]The Technological and Higher Education Institute of Hong Kong, Hong Kong, [3]Cricket Hong Kong, Hong Kong, [4]Athlete Institute, Auckland, New Zealand, [5]Sports Performance Research Institute of New Zealand, Auckland University of Technology, Auckland, New Zealand, [6]Exercise and Rehabilitation Sciences Laboratory, School of Physical Therapy, Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago, Chile

Correspondence: Rohit K. Thapa, School of Physical Education and Sports, Rashtriya Raksha University, Gandhinagar 382305, India. Email: rohitthapa04@gmail.com / rohitkumar.thapa@rru.ac.in

Abstract

This systematic review and meta-analysis aimed to assess the effects of complex contrast training (CT) on aerobic endurance, maximal strength, and repeated sprint ability (RSA) in soccer players. After an electronic search, nine peer-reviewed articles were considered, including soccer players from junior to professional-level (age 14 – 23 years). One study was conducted during the pre-season, seven studies during the in-season, and one study during the off-season period of a competitive schedule. The studies included were of moderate to high methodological quality (PEDro scale) and incorporated CT with soccer practice. Large significant improvements (ES = 1.30; 95% CI = 0.61 – 2.00; $p < 0.001$; $I^2 = 80.6\%$) for maximal strength, and small non-significant improvements for aerobic endurance (ES = 0.33; 95% CI = -0.19 – 0.85; $p = 0.209$; $I^2 = 0.0\%$) and RSA (ES = 0.32; 95% CI = -0.12 – 0.75; $p = 0.156$; $I^2 = 0.0\%$) were noted for CT groups when compared to active or specific-active control groups. Therefore, supplementing regular soccer training with CT induces adaptations to improve maximal strength. CT may be implemented during the pre-season and in-season to induce adaptations similar to traditional strength training (e.g., maximal strength gains), although alternative training strategies may be needed to further improve aerobic endurance and RSA. The use of CT may be applicable during different periods of the season to achieve certain goals, e.g., pre- and in-season for maximal strength development, and off-season to attenuate the decline of strength or power.

Keywords: *football, plyometric exercise, human physical conditioning, resistance training, muscle strength, movement*

@MJSSMontenegro
COMPLEX CONTRAST TRAINING IN SOCCER
http://mjssm.me/?sekcija=article&artid=241

Cite this article: Thapa, R.K., Narvariya, P., Weldon, A., Talukdar, K., & Ramirez-Campillo, R. (2022) Can complex contrast training interventions improve aerobic endurance, maximal strength, and repeated sprint ability in soccer players? A systematic review and meta-analysis. *Montenegrin Journal of Sports Science and Medicine*, 11 (2), 45–55. https://doi.org/10.26773/mjssm.220906

Received: 06 June 2022 | Accepted after revision: 14 August 2022 | Early access publication date: 20 August 2022 | Final publication date: 1 September 2022

© 2022 by the author(s). License MSA, Podgorica, Montenegro. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY).

Conflict of interest: None declared.

Introduction

Soccer requires a combination of aerobic and high-intensity demands (e.g., sprints, changes of direction) (Barnes et al., 2014; Bush et al., 2015), which defines the match running performance among professional soccer players (Modric et al., 2022; Modric, Versic, et al., 2021). Indeed, these demands during training sessions may also determine the outcomes of matches (Modric, Jelicic, et al., 2021). A common method to assess these demands in soccer players is the Yo-Yo intermittent recovery test (Yo-Yo IRT) (Castagna et al., 2020; Deprez et al., 2015). Indeed, elite players show better Yo-Yo IRT performance compared to sub-elite (2,420 m versus 2,030 m) (Bangsbo et al., 2008). In addition to aerobic endurance, short-duration maximal- and near-maximal physical efforts (e.g., vertical jumps) are prevalent in soccer, and are required to overcome opponents during play (Stølen et al., 2005). These maximal- or near-maximal efforts have shown to be positively associated with the strength of lower limbs (e.g., maximal squat strength) (Arnason et al., 2004; Requena et al., 2009; Thapa et al., 2019; Wisløff et al., 2004). Moreover, maximal strength of lower limbs (e.g., one repetition maximum [1RM]) may also be used to differentiate the player's playing level (e.g., professional versus amateur) (Cometti et al., 2001). Another relevant aptitude in soccer players is the ability to repeatedly produce maximal sprints with brief recovery periods (Rampinini et al., 2007), considering the ever-increasing high-intensity running demands (e.g., ~30 % increase in high-intensity running distance between 2006 versus 2012) (Barnes et al., 2014; Bush et al., 2015; Dellal et al., 2011). Based on the available evidence aerobic endurance (Bangsbo et al., 2008), muscle strength (Gissis et al., 2006; Reilly et al., 2000), and repeated sprint ability (RSA) (Chaouachi et al., 2010; Stølen et al., 2005) are important physical characteristics for soccer players.

Traditional strength training with exercises such as heavy squat (McKinlay et al., 2018; Silva et al., 2015) and plyometric jump training with exercises implicating a fast stretch-shortening cycle muscle action (Ramirez-Campillo, Gentil, et al., 2021; Sánchez et al., 2020; van de Hoef et al., 2019) may improve aerobic endurance, strength, and RSA. However, compared to a single training mode, a combination of resistance and plyometric/ballistic exercise (i.e., complex contrast training [CT]) may further improve aerobic endurance, strength, and RSA in soccer players (Faude et al., 2013; Hammami et al., 2017a). CT involves the performance of a high-load low-speed resistance training exercise, followed immediately by the execution of a low-load high-speed plyometric/ballistic exercise (Carter & Greenwood, 2014; Cormier et al., 2022; Ebben, 2002; Fleck & Kontor, 1986). This training format usually involves performing biomechanically similar exercises with a high-load resistance exercise performed first (e.g., squat at 90% of one-repetition maximum [1RM]), followed by a low-load plyometric/ballistic exercise (e.g., squat jump) (Docherty et al., 2004; Fleck & Kontor, 1986). Sequencing exercises in such a format stimulates the post-activation potentiation of performance (Carter & Greenwood, 2014; Docherty et al., 2004; Hodgson et al., 2005; Prieske et al., 2020), subsequently increasing motor unit recruitment and force-production potential of the used musculature (Healy & Comyns, 2017; Thapa et al., 2020). Furthermore, CT may induce neuromuscular adaptations, such as enhanced stretch-shortening cycle function, motor unit recruitment, firing frequency, intra- and inter-muscular coordination, and morphological changes (e.g., fiber type, pennation angle) (Cormie et al., 2011; Markovic & Mikulic, 2010), thus broadly enhancing athletic performance. Another benefit of CT is it provides a time-efficient combination of traditional resistance and plyometric exercise into a single session, which may assist strength and conditioning coaches in overcoming congested weekly micro-cycles (Lim & Barley, 2016; Weldon et al., 2021).

In the last decade, a considerable number of studies have analyzed the effects of CT on soccer player's athletic performance. However, aggregated literature in the form of systematic reviews with meta-analysis are only available for a limited number of physical abilities such as sprint, jump, and change of direction ability (Thapa et al., 2021). Indeed, a recent survey study by Weldon et al. (2021) on the practices of strength and conditioning coaches in professional soccer found the most common application (52%) of plyometric training was in the form of CT when compared to other formats (e.g., before weights, separate days, after weights). However, it is yet to be determined whether CT may favor other key physical abilities such as aerobic endurance, maximal strength, and RSA. Indeed, some studies suggested a greater improvement in aerobic endurance (Miranda et al., 2021), maximal strength (Brito et al., 2014), and RSA (Spineti et al., 2016) after CT compared to single-mode training (e.g., soccer training), but others reported contrasting findings (Faude et al., 2013; Hammami et al., 2017a; Kobal et al., 2017). Part of the controversy in some studies may be related to insufficient statistical power in their analyses, arising from a reduced sample size. Indeed, most studies involving CT among soccer players recruited reduced sample sizes in the experimental interventions (e.g., n=10) (Faude et al., 2013; Kobal et al., 2017; Spineti et al., 2016). A reduced number of participants precludes generalization of findings to other soccer athlete groups (Abt et al., 2020). As an alternative to experimental studies, meta-analysis allows the aggregation of sample sizes from different studies, providing more robust conclusions (Murad et al., 2016). To the author's knowledge, no study has attempted to aggregate the available literature regarding the effects of CT on soccer player's aerobic endurance, maximal strength, and RSA. Therefore, this systematic review with meta-analysis aims to assess the available body of peer-reviewed articles related to the effects of CT on aerobic endurance, maximal strength, and RSA among soccer players compared to active control groups. The results arising from this systematic review may be useful for practitioners to make evidence-based decisions regarding CT interventions for soccer players in relation to the optimization of aerobic endurance, maximal strength, and RSA.

Methods

This systematic review with meta-analysis was conducted following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Page et al., 2021). The lead author conducted preliminary electronic searches in PubMed and Google Scholar databases. Articles published up to February 15th, 2022 were considered. The keywords were selected based on a previous meta-analysis study conducted on CT for similar population (Thapa et al., 2021). The following combination of keywords (Using Boolean logic) was used in the search databases: "complex training" or "contrast training" and "soccer". An example of search strategy used in PubMed was: ((complex training) OR (contrast training)) AND (soccer). For Google Scholar database, the

 DOI 10.26773/mjssm.220906

author used the advanced search option. An example of search strategy in Google Scholar was: with all of the words (complex training soccer); where my words occur (in the title of the article). The same author retrieved the list of articles and removed duplicates. Thereafter, the search results were analyzed according to the eligibility criteria (Table 1).

Table 1. Selection criteria used in the systematic review with meta-analysis.

Category	Inclusion criteria	Exclusion criteria
Population	Apparently healthy soccer players, with no restrictions on their playing level, sex, or age.	Soccer players with health problems (e.g., injuries, recent surgery).
Intervention	A complex contrast training programme, defined as a combination of heavy load strength exercise followed by low load plyometric/power exercise, set by set.	Exercise interventions not involving complex contrast training or exercise interventions involving descending training, where strength training exercises were conducted first and plyometric/power exercises were conducted at the end or during a different session.
Comparator	Active control group (i.e., players participating in regular soccer training) or specific-active control group (i.e., players participating in regular soccer training combined with traditional strength training).	Absence of active control group or specific-active control group.
Outcome	At least one measure related to lower body strength, repeated sprint ability and endurance before and after the training intervention.	Lack of baseline and/or follow-up data.
Study design	Controlled trials.	Non-controlled trials.

For the inclusion of studies two authors (RKT and PN) independently screened the titles, abstracts, and full-text versions of the retrieved studies. Any potential discrepancies between the same two authors regarding the inclusion and exclusion criteria were resolved through the consensus with a third author (RRC). From selected articles, the reference lists were examined to identify further articles for inclusion in the meta-analysis.

Inclusion and exclusion criteria

A PICOS (participants, intervention, comparators, outcomes, and study design) approach was used to rate studies' eligibility (Liberati et al., 2009). Table 1 shows the inclusion/exclusion criteria adopted in this study, with only peer-reviewed articles in English. Articles only published in English were selected considering a recent scoping review which reported 99% of the articles on plyometric jump training (i.e., secondary exercise of CT) research are in English (Ramirez-Campillo et al., 2018).

Methodological quality of included studies

The Physiotherapy Evidence Database (PEDro) scale (https://pedro.org.au/english/resources/pedro-scale/) was used to assess the methodological quality of the included studies, which were rated from 0 to 10, with higher ratings reflecting better quality (Cashin & McAuley, 2020). The validity and reliability of the PEDro scale has been established in previous studies (de Morton, 2009; Maher et al., 2003; Yamato et al., 2017). Two authors (PN and AW) independently assessed the methodological quality of each study, and any discrepancies between them were resolved via consensus with a third author (RKT).

Data extraction

Data were extracted from each eligible study, for aerobic endurance (i.e., Yo-Yo IRT distance [m]), maximal leg strength (1RM squat [kg]), and RSA (mean time [seconds]). Means, standard deviations [SD], and sample size of dependent variables were extracted at pre- and post-CT time points from the included studies using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). However, when data were displayed in a figure or no numerical data were provided by authors after being contacted, a validated (r = 0.99, p <0.001) (Drevon et al., 2017) software (WebPlotDigitizer; https://apps.automeris.io/wpd/) was used to derive numerical data from figures. In addition to study data, sample characteristics (age, playing level), training frequency, duration of intervention, type of training protocol, and measurement procedures used in the study were extracted and recorded. Two authors (RKT and PN) performed data extraction independently, and any discrepancies between them were resolved through consensus with a third author (RRC).

Statistical Analysis

Although meta-analyses can be done with as few as two studies (Valentine et al., 2010), it is recommended within sports-science literature due to commonly containing small sample sizes (Pigott, 2012), that meta-analyses are only conducted when >3 studies are available (García-Hermoso et al., 2019; Moran et al., 2018). The DerSimonian and Laird random-effects model was used to compute the meta-analyses. Between group effect sizes (ES, i.e., Hedge's g) were calculated using pre and post-training mean and standard deviations, and each dependent variable was standardized using post-intervention standard deviation values. The ES values are presented with 95% confidence intervals (95% CIs) and interpreted using the following scale: <0.2 trivial, 0.2 – 0.6 small, >0.6–1.2 moderate, >1.2 – 2.0 large, >2.0–4.0 very large, >4.0 extremely large (Hopkins et al., 2009). The impact of heterogeneity was assessed using the I^2 statistic, with values of <25%, 25–75%, and >75% representing low, moderate, and high levels of heterogeneity, respectively (Higgins & Thompson, 2002). All analyses were carried out using the Comprehensive Meta-Analysis software (version 2, Biostat, Englewood, NJ, USA). Statistical significance was set at p ≤0.05.

Results

The initial search resulted in 494 articles being retrieved and 22 additional articles were extracted through other sources (e.g., reference lists of eligible studies). After the removal of duplicates, systematic reviews, and meta-analyses, 510 articles remained. Additional screening of titles and abstracts resulted in the exclusion of 476 articles and 34 full texts were retained. Further screening based on the inclusion and exclusion criteria resulted in the final inclusion of nine studies in the meta-analysis (Figure 1).

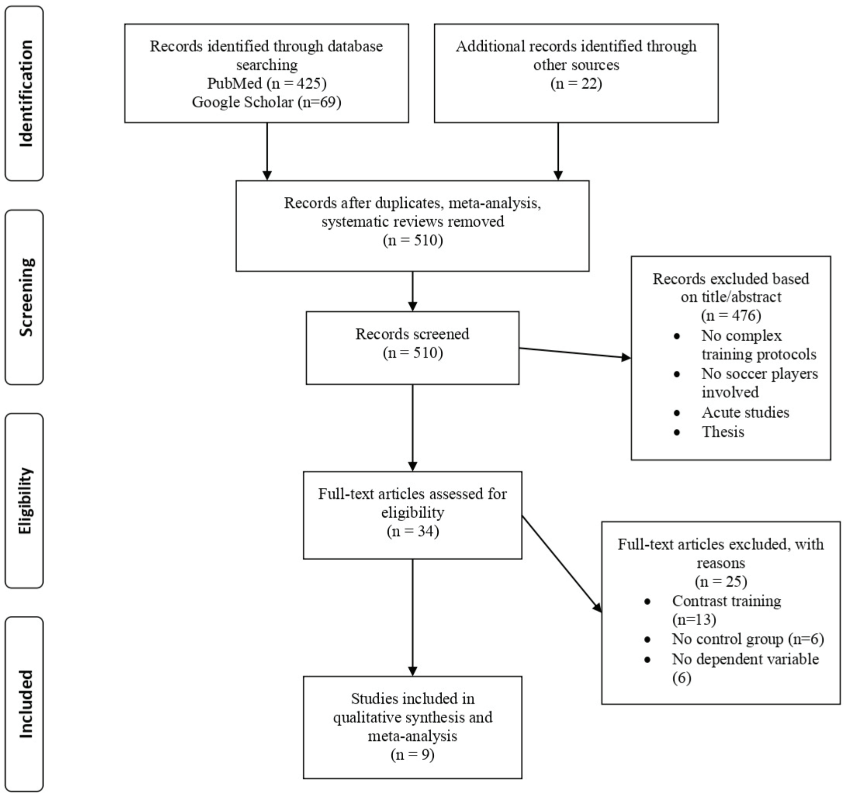


Figure 1. Preferred reporting items for systematic review and meta-analysis (PRISMA) flowchart illustrating the inclusion and exclusion criteria used in the study.

General characteristics of included studies

The study characteristics are presented in Table 2. A total of 211 male subjects were included in this meta-analysis with 112 professional and 99 amateur level players. Among the included studies one study was conducted during the pre-season, seven studies during the in-season, and one study during the off-season period of a competitive schedule (Table 2). The duration of the training programs in the intervention and control groups ranged from four to nine weeks and the frequency of training sessions ranged from two to three per week (Supplementary Table 1). The CT protocol used in each of the included studies are reported in Supplementary Table 1. The testing, measurement and assessment protocols for each of the included dependent variable in the meta-analysis are detailed in Supplementary Table 2.

Table 2. Participant's characteristics from the included studies in the systematic review with meta-analysis.

	Gender	Age (y)	Body mass (kg)	Height (cm)	Playing level	Training period
		Mean				
Brito et a., 2014	Male	20.3	72.0	177.5	College	In-season
Chatzinikolaou et al., 2018	Male	14.2	70.7	178.5	NR	Off-season
Faude et al., 2013	Male	22.5	76.8	179.0	Amateur	In-season
Hammami et al., 2017a	Male	16.0	58.5	173.7	Junior	In-season
Hammami et al., 2017b	Male	16.4	58.7	173.0	Professional	In-season
Hammami et al., 2019	Male	15.8	58.8	174.0	Junior elite	In-season
Kobal et al., 2017	Male	18.9	69.1	176.0	Professional	In-season
Miranda et al., 2021	Male	17.3	66.2	170.0	Professional	Pre-season
Spineti et al., 2016	Male	18.4	70.2	179.9	Professional	In-season

Note: NR – not clearly reported

Methodological quality of included studies

According to the PEDro checklist, the median (i.e., non-parametric) score was 6, with eight studies attaining high quality (6 points), and one study moderate quality (4 – 5 points) (Table 3). The two independent reviewers that performed a methodological appraisal of the included studies achieved a Spearman correlation (i.e., data non-parametric) agreement of 0.75.

DOI 10.26773/mjssm.220906

Table 3. Methodological quality of the included studies using the PEDro rating scale.

	1	2	3	4	5	6	7	8	9	10	11	Score*	Study quality
Brito et a., 2014	1	1	-	1	-	-	-	1	1	1	1	6	High
Chatzinikolaou et al., 2018	1	1	-	1	-	-	-	1	1	1	1	6	High
Faude et al., 2013	1	1	-	1	-	-	-	-	1	1	1	5	Moderate
Hammami et al., 2017a	1	1	-	1	-	-	-	1	1	1	1	6	High
Hammami et al., 2017b	1	1	-	1	-	-	-	1	1	1	1	6	High
Hammami et al., 2019	1	1	-	1	-	-	-	1	1	1	1	6	High
Kobal et al., 2017	1	1	-	1	-	-	-	1	1	1	1	6	High
Miranda et al., 2021	1	1	-	1	-	-	-	1	1	1	1	6	High
Spineti et al., 2016	1	1	-	1	-	-	-	1	1	1	1	6	High

A detailed explanation for each PEDro scale item can be accessed at https://www.pedro.org.au/english/downloads/pedro-scale; *From a possible maximal score of 10 (Note: Item 1 is not used to calculate the score).

Meta-analysis results for endurance

Three studies provided data for the Yo-Yo IRT, involving 3 experimental and 3 control groups (pooled n = 55). Results showed a small non-significant effect favouring the CT groups when compared to the control groups (ES = 0.33; 95% CI = -0.19 – 0.85; p = 0.209; Figure 2; I^2 = 0.0%).

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Chatzinikolaou et al., 2018	0.686	0.425	0.180	-0.146	1.518	1.615	0.106
Faude et al., 2013	0.364	0.477	0.228	-0.571	1.299	0.763	0.445
Miranda et al., 2021	-0.155	0.482	0.233	-1.100	0.791	-0.321	0.748
	0.333	0.265	0.070	-0.187	0.852	1.256	0.209

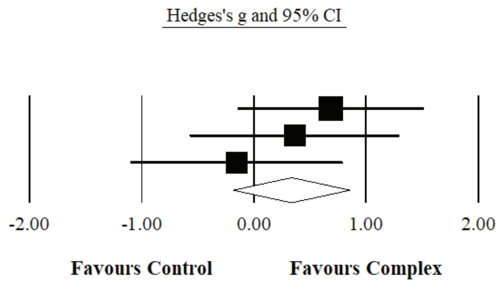


Figure 2. Forest plot for changes in the Yo-Yo test in soccer players after complex contrast training compared to controls. Forest plot values are shown as effect sizes (Hedges' g) with 95% confidence intervals (CI). Black squares represent individual studies and their size represents their relative weights. White rhomboid represents the summary value.

Meta-analysis results for lower body strength performance

Nine studies provided data for squat 1RM, involving 9 experimental and 9 control groups (pooled n = 211; two specific-active control groups). Results showed a large significant effect for the CT groups when compared to the control groups (ES = 1.30; 95% CI = 0.61 – 2.00; p < 0.001; Figure 3; I^2 = 80.6%).

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Brito et al., 2014	1.190	0.382	0.146	0.441	1.939	3.114	0.002
Chatzinikolaou et al., 2018	0.891	0.433	0.188	0.042	1.740	2.056	0.040
Faude et al., 2013	1.044	0.507	0.258	0.049	2.039	2.057	0.040
Hammami et al., 2017a	2.693	0.517	0.267	1.680	3.706	5.212	0.000
Hammami et al., 2017b	2.573	0.498	0.248	1.596	3.549	5.162	0.000
Hammami et al., 2019	2.572	0.522	0.272	1.549	3.595	4.928	0.000
Kobal et al., 2017	0.224	0.451	0.203	-0.659	1.107	0.498	0.618
Miranda et al, 2021	1.080	0.516	0.266	0.069	2.092	2.093	0.036
Spineti et al., 2016	-0.295	0.414	0.172	-1.107	0.517	-0.712	0.476
	1.304	0.352	0.124	0.613	1.995	3.700	0.000

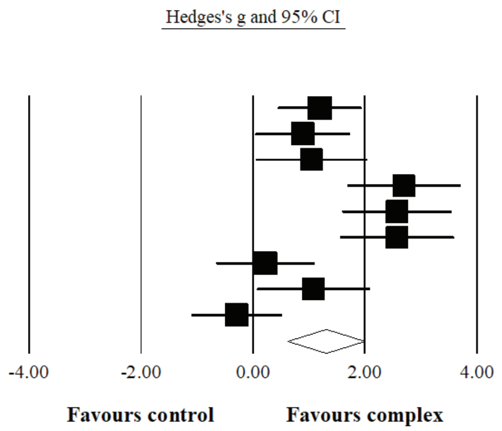


Figure 3. Forest plot for changes in squat one repetition maximum in soccer players after complex contrast training compared to controls. Forest plot values are shown as effect sizes (Hedges' g) with 95% confidence intervals (CI). Black squares represent individual studies and their size represents their relative weights. White rhomboid represents the summary value..

Meta-analysis results for repeated sprint ability performance

Three studies provided data for RSA, involving 3 experimental and 3 control groups (pooled n = 79; one specific-active control group). Results showed a small non-significant effect for the CT groups when compared to the control groups (ES = 0.32; 95% CI = -0.12 – 0.75; p = 0.156; Figure 4; I^2 = 0.0%).

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Spiniti et al., 2016	0.148	0.413	0.170	-0.661	0.956	0.358	0.720
Hammami et al., 2017a	0.438	0.375	0.141	-0.298	1.173	1.166	0.243
Hammami et al., 2017b	0.329	0.369	0.136	-0.394	1.052	0.892	0.373
	0.315	0.222	0.049	-0.120	0.749	1.418	0.156

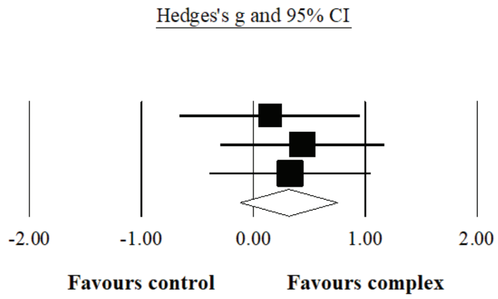


Figure 4. Forest plot for changes in repeated sprint ability in soccer players after complex contrast training compared to controls. Forest plot values are shown as effect sizes (Hedges' g) with 95% confidence intervals (CI). Black squares represent individual studies and their size represents their relative weights. White rhomboid represents the summary value.

Adverse effect of complex contrast training intervention

Among the included studies, no injuries related to CT were reported. In addition, no study reported negative outcomes (i.e., decrement in performance) in any selected variable.

Discussion

This systematic review with meta-analysis aimed to determine the effects of CT on aerobic endurance, maximal strength, and RSA among soccer players. The results of this meta-analysis suggested that CT induced a large significant improvement in lower body strength in male soccer players. However, small but non-significant improvements were reported for aerobic endurance and RSA performance. Among the nine studies that provided data for maximal strength, the potential large beneficial effects were reported across playing levels (i.e., junior and professional), with resistance training exercises at 70 – 90% 1RM, performed 1 – 2 times a week for a total duration of 8 – 9 weeks for lower body maximal strength. Among the three studies that provided data for endurance and RSA, small effects were reported in younger players (i.e., age 14 – 16 years) with minimal strength training experience.

Lower body strength

The large improvement in lower body strength for the CT group may be attributed to specific neuromuscular adaptations such as improved stretch-shortening cycle, increased motor unit recruitment, firing frequency, intra- and inter-muscular coordination, and morphological changes that help with force-generating capacity (e.g., increased tendon stiffness) (Cormie et al., 2011; Healy & Comyns, 2017; Markovic & Mikulic, 2010; Thapa et al., 2021). Indeed, several studies included in this meta-analysis also reported similar benefits in lower body strength with traditional resistance training (i.e., no plyometric or ballistic exercises) (Brito et al., 2014; Chatzinikolaou et al., 2018; Faude et al., 2013; Hammami et al., 2019; Hammami et al., 2017a). However, CT may induce specific adaptations to better optimize the force-velocity profile in soccer players as it incorporates both high-load low-velocity and low-load high-velocity exercises within a session (Cormie et al., 2011). The optimization of the force-velocity curve during training may help with short maximal high-intensity efforts on the field (e.g., changing direction, jumping, sprinting, kicking) due to the recruitment of fast-twitch muscle fibers (Fry et al., 2003; Gołaś et al., 2016; Jiménez-Reyes et al., 2022; Macaluso et al., 2012; Thapa et al., 2021). In addition, CT may also induce hormonal (e.g., increased testosterone) (Ali et al., 2019; Beaven et al., 2011) and structural adaptations (e.g., increased leg muscle volume) (Hammami et al., 2019; Hammami et al., 2017a, 2017b) which may have favored the strength development in soccer players. Therefore, CT can be considered a time-effective mode of training, particularly during the in-season period to improve the lower body strength of soccer players (Lim & Barley, 2016; Weldon et al., 2021).

Endurance and repeated sprint ability

Although the primary adaptation from CT is neuromuscular, therefore may not elicit meaningful changes in aerobic performance (Barnes & Kilding, 2015). However, a recent meta-analysis by Sole et al. (2021) reported small (ES = 0.30) endurance improvements in individual-sport athletes after plyometric-jump training. Similarly, in another meta-analysis Ramirez-Campillo, Andrade, et al. (2021) reported moderate (ES = 0.88) improvement in time-trial performance in endurance runners after plyometric jump training. Indeed, such training may improve anaerobic performance qualities (Assunção et al., 2018) related to endurance performance. Moreover, the neuromuscular adaptations may have improved rate of force development, motor unit recruitment, and increased tendon stiffness (Markovic & Mikulic, 2010), thus positively influencing the running economy of soccer players (Balsalobre-Fernández et al., 2016; Ramirez-Campillo, Andrade, et al., 2021). Furthermore, in this meta-analysis, the sample size for the Yo-Yo IRT was comparatively small (i.e., n = 55) with only three studies included for the final analysis. Out of the three included studies only one group that performed a combination of CT and strength training had a moderate effect (g = 0.69) on Yo-Yo IRT performance (Chatzinikolaou et al., 2018). Possible reasons for such findings may be due to the inclusion of younger male players (i.e., age 14 – 15 years) with no strength training background and additional inclusion of two strength training sessions per week. Therefore, a greater volume in training, lack of previous strength training experience, and no competitive demands during the off-season could have influenced these results. Similarly, three studies reported the effects of CT on RSA, and results indicated that studies incorporating CT for 7 – 8 weeks, elicited small improvements for RSA in young (i.e., ~16 years) junior and professional male soccer players. Indeed, CT may improve the stretch-shortening cycle function via an improved rate of force development, thus sprinting performance (Thapa et al., 2021). However, RSA also relies on aerobic capacity to improve recovery between bouts of maximal sprinting (Jones et al., 2013). Accordingly, it should be considered that the aerobic system plays a role in recovering anaerobic reserves, restoring body temperature, and decreasing the high concentration of

DOI 10.26773/mjssm.220906

blood lactate after high-intensity efforts (Dupont et al., 2010).

The results of this meta-analysis suggests that CT may induce small magnitude improvements in aerobic endurance and RSA when compared with soccer training. However, the non-significant difference between CT groups and control groups may be partially explained by the nature of the controls. In this meta-analysis, the active control groups and specific-active control groups were either involved in regular soccer training (Faude et al., 2013; Hammami et al., 2017a; Miranda et al., 2021) or resistance training combined with soccer training (Kobal et al., 2017; Spineti et al., 2016). Therefore, the soccer training itself may have induced physiological changes underpinning the Yo-Yo IRT and RSA performance (Stølen et al., 2005). Alternatively, the use of resistance training only, combined with regular soccer practice, may have led to improvements in the aforementioned outcomes (Miranda et al., 2021; Silva et al., 2015). Additionally, the reduced number of studies included in the meta-analyses for Yo-Yo IRT and RSA performance may have reduced the statistical power of the analyses, as discussed in the limitation section.

Limitations

Limitations of this meta-analysis are; 1) only three studies specifically assessed endurance and RSA. Moreover, the relatively reduced number of participants in each of the included studies in the meta-analysis might have reduced statistical power, thus producing false negative results. Future large randomized-controlled studies should be conducted to produce more robust conclusions; 2) most studies were conducted during the in-season period, which due to the competitive in-season demands, it can be challenging to measure the effect of CT alone on physical performance. Although controlled-study designs may reduce confounding factors arising from regular soccer-related training and competitive demands, future studies are encouraged to provide evidence for CT interventions conducted in periods other than the in-season, and to monitor the potential interference effects of soccer-training through the use of measures such as RPE (or similar); 3) studies not including female soccer players limits the findings to males only, considering physical and physiological differences between both genders. Additionally, considering the increased participation of females in competitive soccer (e.g. a 50% increase in the number of female soccer players was observed between 2000 to 2006 (FIFA, 2007), future studies are encouraged to include female participants; 4) as some studies did not specify the testing equipment used for measurement protocols or the explanation of exercises were ambiguous [e.g., Brito et al. (2014) did not specify the equipment used for 1RM testing], the replication of these studies across different populations may be difficult, as well as their inclusion in moderator analyses. Future studies are encouraged to provide a comprehensive description of the study protocol (including a protocol register), and to follow international guidelines for quality description (e.g., CONSORT guidelines); and 5) related to the previous limitation, no studies reported the intra-set recovery duration between the high-load resistance and low-load plyometric/ballistic exercise, which is a crucial factor in eliciting post-activation performance enhancements.

Conclusions

The findings suggest that combining regular soccer training sessions with CT improves maximal strength compared to soccer training alone. Strength and conditioning coaches may use CT to induce adaptations similar to traditional strength training (e.g., maximal strength gains), while also targeting the force-velocity spectrum (i.e., through plyometric/ballistic exercises) in soccer players. Furthermore, current literature (seven out of nine studies) advocates the use of CT for soccer players during the in-season period. However, strength and conditioning coaches may also use CT during the pre-season period (i.e., during the maximal strength development phase without adverse effects). Indeed, CT may also be used during the off-season period to attenuate the decline of strength/power performance in soccer players. Furthermore, future research should investigate the effects of CT on endurance, maximal strength, and RSA during periods other than the in-season (e.g., pre-season, off-season), across a more diverse range of age groups in male and (particularly) female soccer players from different physical fitness or competitive levels, considering these variables are potential moderators for the effect of CT (Loturco et al., 2020; Sansonio de Morais et al., 2018). In addition, future research should also focus on different intra-set recovery duration, considering that different recovery periods may affect the post-activation performance enhancement (Boullosa, 2021).

Registration

The protocol for this systematic review with meta-analysis was published in the Open Science platform (OSF) on March 06, 2022, under the registration doi 10.17605/OSF.IO/WH3MK. (internet archive link: https://archive.org/details/osf-registrations-wh3mk-v1).

Funding

No financial support was received for the conduction of this study or the preparation of this manuscript.

Conflict of interest

All authors declare no conflicts of interest relevant to the content of this review.

Author contributions

Rohit K. Thapa and Rodrigo Ramirez-Campillo conceived the idea for the article. Rohit K. Thapa, Pushpendra Narvariya, Anthony Weldon, and Rodrigo Ramirez-Campillo performed the literature search and/or data analysis. Rohit K. Thapa, Pushpendra Narvariya, Anthony Weldon, Kaushik Talukdar, and Rodrigo Ramirez-Campillo drafted and/or critically revised the work. All authors read and approved the final manuscript.

Availability of data and material

All data generated or analyzed during this study will be/are included in the published article as Table(s), Figure(s) and Supplementary Table(s). Any other data requirement can be directed to the corresponding author upon reasonable request.

Supplementary tables are available here: https://mjssm.me/suplementaries/supplementary_Thapa.docx

References

Abt, G., Boreham, C., Davison, G., Jackson, R., Nevill, A., Wallace, E., & Williams, M. (2020). Power, precision, and sample size estimation in sport and exercise science research. *Journal of Sports Sciences*, *38*(17), 1933-1935.

https://doi.org/10.1080/02640414.2020.1776002

Ali, K., Verma, S., Ahmad, I., Singla, D., Saleem, M., & Hussain, M. E. (2019). Comparison of complex versus contrast training on steroid hormones and sports performance in male soccer players. *Journal of Chiropractic Medicine*, *18*(2), 131-138. https://doi.org/10.1016/j.jcm.2018.12.001

Arnason, A., Sigurdsson, S. B., Gudmundsson, A., Holme, I., Engebretsen, L., & Bahr, R. (2004). Physical fitness, injuries, and team performance in soccer. *Medicine & Science in Sports & Exercise*, *36*(2), 278-285. https://doi.org/10.1249/01.Mss.0000113478.92945.Ca

Assunção, A. R., Bottaro, M., Cardoso, E. A., Dantas da Silva, D. P., Ferraz, M., Vieira, C. A., & Gentil, P. (2018). Effects of a low-volume plyometric training in anaerobic performance of adolescent athletes. *The Journal of Sports Medicine & Physical Fitness*, *58*(5), 570-575. https://doi.org/10.23736/s0022-4707.17.07173-0

Balsalobre-Fernández, C., Santos-Concejero, J., & Grivas, G. V. (2016). Effects of strength training on running economy in highly trained runners: a systematic review with meta-analysis of controlled trials. *The Journal of Strength & Conditioning Research*, *30*(8), 2361-2368. https://doi.org/10.1519/jsc.0000000000001316

Bangsbo, J., Iaia, F. M., & Krustrup, P. (2008). The Yo-Yo intermittent recovery test : a useful tool for evaluation of physical performance in intermittent sports. *Sports Medicine*, *38*(1), 37-51. https://doi.org/10.2165/00007256-200838010-00004

Barnes, C., Archer, D. T., Hogg, B., Bush, M., & Bradley, P. S. (2014). The evolution of physical and technical performance parameters in the English Premier League. *International Journal of Sports Medicine*, *35*(13), 1095-1100. https://doi.org/10.1055/s-0034-1375695

Barnes, K. R., & Kilding, A. E. (2015). Running economy: measurement, norms, and determining factors. *Sports Medicine Open*, *1*(1), 8. https://doi.org/10.1186/s40798-015-0007-y

Beaven, C. M., Gill, N. D., Ingram, J. R., & Hopkins, W. G. (2011). Acute salivary hormone responses to complex exercise bouts. *The Journal of Strength & Conditioning Research*, *25*(4), 1072-1078. https://doi.org/10.1519/JSC.0b013e3181bf4414

Boullosa, D. (2021). Post-activation performance enhancement stragies in sport: a brief review for practitioners. *Human Movement*, *22*(1), 101-109. https://doi.org/10.5114/hm.2021.103280

Brito, J., Vasconcellos, F., Oliveira, J., Krustrup, P., & Rebelo, A. (2014). Short-term performance effects of three different low-volume strength-training programmes in college male soccer players. *Journal of Human Kinetics*, *40*, 121-128. https://doi.org/10.2478/hukin-2014-0014

Bush, M., Barnes, C., Archer, D. T., Hogg, B., & Bradley, P. S. (2015). Evolution of match performance parameters for various playing positions in the English Premier League. *Human Movement Science*, *39*, 1-11. https://doi.org/10.1016/j.humov.2014.10.003

Carter, J., & Greenwood, M. (2014). Complex training reexamined: Review and recommendations to improve strength and power. *Strength & Conditioning Journal*, *36*(2), 11-19.

Cashin, A. G., & McAuley, J. H. (2020). Clinimetrics: Physiotherapy Evidence Database (PEDro) Scale. *Journal of Physiotherapy*, *66*(1), 59. https://doi.org/10.1016/j.jphys.2019.08.005

Castagna, C., Krustrup, P., & Póvoas, S. (2020). Yo-Yo intermittent tests are a valid tool for aerobic fitness assessment in recreational football. *European Journal of Applied Physiology*, *120*(1), 137-147. https://doi.org/10.1007/s00421-019-04258-8

Chaouachi, A., Manzi, V., Wong del, P., Chaalali, A., Laurencelle, L., Chamari, K., & Castagna, C. (2010). Intermittent endurance and repeated sprint ability in soccer players. *The Journal of Strength & Conditioning Research*, *24*(10), 2663-2669. https://doi.org/10.1519/JSC.0b013e3181e347f4

Chatzinikolaou, A., Michaloglou, K., Avloniti, A., Leontsini, D., Deli, C. K., Vlachopoulos, D., Gracia-Marco, L., Arsenis, S., Athanailidis, I., Draganidis, D., Jamurtas, A. Z., Williams, C. A., & Fatouros, I. G. (2018). The Trainability of Adolescent Soccer Players to Brief Periodized Complex Training. *International Journal of Sports Physiology & Performance*, *13*(5), 645-655. https://doi.org/10.1123/ijspp.2017-0763

Cometti, G., Maffiuletti, N. A., Pousson, M., Chatard, J. C., & Maffulli, N. (2001). Isokinetic strength and anaerobic power of elite, subelite and amateur French soccer players. *International Journal of Sports Medicine*, *22*(1), 45-51. https://doi.org/10.1055/s-2001-11331

Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power: Part 1--biological basis of maximal power production. *Sports Medicine*, *41*(1), 17-38. https://doi.org/10.2165/11537690-000000000-00000

Cormier, P., Freitas, T., Loturco, I., Turner, A., Virgile, A., Haff, G., Blazevich, A., agar-newman, D., Henneberry, M., Baker, D., McGuigan, M., Alcaraz, P., & Bishop, C. (2022). Within session exercise sequencing during programming for complex training: historical perspectives, terminology, and training considerations. *Sports Medicine*, *Ahead of print*. https://doi.org/10.1007/s40279-022-01715-x

de Morton, N. A. (2009). The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study. *Australian Journal of Physiotherapy*, *55*(2), 129-133. https://doi.org/10.1016/s0004-9514(09)70043-1

Dellal, A., Chamari, K., Wong, D. P., Ahmaidi, S., Keller, D., Barros, R., Bisciotti, G. N., & Carling, C. (2011). Comparison of physical and technical performance in European soccer match-play: FA Premier League and La Liga. *European Journal of Sport Science*, *11*(1), 51-59. https://doi.org/10.1080/17461391.2010.481334

Deprez, D., Fransen, J., Lenoir, M., Philippaerts, R., & Vaeyens, R. (2015). The Yo-Yo intermittent recovery test level 1 is reliable in young high-level soccer players. *Biology of Sport*, *32*(1), 65-70. https://doi.org/10.5604/20831862.1127284

Docherty, D., Robbins, D., & Hodgson, M. (2004). Complex training revisited: A review of its current status as a viable training approach. *Strength & Conditioning Journal*, *26*(6), 52.

Drevon, D., Fursa, S. R., & Malcolm, A. L. (2017). Intercoder reliability and validity of WebPlotDigitizer in extracting graphed data. *Behavior Modification*, *41*(2), 323-339. https://doi.org/10.1177/0145445516673998

Dupont, G., McCall, A., Prieur, F., Millet, G. P., & Berthoin, S. (2010). Faster oxygen uptake kinetics during recovery is related to better repeated sprinting ability. *European Journal of Applied Physiology*, *110*(3), 627-634. https://doi.org/10.1007/s00421-010-1494-7

Ebben, W. P. (2002). Complex training: A brief review. *Journal of Sports Science and Medicine*, *1*(2), 42.

Faude, O., Roth, R., Di Giovine, D., Zahner, L., & Donath, L. (2013). Combined strength and power training in high-level amateur football during the competitive season: a randomised-controlled trial. *Journal of Sports Sciences*, *31*(13), 1460-1467. https://doi.org/10.1080/02640414.2013.796065

FIFA. (2007). FIFA Big Count 2006: 270 million people active in football. *FIFA Communications Division, Information Services*. http://www.fifa.com/mm/document/fifafacts/bcoffsurv/bigcount.statspackage_7024.pdf

Fleck, S., & Kontor, K. (1986). Soviet Strength and Conditioning: Complex training. *Strength & Conditioning Journal*, *8*(5), 66-72.

Fry, A. C., Webber, J. M., Weiss, L. W., Harber, M. P., Vaczi, M., & Pattison, N. A. (2003). Muscle fiber characteristics of competitive power lifters. *The Journal of Strength & Conditioning Research*, *17*(2), 402-410.

García-Hermoso, A., Ramírez-Campillo, R., & Izquierdo, M. (2019). Is muscular fitness associated with future health benefits in children and adolescents? a systematic review and meta-analysis of longitudinal studies. *Sports Medicine*, *49*(7), 1079-1094. https://doi.org/10.1007/s40279-019-01098-6

Gissis, I., Papadopoulos, C., Kalapotharakos, V. I., Sotiropoulos, A., Komsis, G., & Manolopoulos, E. (2006). Strength and speed characteristics of elite, subelite, and recreational young soccer players. *Research in Sports Medicine*, *14*(3), 205-214. https://doi.org/10.1080/15438620600854769

Gołaś, A., Maszczyk, A., Zajac, A., Mikołajec, K., & Stastny, P. (2016). Optimizing post activation potentiation for explosive activities in competitive sports. *Journal of Human Kinetics*, *52*, 95-106. https://doi.org/10.1515/hukin-2015-0197

Hammami, M., Gaamouri, N., Shephard, R. J., & Chelly, M. S. (2019). Effects of contrast strength vs. plyometric training on lower-limb explosive performance, ability to change direction and neuromuscular adaptation in soccer players. *The Journal of Strength & Conditioning Research*, *33*(8), 2094-2103. https://doi.org/10.1519/jsc.0000000000002425

Hammami, M., Negra, Y., Shephard, R. J., & Chelly, M. S. (2017a). The effect of standard strength vs. contrast strength training on the development of sprint, agility, repeated change of direction, and jump in junior male soccer players. *The Journal of Strength & Conditioning Research*, *31*(4), 901-912. https://doi.org/10.1519/jsc.0000000000001815

Hammami, M., Negra, Y., Shephard, R. J., & Chelly, M. S. (2017b). Effects of leg contrast strength training on sprint, agility and repeated change of direction performance in male soccer players. *The Journal of Sports Medicine & Physical Fitness*, *57*(11), 1424-1431. https://doi.org/10.23736/s0022-4707.17.06951-1

Healy, R., & Comyns, T. M. (2017). The application of postactivation potentiation methods to improve sprint speed. *Strength & Conditioning Journal*, *39*(1), 1-9. https://doi.org/10.1519/ssc.0000000000000276

Higgins, & Thompson, S. G. (2002). Quantifying heterogeneity in a meta-analysis. *Statistics in Medicine*, *21*(11), 1539-1558. https://doi.org/10.1002/sim.1186

Hodgson, M., Docherty, D., & Robbins, D. (2005). Post-activation potentiation: underlying physiology and implications for motor performance. *Sports Medicine*, *35*(7), 585-595. https://doi.org/10.2165/00007256-200535070-00004

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine & Science in Sports & Exercise*, *41*(1), 3-13. https://doi.org/10.1249/MSS.0b013e31818cb278

Jiménez-Reyes, P., Garcia-Ramos, A., Párraga-Montilla, J. A., Morcillo-Losa, J. A., Cuadrado-Peñafiel, V., Castaño-Zambudio, A., Samozino, P., & Morin, J. B. (2022). Seasonal changes in the sprint acceleration force-velocity profile of elite male soccer players. *The Journal of Strength & Conditioning Research*, *36*(1), 70-74. https://doi.org/10.1519/jsc.0000000000003513

Jones, R. M., Cook, C. C., Kilduff, L. P., Milanović, Z., James, N., Sporiš, G., Fiorentini, B., Fiorentini, F., Turner, A., & Vučković, G. (2013). Relationship between repeated sprint ability and aerobic capacity in professional soccer players. *The Scientific World Journal 2013*, 952350. https://doi.org/10.1155/2013/952350

Kobal, R., Loturco, I., Barroso, R., Gil, S., Cuniyochi, R., Ugrinowitsch, C., Roschel, H., & Tricoli, V. (2017). Effects of different combinations of strength, power, and plyometric training on the physical performance of elite young soccer players. *The Journal of Strength & Conditioning Research*, *31*(6), 1468-1476. https://doi.org/10.1519/jsc.0000000000001609

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P., Clarke, M., Devereaux, P. J., Kleijnen, J., & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. *The BMJ*, *339*, b2700. https://doi.org/10.1136/bmj.b2700

Lim, J., & Barley, C. (2016). Complex training for power development: practical applications for program design. *Strength & Conditioning Journal*, *38*, 33-43. https://doi.org/10.1519/SSC.0000000000000265

Loturco, I., Jeffreys, I., Abad, C. C. C., Kobal, R., Zanetti, V., Pereira, L. A., & Nimphius, S. (2020). Change-of-direction, speed and jump performance in soccer players: a comparison across different age-categories. *Journal of Sports Sciences*, *38*(11-12), 1279-1285. https://doi.org/10.1080/02640414.2019.1574276

Macaluso, F., Isaacs, A. W., & Myburgh, K. H. (2012). Preferential type II muscle fiber damage from plyometric exercise. *Journal of Athletic Training*, *47*(4), 414-420. https://doi.org/10.4085/1062-6050-47.4.13

Maher, C. G., Sherrington, C., Herbert, R. D., Moseley, A. M., & Elkins, M. (2003). Reliability of the PEDro scale for rating quality of randomized controlled trials. *Physical Therapy*, *83*(8), 713-721.

Markovic, G., & Mikulic, P. (2010). Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. *Sports Medicine*, *40*(10), 859-895. https://doi.org/10.2165/11318370-000000000-00000

McKinlay, B. J., Wallace, P., Dotan, R., Long, D., Tokuno, C., Gabriel, D. A., & Falk, B. (2018). Effects of plyometric and resistance training on muscle strength, explosiveness, and neuromuscular function in young adolescent soccer players. *The Journal of Strength & Conditioning Research*, *32*(11), 3039-3050. https://doi.org/10.1519/jsc.0000000000002428

Miranda, C., Rago, V., Silva, J. R., & Rebelo, A. (2021). 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*. https://doi.org/10.1007/s11332-021-00833-9

Modric, T., Jelicic, M., & Sekulic, D. (2021). Relative training load and match outcome: are professional soccer players actually undertrained during the in-season? *Sports (Basel)*, *9*(10). https://doi.org/10.3390/sports9100139

Modric, T., Versic, S., Chmura, P., Konefał, M., Andrzejewski, M., Jukic, I., Drid, P., Pocek, S., & Sekulic, D. (2022). Match Running Performance in UEFA Champions League: Is There a Worthwhile Association with Team Achievement? *Biology (Basel)*, *11*(6). https://doi.org/10.3390/biology11060867

Modric, T., Versic, S., & Sekulic, D. (2021). Does aerobic performance define match running performance among professional soccer players? A position-specific analysis. *Research in Sports Medicine*, *29*(4), 336-348. https://doi.org/10.1080/15438627.2021.1888107

Moran, J., Ramirez-Campillo, R., & Granacher, U. (2018). Effects of jumping exercise on muscular power in older adults: a meta-analysis. *Sports Medicine*, *48*(12), 2843-2857. https://doi.org/10.1007/s40279-018-1002-5

Murad, M. H., Asi, N., Alsawas, M., & Alahdab, F. (2016). New evidence pyramid. *BMJ Evidence-Based Medicine*, *21*(4), 125-127. https://doi.org/10.1136/ebmed-2016-110401

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P., & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *The BMJ*, *372*, n71. https://doi.org/10.1136/bmj.n71

Pigott, T. (2012). *Advances in meta-analysis*. Springer-Verlag New York. https://doi.org/10.1007/978-1-4614-2278-5

Prieske, O., Behrens, M., Chaabene, H., Granacher, U., & Maffiuletti, N. A. (2020). Time to differentiate postactivation "Potentiation" from "Performance Enhancement" in the strength and conditioning community. *Sports Medicine*, *50*(9), 1559-1565. https://doi.org/10.1007/s40279-020-01300-0

Ramirez-Campillo, R., Álvarez, C., García-Hermoso, A., Ramírez-Vélez, R., Gentil, P., Asadi, A., Chaabene, H., Moran, J., Meylan, C., García-de-Alcaraz, A., Sanchez-Sanchez, J., Nakamura, F. Y., Granacher, U., Kraemer, W., & Izquierdo, M. (2018). Methodological characteristics and future directions for plyometric jump training research: a scoping review. *Sports Medicine*, *48*(5), 1059-1081. https://doi.org/10.1007/s40279-018-0870-z

Ramirez-Campillo, R., Andrade, D. C., García-Pinillos, F., Negra, Y., Boullosa, D., & Moran, J. (2021). Effects of jump training on physical fitness and athletic performance in endurance runners: A meta-analysis. *Journal of Sports Sciences*, *39*(18), 2030-2050. https://doi.org/10.1080/02640414.2021.1916261

Ramirez-Campillo, R., Gentil, P., Negra, Y., Grgic, J., & Girard, O. (2021). Effects of plyometric jump training on repeated sprint ability in athletes: a systematic review and meta-analysis. *Sports Medicine*, *51*(10), 2165-2179. https://doi.org/10.1007/s40279-021-01479-w

Rampinini, E., Bishop, D., Marcora, S. M., Ferrari Bravo, D., Sassi, R., & Impellizzeri, F. M. (2007). Validity of simple field tests as indicators of match-related physical performance in top-level professional soccer players. *International Journal of Sports Medicine*, *28*(3), 228-235. https://doi.org/10.1055/s-2006-924340

Reilly, T., Williams, A. M., Nevill, A., & Franks, A. (2000). A multidisciplinary approach to talent identification in soccer. *Journal of Sports Sciences*, *18*(9), 695-702. https://doi.org/10.1080/02640410050120078

Requena, B., González-Badillo, J. J., Villareal, E. S. S. d., Ereline, J., García, I., Gapeyeva, H., & Pääsuke, M. (2009). Functional performance, maximal strength, and power characteristics in isometric and dynamic actions of lower extremities in soccer players. *The Journal of Strength & Conditioning Research*, *23*(5), 1391-1401. https://doi.org/10.1519/JSC.0b013e3181a4e88e

Sánchez, M., Sanchez-Sanchez, J., Nakamura, F. Y., Clemente, F. M., Romero-Moraleda, B., & Ramirez-Campillo, R. (2020). Effects of plyometric jump training in female soccer player's physical fitness: a systematic review with meta-analysis. *International Journal of Environmental Research & Public Health*, *17*(23). https://doi.org/10.3390/ijerph17238911

Sansonio de Morais, A., Ferreira, G. A., Lima-Silva, A. E., & Gomes Filho, A. (2018). Gender-related cardiac dimension differences between female and male professional soccer players. *The Journal of Sports Medicine & Physical Fitness*, *58*(9), 1354-1359. https://doi.org/10.23736/s0022-4707.17.07422-9

Silva, J. R., Nassis, G. P., & Rebelo, A. (2015). Strength training in soccer with a specific focus on highly trained players. *Sports Medicine Open*, *1*(1), 17. https://doi.org/10.1186/s40798-015-0006-z

Sole, S., Ramírez-Campillo, R., Andrade, D. C., & Sanchez-Sanchez, J. (2021). Plyometric jump training effects on the physical fitness of individual-sport athletes: a systematic review with meta-analysis. *PeerJ*, *9*, e11004. https://doi.org/10.7717/peerj.11004

Spineti, J., Figueiredo, T., Bastos, D. E. O. V., Assis, M., Fernandes, D. E. O. L., Miranda, H., Machado, D. E. R. R. V. M., & Simão, R. (2016). Comparison between traditional strength training and complex contrast training on repeated sprint ability and muscle architecture in elite soccer players. *The Journal of Sports Medicine & Physical Fitness*, *56*(11), 1269-1278.

Stølen, T., Chamari, K., Castagna, C., & Wisløff, U. (2005). Physiology of soccer: an update. *Sports Medicine*, *35*(6), 501-536. https://doi.org/10.2165/00007256-200535060-00004

Thapa, R. K., Kumar, A., Kumar, G., & Narvariya, P. (2020). A combination of ballistic exercises with slow and fast stretch-shortening cycle induces post-activation performance enhancement. *Trends in Sport Sciences*, *27*(4),

 DOI 10.26773/mjssm.220906

203-211. https://doi.org/10.23829/TSS.2020.27.4-3

Thapa, R. K., Kumar, A., Sharma, D., Rawat, J., & Narvariya, P. (2019). Lower limb muscle activation during instep kick from different approach angles and relationship of squat jump with 10-m sprint, 30-m sprint, static balance,change of direction speed and ball velocity among soccer players. *Journal of Physical Education & Sport*, *19*(6), 2264-2272. https://doi.org/10.7752/jpes.2019.s6341

Thapa, R. K., Lum, D., Moran, J., & Ramirez-Campillo, R. (2021). Effects of complex training on sprint, jump, and change of direction ability of soccer players: a systematic review and meta-analysis. *Frontiers in Psychology*, *11*, 627869. https://doi.org/10.3389/fpsyg.2020.627869

Valentine, J. C., Pigott, T. D., & Rothstein, H. R. (2010). How many studies do you need?: a primer on statistical power for meta-analysis. *Journal of Educational & Behavioral Statistics*, *35*(2), 215-247. https://doi.org/10.3102/1076998609346961

van de Hoef, P. A., Brauers, J. J., van Smeden, M., Backx, F. J. G., & Brink, M. S. (2019). The effects of lower-extremity plyometric training on soccer-specific outcomes in adult male soccer players: a systematic review and meta-analysis. *International Journal of Sports Physiology & Performance*, 1-15. https://doi.org/10.1123/ijspp.2019-0565

Weldon, A., Duncan, M. J., Turner, A., Sampaio, J., Noon, M., Wong, D. P., & Lai, V. W. (2021). Contemporary practices of strength and conditioning coaches in professional soccer. *Biology of Sport*, *38*(3), 377-390. https://doi.org/10.5114/biolsport.2021.99328

Wisløff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British Journal of Sports Medicine*, *38*(3), 285-288. https://doi.org/10.1136/bjsm.2002.002071

Yamato, T. P., Maher, C., Koes, B., & Moseley, A. (2017). The PEDro scale had acceptably high convergent validity, construct validity, and interrater reliability in evaluating methodological quality of pharmaceutical trials. *Journal of Clinical Epidemiology*, *86*, 176-181. https://doi.org/10.1016/j.jclinepi.2017.03.002

ORIGINAL SCIENTIFIC PAPER

Effect of Post-Warm-Up Three Different Duration Self-Selected Active Rests on 100 Meter Swimming Performance: Preliminary Findings

Denizhan Türkmen[1], Erkan Günay[2], Çağdaş Güdücü[3], Adile Öniz[4], Cem Ş. Bediz[5]

Affiliations: [1]Institute of Health Science, Dokuz Eylul University, Izmir, Turkey, [2]Faculty of Sport Sciences, Celal Bayar University, Manisa, Turkey, [3]Faculty of Medicine, Department of Biophysics, Dokuz Eylul University, Izmir, Turkey, [4]Faculty of Health Sciences, Near East University, Nicosia, Cyprus, [5]Faculty of Medicine, University of Kyrenia, Kyrenia, Cyprus.

Correspondence: E. Günay, Faculty of Sport Sciences, Celal Bayar University, Manisa, Turkey. E-mail: erkanswim@gmail.com

Abstract

The question of when the optimal effect of warm-up is reached after the warm-up phase in swimming competitions is still not fully elucidated. The purpose of this study was to see how self-selected active rest in three different duration periods affected 100-m maximum swimming performance. Eight well-trained elite swimmers (6 males and 2 females, mean age: 17.2 ± 3, mean 616 FINA points) were included in the study. After the participants completed a standard warm-up consisting of dryland-based dynamic warm-up (10-min) and in-water warm-up protocols (1200-m / ~25-min) in 3 different sessions, they observed different transition phase periods (15, 30 and 45-min) with standard clothes in their maximum heart rate of 30% and self-selected movement forms (stretching, walking, etc.) completed by active rest. Subsequently, swimmers carried out the 100-m maximum time-trial swim test using their main stroke. Tympanic temperature ($T_{tympanic}$), forehead temperature ($T_{forehead}$), heart rate (HR), rating of perceived exertion (RPE), and maximal 100-m-time-trial (TT) were recorded during all sessions. Measurements were evaluated in repeated measures ANOVA. Delta (Δ) calculation was used to score changes and strengthen the analysis. The 100-m time-trial demonstrated a trend of improvement in 30-min active rest (p=0.037). In addition, there was no difference between rest times in $T_{forehead}$, $T_{tympanic}$, HR, and RPE conditions (p>0.05). The 30-min active rest interval improved 100-m swimming performance by 1.6% and 0.8% compared to 15-min and 45-min active rest. The positive effect of pool warm-up can be maintained for up to 30 minutes with self-paced active rest.

Keywords: *Active Rest, Thermoregulation, Sprint Swimming Performance, Thermal Imaging*

@MJSSMontenegro
COMPLEX CONTRAST TRAINING IN SOCCER
http://mjssm.me/?sekcija=article&artid=242

Cite this article: Türkmen, D., Günay, E., Güdücü, Ç., Öniz, A., & Bediz, C.Ş. (2022) Effect of Post-Warm-Up Three Different Duration Self-Selected Active Rests on 100 Meter Swimming Performance: Preliminary Findings. *Montenegrin Journal of Sports Science and Medicine*, 11 (2), 57–64. https://doi.org/10.26773/mjssm.220907

Introduction

Warm-up protocol models preceding competitions and training have become a popular topic for researchers and coaches (McGowan et al., 2015; Neiva et al., 2017). Engaging in a warm-up routine before physical activity has many positive physiological and metabolic effects on performance. For instance, it reduces the viscous resistance of muscle, increases nerve conduction velocity (Pearce et al.,

Received: 15 March 2022 | Accepted after revision: 20 August 2022 | Early access publication date: 30 August 2022 | Final publication date: 1 September 2022

© 2022 by the author(s). License MSA, Podgorica, Montenegro. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY).

Conflict of interest: None declared.

2012), accelerates the metabolic reaction, and enhances both the baseline oxygen consumption (Burnley et al., 2011) and post-activation potentiation (McGowan et al., 2015). However, the major contributing factors for these metabolic changes are mostly related to an increase in body temperature (Bishop, 2003). With the beginning of the warm-up (especially for dryland-based sports), core and muscle temperature (Tm) increase and reach a plateau after ~15-min of exercise (Bishop, 2003). After cessation of exercise, muscle and core temperature begin to rapidly decrease (Mohr et al., 2004). But this rapid decrement negatively affects subsequent performance. Sargeant et al. (1987) observed that every 1°C cooling of the muscle temperature resulted in a 3% drop in leg muscle power. Similarly, Faulkner et al. (2013) reported that every 1°C increase in muscle temperature is correlated with a 9% improvement in peak power output. Thus, studies underlined that maintaining body temperature that is raised with a warm-up is important for subsequent performance (Galbraith & Willmott, 2018; Kilduff et al., 2013).

Warm-up protocols in swimming consist of two main parts: dryland and water warm-up. The Dryland session is performed out of the water and includes a general warm-up, dynamic stretching, and may include some resistance (such as theraband) exercises (Neiva et al., 2014). Water warm-up involves low to moderate intensity swimming, kicking and arm pulling, technical and coordination drills, short distance race-pace phase, turning, finish and swimming start combination. There is a cool-down period to conclude the water warm-up; this has several components, such as intensity, duration, and transition phase (Neiva et al., 2014). Out of these factors, the transition phase is defined as the duration of time between warm-up and the start of the competition (McGowan et al., 2015). The researchers reported that during these transitions, the metabolic effects of pool warm-up should be maintained. It has been indicated that shorter passive rest times after post-warm-up increase performance. Such as, when compared to 45-min rest, 10-min (1.5%) (Zochowski et al., 2007) and 20-min (1.4%) (West et al., 2013), passive rest enhanced 200-m freestyle swimming performance. Similarly, Neiva et al. (2014) found that 100-m freestyle swimming performance was 1.12% improved after 10-min compared to a 20-min time gap during passive rest conditions. Based on these findings, increasing the muscle temperature, and starting the race with a higher core temperature were found to be the main mechanisms related to improved performance (Neiva et al., 2014; West et al., 2013). However, these passive rests are not suitable for real competition conditions, because swimmers have to complete tasks such as wearing swimsuits, which keep them active during this period, and spend 20 minutes outside the water in a call room for grouping before the race starts. Therefore, the real-race transition phase may extend up to 30-45 min.

Active rest seems to be more effective on performance due to the change in body temperature (McGowan et al., 2015), faster metabolic recovery (Mota et al., 2017), and an increased feeling of well-being (Cortis et al., 2010). In this context, previous studies reported that active rest strategies, such as dry-land-based exercises (McGowan et al., 2017), dynamic stretching routines (Athanasios A. Dalamitros et al., 2018), and neuromuscular effects (Sarramian et al., 2015), were all used as additional warm-up schemes during transition duration for improved swimming performance (Toubekis et al., 2008). For example, Mcgowan et al. (2016) reported that during the 30-min transition phase, active rest had a better effect on 100-m swimming performance than passive rest. In another study, Dalamitros et al. (2018) demonstrated that a dynamic stretching routine or a power exercise circuit had better performance in 50-m swimming performance than in passive conditions.

However, these active rest strategies cannot be used in real racing conditions due to the regulations of competition preparation (equipment) described in the above paragraph and the need for mental preparation in the last minutes before the race. Practically speaking, in real racing conditions during the transition phase, the swimmers would prepare themselves for the race with their prescribed movements, which could increase their motivation and feelings of physical and psychological well-being. Therefore, non-structured or semi-structured movements (stretching, walking, gymnastics, etc.) can be used easily without any specific equipment as a transition phase strategy in competitions.

To the best of our knowledge, previous studies have focused on the effects of different passive rest times during the transition phase on swimming performance. Moreover, no studies have compared the effects of different self-paced active transition phases after warm-up in swimming performances. Therefore, the purpose of this study was to examine the impact of three different durations of self-paced active rest (15, 30 and 45-min) on 100-m swimming performance in competitive swimmers. Also, it aimed to reveal the possible relationship between the thermal responses during active rest periods and swimming performance. We first hypothesized that the duration of active rest would have an impact on swimming performance. Additionally, it was hypothesized that the different active rest durations could have different thermoregulatory responses and could lead to different swimming performances.

Material and methods

Participants

Eight national and international level competitive swimmers (6 males, 2 females) volunteered to take part in this study (table 1). All swimmers had at least 6 years of experience in competition and performed 40.000 ± 5.000 m per week during 6-8 training sessions. All swimmers had previously participated in national competitions, and their maximum test performances for their strokes corresponded to 616 FINA (2020) scoring points (table 1). All test procedures were completed during the taper period. Swimmers and their parents were informed of potential risks associated with the study and about experimental designs before all of the tests; they also signed an informed consent form. For this study, all procedures and experimental design were approved by the local Ethics Committee (approval number and date: 2019/01- 48, 18.01.2019), and the study was conducted according to the Helsinki declaration.

Study Protocol

Each swimmer completed three testing sessions with different active rest times (15-min, 30-min, and 45-min) on 3 different days; these were separated by at least 48 hours. All test sessions were randomized among the swimmers. Sessions took place at the same time of the day (16.00-

DOI 10.26773/mjssm.220907

Table 1. Participant characteristics

Participant	Gender	Age (yr)	Height (cm)	Weight (kg)	Main Stroke	100-m Time* (s)	FİNA Points
1	M	17	187	80	Freestyle	53.66	663
2	F	14	169	56	Freestyle	69.50	513
3	M	21	180	76	Breaststroke	65.78	646
4	M	17	183	67	Butterfly	57.21	647
5	F	14	163	50	Freestyle	61.90	635
6	M	18	176	70	Freestyle	55.99	588
7	M	15	176	68	Ind. Med	68.50	575
8	M	22	180	74	Freestyle	53.67	667
Mean		17.2	176,7	67,6			616

* 100-m Time is the best swimming performance time of swimmers in the last year.

19.00) and under similar environmental conditions (pool water temperature of 26,3 ± 2.2°C, air temperature of 24.6 ± 2.3°C, humidity 67.2 ± 12.8%). Swimmers maintained the same training and diet routine, abstained from caffeine intake during the 12 h before each test. Additionally, it was not allowed to test the thermic effect of food consumption before the last two-hours of testing.

In each session, all swimmers completed a warm-up protocol followed by a 100-m-time-trial test (figure 1). The warm-up protocol consisted of two main sections with a 5-min rest between them. Swimmers performed a land-based dynamic warm-up protocol for 10 minutes. This period included dynamic stretching and mobility exercises. In the 5-minutes between dynamic warm-up and water warm-up, swimmers completed preparations for water warm-up and conferred with their coach for the last reminder. After this preparation phase, they carried out a 1200-m (~25-min) standard pool warm-up in the swimming pool (table 2).

Table 2. Standardized pool-warm-up

Distance (meters)	Content
400	Freestyle, free I.M
200	Kick
200	Pulling
200	I.M. drill/sw
2x50	Race-pace rest: 30 s
100	Easy sw
Total: 1200 m (~ 25 min)	

I.M: Individual Medley, Sw: Swim, S: Second.

After completing the warm-up protocol, swimmers promptly donned their standard clothes (race swimsuit, t-shirts, trousers, socks, and shoes) and performed active rest periods (figure 1). During this period, participants were not allowed to sit or do any movements that could cause neuromuscular activity. They were completed with 30% of maximum heart rate physical load in all active rest sessions with self-selected movements (stretching, walking, gymnastics, etc.) before completing a 100-m-time-trial using their main stroke. However, during the active rest periods of the swimmers, their heart rate controls were regularly checked at 5-minute intervals.

Measurements

This study included evaluation of tympanic ($T_{tympanic}$) and forehead ($T_{forehead}$) temperature, heart rate (HR), rating of perceived exertion (RPE), and a 100-m time-trial (TT). All measurement points were demonstrated in figure 1. The tympanic membrane temperature was measured as core temperature using a Braun thermometer (Braun thermoscan IRT 6520, Germany). A clean lens filter was used for each measurement to achieve correct data collection. A thermal imager was used to evaluate changes in skin temperature. The forehead was marked as a reference point in measurements. The thermal imaging camera (FLIR SC305, USA) was mounted at a distance of 1.5 m from the subject. The device had 320x240 pixels at 7.5-13 μm in bandwidth. Heart rate was recorded using fingertip pulse oximeters (Beurer P030, Germany) during active rest sessions. A fingertip pulse oximeter was placed on the thumb of the right hand. Before each measurement of the heart rate, fingers were dried with a towel.

Measuring points of tympanic ($T_{tympanic}$) and forehead ($T_{forehead}$) temperature, and HR were recorded as baseline (Base), immediately post-dynamic-warm-up ($Post_{DWU}$), immediately post-pool-warm-up ($Post_{PWU}$), and immediately pre-100-m-time-trial (Pre_{TT}). HR was additionally measured at active rest duration every 5 minutes until pre-TT.

The rate of perceived exertion (RPE) was recorded immediately following the 100m time trial (Figure 1). All 100-m-time-trial swim tests were carried out at maximum effort. They were recorded manually by a level 5 qualified coach (member of the Turkish national team) using two digital chronographs (Casio hs-80tw-1df, Tokyo, Japan) at the point where their contact with the wall is most clearly visible. The average value of the two chronographs was recorded. Swimmers started the time trials with a dive start from the starting blocks to simulate competitive race condi-

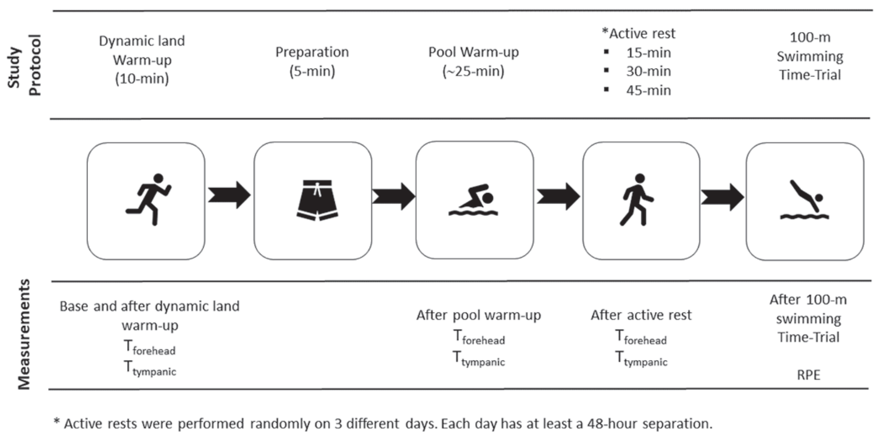


Figure 1. The experimental design and measurement points of the study. $T_{tympanic}$: Tympanic temperature; $T_{forehead}$: Forehead temperature; RPE: Ratings of perceived exertion.

tions. For high motivation and best performance, all swimmers completed performance tests in their main strokes. In this context, five swimmers completed the freestyle technique, one swimmer the butterfly technique, one swimmer the breaststroke technique, and one swimmer the medley technique during test sessions. Immediately following each 100-m-time trial, RPE was recorded using a 10-point Borg scale.

Statistical analysis

The results are presented as mean ± SD. All statistical analyses were carried out using SPSS software (version 24; SPSS Inc., Chicago, USA). The distribution of dependent data was checked using the Shapiro–Wilk test. Measurements were evaluated with two factors: ANOVA (4x3, measurement points x rest times) to check the session difference in $T_{tympanic}$, $T_{forehead}$, and HR. A Delta (Δ) calculation was used to score changes and strengthen the analysis. Delta values were calculated by subtracting the post-pool-warm-up data from the pre-time-trial data. Analysis of variance for repeated measures on one-factor analysis of variance (ANOVA) was used to compare the Delta (Δ) parameters. To analyze the effect of the 100-m time-trial and RPE, we used one-way repeated measures ANOVA. The sphericity was conducted by Mauchly's test. If sphericity was not violated, Greenhouse–Geisser correction was employed to determine the significance of F-ratios. A Bonferroni confidence-interval adjustment was applied to the pairwise comparison. Effect sizes were determined by calculating partial eta-squared values using SPSS.

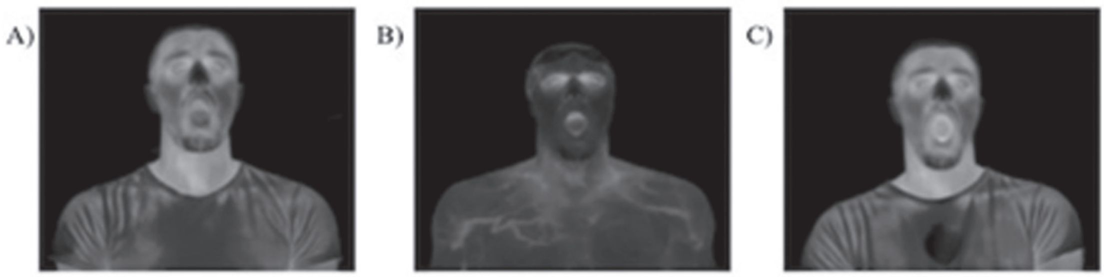


Figure 2. Thermal images of; A) baseline, B) immediately post-pool warm-up, and C) pre-time-trial, during the 30-min rest time. As the color gets lighter, the body temperature increases.

Results

100-m-Time-Trial and Rating of Perceived Exertion

The result of the one-way ANOVA revealed a significant interaction between rest times in the 100-m test time ($p=0.037$, $\eta^2=0.375$; table 3). It showed that 30-min active rest (62.65±7.62 s) improved the time trials 1.6% when compared to the 15-min rest (63.66±8.16 s) and, 0.8% when compared to the 45-min active rest period (63.17±8.44). In RPE values, there were no significant effects in three rest times at all measurement points (p=0, 916, $\eta^2=0.013$; table 3).

Physiological responses

$T_{forehead}$, $T_{tympanic}$, and HR raw data were given in table 3. There were significant effect measurement points in $T_{forehead}$ ($p=0.000$, η^2= high effect) and in $T_{tympanic}$ ($p=0.000$, η^2=high effect), but there were no significant rest times and measurement point x rest time interaction effects ($p>0.05$).

Figure 2 illustrates the $T_{forehead}$ responses in the thermal images. $T_{forehead}$ decreased similarly during dynamic land warm-up and water warm-up in rest sessions (figure 3). There was a significant difference between $Post_{DWU}$ and $Post_{PWU}$ in $T_{forehead}$ measurement points in all sessions ($p=0.007$), but this was not significant between rest times in these measurement points ($p>0.05$; figure 3). During the transition phase, $T_{forehead}$ increased in all sessions ($p = 0.01$), but there was no significant difference between rest times ($p>0.05$). According to one-way ANOVA in delta calculations ($\Delta=Post_{PWU}-Pre_{TT}$) for $T_{forehead}$, there was a significant change in forehead temperature between the rest times ($\Delta_{15min}=-2.17$, $\Delta_{30min}=-2.92$, $\Delta_{45min}=-3.45$; $p=0.015$, η^2=high effect). When multiple pairwise comparisons were employed, a significant change was found between the 15-min and 45-min active rests ($p=0.007$), while there was

DOI 10.26773/mjssm.220907

no significant change between 15-min and 30-min (p=0.216), and 15-min and 45-min (p=0.927). Measurements of tympanic temperature were shown in Figure 3. There was a significant decrease between $Post_{DWU}$ and $Post_{PWU}$ in $T_{tympanic}$ measurement in all rest times (p=0.001). $T_{tympanic}$ increased during the transition phase (p = 0.04), but there was no significant change between rest times (p>0.05; figure 3) and delta values (Δ_{15min}=-0.65, Δ_{30min}= -1.03, Δ_{45min}=-1.15; p=0.116, η^2=high effect). in HR, there were no significant effects in three rest times at all measurement points (p=0.148, η^2=high effect).

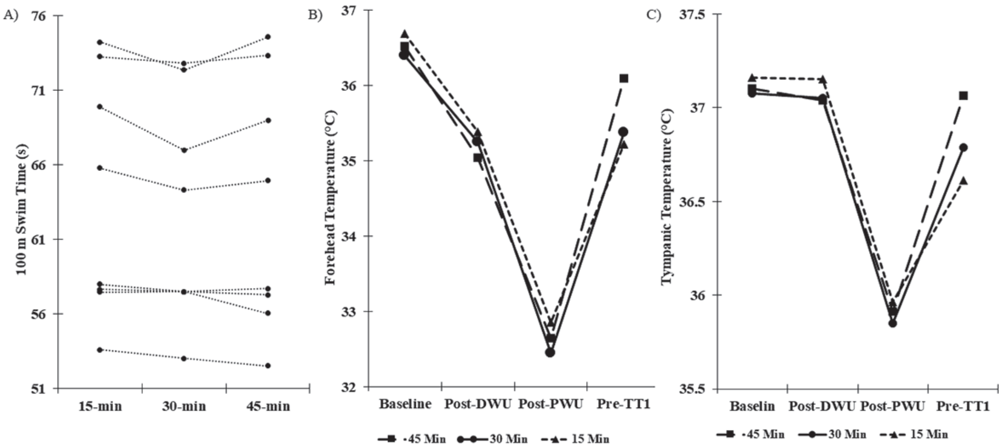


Figure 3. A) Individual 100-m swimming time changes between rest times on time-trial, B) forehead temperature ($T_{forehead}$) and C) tympanic temperature ($T_{tympanic}$) responses throughout to the trials, data presented as mean±SD (n=8).

Discussion

This study examined the effect of post-warm-up 15, 30, and 45-min active rest times on 100-m-time-trial swimming performance. The results of this study showed that the 30-minute active rest time improved the 100-m time trial. This improvement was between 1.6% and 0.8%. In the study of Pyne et al. (2004), it was considered that the chance of medals could be significantly enhanced if the swimmers improved their performance by 1% in the year leading up to the race and an additional increase of 0.4% in the main competition. Therefore, performance improvements in the current study are a remarkable contribution for swimming competitors. In addition, there was no significant effect between rest times in $T_{forehead}$ and $T_{tympanic}$. Therefore, the acute changes in $T_{forehead}$ and $T_{tympanic}$ may not have a direct effect on swimming performance.

Active Rest Versus Passive Rest

It is clear that water warm-up improves swimming performance. In studies based on passive rest after water warm-up, Zochowski et al. (2007) demonstrated 1.4% better swimming performance following the 10-min transition phase, compared to 45-min rest time. Similarly, West et al. (2013) reported a 1.5% improvement in swimming performance

Table 3. Tympanic temperature ($T_{tympanic}$), forehead temperature ($T_{forehead}$), heart rate (HR) raw data at baseline (base), post-dynamic warm-up ($Post_{DWU}$), post-pool warm-up ($Post_{PWU}$), pre-time-trial (Pre_{TT}); 100-m Time-Trial (TT) and rating of perceived exertion (RPE) raw data at post-time-trial ($Post_{TT}$), for 15, 30, 45 min rest times

	Rest Times (min)	$T_{tympanic}$ (C°)	$T_{forehead}$ (C°)	HR	TT (s)	RPE
	15	37.1 ± 0.3	36.6 ± 0.4	81.6 ± 12.7	-	-
Base	30	37.07 ± 0.7	36.4 ± 0.5	87.2 ± 14	-	-
	45	37.1 ± 0.2	36.5 ± 1.2	94.6 ± 15	-	-
	15	37.15 ± 0.2	35.03 ± 0.5	98.1 ± 14.5	-	-
$Post_{DWU}$	30	37.05 ± 0.2	35.25 ± 0.8	103.5 ± 12.7	-	-
	45	37.03 ± 0.3	35 ± 1.4	109.7 ± 10.6	-	-
	15	35.09 ± 0.9	33.05 ± 0.8	119.1 ± 11.1	-	-
$Post_{PWU}$	30	35.8 ± 0.7	32.4 ± 0.9	117.3 ± 15.5	-	-
	45	35.9 ± 0.5	32.6 ± 1.4	122.6 ± 23.1	-	-
	15	36.6 ± 0.3	35.2 ± 0.8	99.6 ± 9.2	-	-
Pre_{TT}	30	36.7 ± 0.2	35.3 ± 0.7	95.1 ± 14.3	-	-
	45	37.06 ± 0.3	36.1 ± 0.7	103.2 ± 13.1	-	-
	15	-	-	-	63.66±8.16	8.5±0.5
$Post_{TT}$	30	-	-	-	62.65±7.62	8.3±1
	45	-	-	-	63.17±8.44	8.3±0.9

All data presented as mean ± SD

following a 20-min passive rest time, compared to the 45-min passive recovery period. Therefore, a short passive rest time between warm-up and competition has been recommended for better performance in swimming. However, since the swimmers must be prepared for the race and must notify the call room 20 minutes before the race, these short passive rest times are not suitable for the competitions. Hence, the benefits of warm-up in the transition phase need to be maintained for a longer time. Mcgowan et al. (2016) investigated the effects of different transition phase strategies, such as conventional tracksuit top and pants (Control), insulated top with integrated heating elements (Passive), 5-min dryland-based exercise circuit (Dryland), and a combination of Passive and Dryland (Combo) during the 30-min transition phase on 100-meter swimming performance. Dryland and Combo strategies caused 0.7% and 1.1% faster time-trial performances, respectively, and less reduction in core temperature. Similarly, Dalamitros et al. (2018) compared two different dryland active rest strategies to 50m swimming performance during the 30-min transition phase, and found an improvement in the 50-m swimming performance. The Dryland protocols consisted of a dynamic stretching routine or a power exercise circuit. In the current study, active rest periods were compared, and unexpectedly, the improving effects of 30-min active rest time were 1.6% and 0.8% higher than the 15-min and 45-min active rest times, respectively. But these performance improvements were in line with the previous studies. Active rest in addition to the post-warm-up may positively affect the benefits of the warm-up.

The Effect of Active Rests on Swimming Performance

The optimal post-warm-up passive rest time is recommended to be between 5 and 20 minutes (Bishop, 2003; West et al., 2013; Zochowski et al., 2007). These passive rest times cannot be performed in a real competition environment, so they are insufficient between warm-up and race. At least 20 min before their race, swimmers must change their swimsuit and enter the call-room. However, if swimmers stay active in this period, the suggested recovery time may be extended to 30-min (Athanasios A. Dalamitros et al., 2018; McGowan et al., 2016). This current study demonstrated that when comparing active rest durations (15 vs 30 vs 45-min), subsequent swimming performance after 30-minute rest may reach its peak. These results suggest that the positive effects of warm-up may be maximized up to 30 minutes with low-intensity active rest.

The Effect of Water Temperature on Forehead and Tympanic Temperature

Many studies reported that performance may be related to the concomitant reduction in body core temperature after warm-up. We also could not observe any link between body temperature and swimming performance since body temperature was not measured with an invasive method. During pool warm-up, the core temperature of the body increases only slightly (~0,7°C) (Fujishima et al., 2001; McGowan et al., 2016; Neiva et al., 2017; West et al., 2013) whereas the skin temperature decreases significantly (~4°C) (Jimenez-Perez et al., 2021). In the current study, there was observed an increase in $T_{forehead}$ and $T_{tympanic}$ when active rest durations are performed (table 3). We used two non-contact infrared devices (infrared thermography and infrared thermometer) to monitor the body. These devices detect the heat emitted from a surface and directly measure the object's temperature. In the current study, the forehead and tympanic temperature values increased immediately during the post-pool warm-up relatively compared to the baseline (figure 3). This is most likely since, when the nature of the heat transfer is considered, the heat transfer rate of water is higher than air; this means that faster heat exchange occurs in the water (Fujishima et al., 2001). So, the skin temperature will have a sharp decrease when the swimmers dive into the water (Fujishima et al., 2001; Sagawa et al., 1988). The sharp decreases in skin temperature are due to the clamping of skin temperature to water temperature and may not reflect any true shifts in core temperature in the study, which depend on the duration of the rest (Jimenez-Perez et al., 2021). Therefore, in the water, forehead and tympanic temperatures may have acted as skin temperatures.

The Effect of Water on the Body's Physiological System

In the current study, there was no significant difference between $T_{forehead}$ and $T_{tympanic}$ rest periods in immediately pre-measurement points of 100-m swimming performance. It was observed that the swimmers made rapid skin thermoregulatory adjustments up to 15 minutes, but its speed slowed down after 15 minutes. Cold-induced vasoconstriction in cutaneous blood vessels (Giovanni Tanda, 2018). Thus, blood is retained in the core regions to decrease heat loss from the body (Charkoudian, 2003; Giovanni Tanda, 2018). However, body temperature is compensated by the thermoregulation mechanism and muscle activity. By increasing the skin blood flow again, muscle performance is increased. Therefore, the first 15 minutes may have an important role in the thermoregulation system's adaptation to land conditions after swimming warm-up. Indeed, besides body temperature, oxygen uptake and heart rate changes during warm-up may have direct effects on swimming performance (Neiva et al., 2014). Although the effect of warm-up on performance may be attributed to temperature-related mechanisms, such as rapid metabolic reactions and increased nerve conduction velocity, it can be concluded that water-based warm-up may not be directly related to body skin temperature changes. Therefore, swimmers need to adapt to aquatic environments and stimulate physiological systems related to performance before the race. There might be numerous underlying mechanisms to explain this topic, but the factor addressing physiological mechanisms affecting warm-up on swimming performance would be one of the further research.

One of the limitations of this study is the fact that the age range of the swimmers is wide. Due to the requirement of participation in the study of 500 FINA points and above and the low number of athletes engaged in swimming, the study was conducted with a rather small number of participants. But since the age range of world record-breaking athletes is wide, it is reasonable to suggest that the results of this study are applicable. Finally, the lack of more valid devices, such as ingestible telemetric body core temperature sensors (ingestible thermal pills), for monitoring core temperature was a second limitation. Nevertheless, as the tympanic thermometer and thermal imaging use infrared technology, it is important to note that the ambient conditions are similar.

 DOI 10.26773/mjssm.220907

Therefore, the environmental conditions were controlled and stabilized during all test sessions. However, with an ingestible thermal pill, the core body temperature could have been more precisely captured.

The present study revealed the possible effects of active rest times on swimming performance. The 30-min active rest time applied after warm-up, which can be easily adapted to the race conditions, improves the 100 meter swimming performance. Individual differences (such as age, gender, amount of muscle) may affect those performances. Therefore, we suggest that the coaches and swimmers should observe the best effective rest-time duration by making trials during the training period to determine which time duration can fit the swimmers' performance after the warm-up.

Conclusions

One of the key findings of this study was that the 100-m swimming performance was improved with a 30-min self-paced active rest time. When the nature of the competitions was considered, swimmers need sufficient time to prepare for the race and have to report to a call room 20-min before the start of their race sessions. This information showed that the transition phase duration with low-intensity active rest can extend up to 30 min after warm-up. In addition, our results demonstrated that $T_{tympanic}$ and $T_{forehead}$ had similar track records and did not have a direct effect on swimming performance.

During international and national swimming competitions, swimmers may need to repeatedly perform maximum effort throughout the same session. Particularly in competitions without a extra warm-up pool, the inability to warm up in the water between races is a problem for second maximal effort. That is why determining the effects of a rest period after a warm-up on a second maximal effort may be regarded as important information for swimmers and coaches.

Acknowledgments

We would like to give special thanks for the help of the swimmers who participated in this study. We would also like to thank master's students at the university for their contribution to data collection. This research received no external funding. The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author, who was an organizer of the study.

References

Athanasios A. Dalamitros, Athanasios Vagios, Argyris G. Toubekis, Georgios Tsalis, Vicente J. Clemente-Suarez, & Vasiliki Manou. (2018). The effect of two additional dry-land active warm-up protocols on the 50-m front-crawl swimming performance. *Human Movement*, *19*(3), 75–81. https://doi.org/10.5114/hm.2018.76082

Bishop, D. (2003). Warm up I: Potential mechanisms and the effects of passive warm up on exercise performance. *Sports Medicine*, *33*(6), 439–454. https://doi.org/10.2165/00007256-200333060-00005

Burnley, M., Davison, G., & Baker, J. R. (2011). Effects of priming exercise on VO2 kinetics and the power-duration relationship. *Medicine and Science in Sports and Exercise*, *43*(11), 2171–2179. https://doi.org/10.1249/mss.0b013e31821ff26d

Charkoudian, N. (2003). Skin blood flow in adult human thermoregulation: How it works, when it does not, and why. *Mayo Clinic Proceedings*, *78*(5), 603–612. https://doi.org/10.4065/78.5.603

Cortis, C., Tessitore, A., D'Artibale, E., Meeusen, R., & Capranica, L. (2010). Effects of post-exercise recovery interventions on physiological, psychological, and performance parameters. *International Journal of Sports Medicine*, *31*(5), 327–335. https://doi.org/10.1055/s-0030-1248242

Faulkner, S. H., Ferguson, R. A., Gerrett, N., Hupperets, M., Hodder, S. G., & Havenith, G. (2013). Reducing muscle temperature drop after warm-up improves sprint cycling performance. *Medicine and Science in Sports and Exercise*, *45*(2), 359–365. https://doi.org/10.1249/MSS.0b013e31826fba7f

Fujishima, K., Shimizu, T., Ogaki, T., Hotta, N., Kanaya, S., Shono, T., & Ueda, T. (2001). Thermoregulatory responses to low-intensity prolonged swimming in water at various temperatures and treadmill walking on land. *Journal of Physiological Anthropology and Applied Human Science*, *20*(3), 199–206. https://doi.org/10.2114/jpa.20.199

Galbraith, A., & Willmott, A. (2018). Transition phase clothing strategies and their effect on body temperature and 100-m swimming performance. *European Journal of Sport Science*, *18*(2), 182–189. https://doi.org/10.1080/17461391.2017.1411528

Giovanni Tanda. (2018). Total body skin temperature of runners during treadmill exercise A pilot study. *Journal of Thermal Analysis and Calorimetry Volume*, *131*(2), 1967–1977. https://doi.org/10.1007/s10973-017-6634-4

Jimenez-Perez, I., Gil-Calvo, M., Vardasca, R., Fernandes, R. J., & Vilas-Boas, J. P. (2021). Pre-exercise skin temperature evolution is not related with 100 m front crawl performance. *Journal of Thermal Biology*, *98*, 102926. https://doi.org/10.1016/j.jtherbio.2021.102926

Kilduff, L. P., West, D. J., Williams, N., & Cook, C. J. (2013). The influence of passive heat maintenance on lower body power output and repeated sprint performance in professional rugby league players. *Journal of Science and Medicine in Sport*, *16*(5), 482–486. https://doi.org/10.1016/j.jsams.2012.11.889

McGowan, C. J., Pyne, D. B., Thompson, K. G., Raglin, J. S., Osborne, M., & Rattray, B. (2017). Elite sprint swimming performance is enhanced by completion of additional warm-up activities. *Journal of Sports Sciences*, *35*(15), 1493–1499. https://doi.org/10.1080/02640414.2016.1223329

McGowan, C. J., Pyne, D. B., Thompson, K. G., & Rattray, B. (2015). Warm-Up Strategies for Sport and Exercise: Mechanisms and Applications. *Sports Medicine (Auckland, N.Z.)*, *45*(11), 1523–1546. https://doi.org/10.1007/s40279-015-0376-x

McGowan, C. J., Thompson, K. G., Pyne, D. B., Raglin, J. S., & Rattray, B. (2016). Heated jackets and dryland-based activation exercises used as additional warm-ups during transition enhance sprint swimming performance. *Journal of Science and Medicine in Sport*, *19*(4), 354–358.

https://doi.org/10.1016/j.jsams.2015.04.012

Mohr, M., Krustrup, P., Nybo, L., Nielsen, J. J., & Bangsbo, J. (2004). Muscle temperature and sprint performance during soccer matches—Beneficial effect of re-warm-up at half-time. *Scandinavian Journal of Medicine & Science in Sports*, *14*(3), 156–162. https://doi.org/10.1111/j.1600-0838.2004.00349.x

Mota, M. R., Dantas, R. A. E., Oliveira-Silva, I., Sales, M. M., Sotero, R. da C., Venâncio, P. E. M., Teixeira Júnior, J., Chaves, S. N., & de Lima, F. D. (2017). Effect of self-paced active recovery and passive recovery on blood lactate removal following a 200 m freestyle swimming trial. *Open Access Journal of Sports Medicine*, *8*, 155–160. https://doi.org/10.2147/OAJSM.S127948

Neiva, H. P., Marques, M. C., Barbosa, T. M., Izquierdo, M., & Marinho, D. A. (2014). Warm-up and performance in competitive swimming. *Sports Medicine (Auckland, N.Z.)*, *44*(3), 319–330. https://doi.org/10.1007/s40279-013-0117-y

Neiva, H. P., Marques, M. C., Barbosa, T. M., Izquierdo, M., Viana, J. L., & Marinho, D. A. (2017). Effects of 10min vs. 20min passive rest after warm-up on 100m freestyle time-trial performance: A randomized crossover study. *Journal of Science and Medicine in Sport*, *20*(1), 81–86. https://doi.org/10.1016/j.jsams.2016.04.012

Pearce, A. J., Rowe, G. S., & Whyte, D. G. (2012). Neural conduction and excitability following a simple warm up. *Journal of Science and Medicine in Sport*, *15*(2), 164–168. https://doi.org/10.1016/j.jsams.2011.09.001

Pyne, D., Trewin, C., & Hopkins, W. (2004). Progression and variability of competitive performance of Olympic swimmers. *Journal of Sports Sciences*, *22*(7), 613–620. https://doi.org/10.1080/02640410310001655822

Sagawa, S., Shiraki, K., Yousef, M. K., & Konda, N. (1988). Water temperature and intensity of exercise in maintenance of thermal equilibrium. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, *65*(6), 2413–2419. https://doi.org/10.1152/jappl.1988.65.6.2413

Sargeant, A. J. (1987). Effect of muscle temperature on leg extension force and short-term power output in humans. *European Journal of Applied Physiology and Occupational Physiology*, *56*(6), 693–698. https://doi.org/10.1007/BF00424812

Sarramian, V. G., Turner, A. N., & Greenhalgh, A. K. (2015). Effect of postactivation potentiation on fifty-meter freestyle in national swimmers. *Journal of Strength and Conditioning Research*, *29*(4), 1003–1009. https://doi.org/10.1519/JSC.0000000000000708

Toubekis, A. G., Tsolaki, A., Smilios, I., Douda, H. T., Kourtesis, T., & Tokmakidis, S. P. (2008). Swimming performance after passive and active recovery of various durations. *International Journal of Sports Physiology and Performance*, *3*(3), 375–386. https://doi.org/10.1123/ijspp.3.3.375

West, D. J., Dietzig, B. M., Bracken, R. M., Cunningham, D. J., Crewther, B. T., Cook, C. J., & Kilduff, L. P. (2013). Influence of post-warm-up recovery time on swim performance in international swimmers. *Journal of Science and Medicine in Sport*, *16*(2), 172–176. https://doi.org/10.1016/j.jsams.2012.06.002

Zochowski, T., Johnson, E., & Sleivert, G. G. (2007). Effects of varying post-warm-up recovery time on 200-m time-trial swim performance. *International Journal of Sports Physiology and Performance*, *2*(2), 201–211. https://doi.org/10.1123/ijspp.2.2.201

DOI 10.26773/mjssm.220907

ORIGINAL SCIENTIFIC PAPER

Collegiate soccer players consistently underestimate practice sweat losses regardless of practice sweat loss volume

Brett A. Davis[1], Lynnsey R. Bowling[2], Tate M. Dean[1], Savanna N. Knight[2], Marcus A. Robinson[1], Angela R. Russell[1], Eric K. O'Neal[2]

Affiliations: [1]Auburn University at Montgomery, Montgomery, AL, [2]University of North Alabama, Florence, AL

Correspondence: Eric O'Neal, University of North Alabama, Professor of Exercise Science, 236 Chestnut Oak Drive, Florence, Alabama 35633. E-mail: eoneal1@una.edu

Abstract

Soccer play in hot environments can result in major fluid deficit. If competitors are unsure of their sweat losses, accurate fluid intake needs during and between training bouts cannot be established. This study evaluated sweat loss estimation accuracy among collegiate male soccer players (n = 17) following three, 90-minute practice sessions in the heat. Data were collected during the last week of pre-season training during a morning (P1; wet bulb globe temperature (WBGT) = 31.2 °C) and same day afternoon (P2; WBGT = 26.9 °C) practice. The third estimation took place after a regular season morning practice (P3; WBGT = 31.5 °C) the following week. Change in nude body mass, with adjustment for fluid intake and urine output, from pre- to post-practice was assessed to determine sweat loss volume. After each practice participants estimated their sweat loss volume by filling cups with a volume of water equivalent to the volume of sweat they believed they lost during the practice session. Sweat losses differed ($p < 0.05$) among all 3 practices (P1 2.181 ± 0.693; P2 1.706 ± 0.474; P 3.360 ± 0.956 L). Estimated sweat loss volume was less ($p < 0.001$) than actual sweat losses for P1 (0.804 ± 0.329 L; 40.2 ± 21.5%), P2 (0.672 ± 0.324 L; 40.1 ± 19.9%) and P3 (1.076 ± 0.489 L; 31.8 ± 11.6%), but there were no differences in percentage accuracy. Players estimations of sweat loss trended up and downward with actual sweat losses, but players greatly and consistently underestimated sweat losses. Visual depiction of sweat loss volume could potentially increase awareness of between training bout fluid intake needs of soccer players training in hot conditions.

Keywords: *Football, hydration, perceptual measures*

@MJSSMontenegro
SOCCER PLAYERS' ABILITY TO ESTIMATE SWEAT LOSSES
http://mjssm.me/?sekcija=article&artid=243

Cite this article: Davis, B.A., Bowling, L.R., Dean, T.M., Knight, S.N., Robinson, M.A., Russell, A.R., & O'Neal, E.K. (2022) Collegiate soccer players consistently underestimate practice sweat losses regardless of practice sweat loss volume. *Montenegrin Journal of Sports Science and Medicine*, 11 (2), 65–70. https://doi.org/10.26773/mjssm.220908

Introduction

It is suggested that physical activity take place in a euhydrated state to combat dehydration elicited deficits to performance (McDermott et al., 2017). However, collegiate athletes in general (Volpe, Poule, & Bland, 2009) and collegiate soccer players specifically (Clarke, Carpenter, Spain-Mansmann, Taylor, & Schubert, 2021b; Sekiguchi, Adams, Curtis, Benjamin, & Casa, 2019) often report to practice with a high prevalence of dehydration based

Received: 7 June 2022 | Accepted after revision: 20 August 2022 | Early access publication date: 30 August 2022 | Final publication date: 1 September 2022

© 2022 by the author(s). License MSA, Podgorica, Montenegro. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY).

Conflict of interest: None declared.

on urinary hydration markers. Soccer match play rules also limit opportunities for fluid consumption. Restricted fluid intake is commonly reported to result in increased core temperature, cardiovascular strain, and higher perceived exertion (Ali, Gardiner, Foskett, & Gant, 2011; Edwards et al., 2007; McGregor, Nicholas, Lakomy, & Williams, 1999) during soccer research. However, the effects of dehydration on soccer performance are equivocal.

Investigators reported fluid restriction had no influence on a variety of soccer skill-based tasks or shuttle running challenges in cool training conditions among male soccer players (Owen 2013). Female soccer players also presented no difference in performance during six sets of Loughborough Shuttle Tests when fluid intake was allowed or disallowed (Ali et al., 2011). In contrast, McGregor et al. (1999) found male shuttle running performance in the same protocol design as Ali and colleagues (2011) during fluid restriction trials began trending towards impaired running performance on the fourth and fifth 15 min shuttle running bouts and reached statistical significance during the 6th shuttle bout. Additionally, sweat losses incurred through 45 min of cycling followed by 45 min of match play reduced distance covered during a shuttle running task when no fluids were ingested (Edwards et al., 2007).

Creating individualized fluid intake schedules for athletes during or between training or competition bouts is not possible without an approximate knowledge of induced sweat loss volume. A recent review of 9 studies that included 243 athletes that were asked to estimate their sweat losses after training reported overwhelming support that sweat losses are vastly underestimated regardless of sex or sport type in moderate to hot environments (O'Neal et al., 2020). Three groups of team sport (rugby and basketball) athletes were observed in these studies (Love, Baker, Healey, & Black, 2018; Muth, Pitchett, Pritchett, DePaepe, & Blank, 2019; Thigpen, Green, & O'Neal, 2014), but we are unaware of any sweat loss estimation investigations with soccer players. Furthermore, to our knowledge, only three studies have examined sweat loss estimation during more than one activity session to determine the strength of conviction of athletes estimating sweat losses (Davis, O'Neal, Johnson, & Farley, 2019; Shaver, O'Neal, Hall, & Nepocatych, 2018; Thigpen et al., 2014). Therefore, the purpose of this study was to evaluate sweat loss estimation accuracy among collegiate, male soccer players following three, 90-minute practice sessions with different coaching focuses during hot climate training sessions. The authors hypothesized that athletes would consistently and greatly underestimate their sweat losses across the practice sessions.

Methods

Participants

Male, National Collegiate Athletic Association (NCAA) Division II soccer players practicing in the hot and humid southeastern region of the United States (latitude = north 32° 22' 0.498") were recruited for this study. Seventeen players (age = 21 ± 3 y; height = 178 ± 123 cm; body mass = 68.7 ± 15.8 kg) provided sweat loss estimates across three practices. All participants passed a physician administered physical and standard health questionnaires for physical activity participation. Written informed consent was obtained by participants prior to participation. This study was approved by the Auburn University at Montgomery Institutional Review Board and was conducted in accordance with the Declaration of Helsinki.

Procedures

Data collection took place during three coach led practices. The first two practices included a mid-morning (P1) and afternoon practice (P2) on the same day during the final week of pre-season training camp. The third practice (P3) took place the following week (i.e. first week of in-season) during the players' normal in-season mid-morning training time. Each practice lasted 90 minutes but consisted of different training emphases. A detailed description of the practices and environmental conditions is provided in Table 1. A schematic of data collection procedures for practice is provided in Figure 1.

Table 1. Description of practice conditions and activities.

	P1	P2	P3
Time of day	10:00 AM	5:00 PM	10:00 AM
Duration (min)	90	90	90
WBGT (^{0}C)	31.2	26.9	31.5

Practice activities (duration in min)

P1	P2	P3
- Dynamic warm up (15) - Speed and agility training (15) - Soccer skills training (30) - Scrimmage (30)	- Dynamic warm up (15) - Soccer skills training (15) - Scrimmage (60)	- Dynamic warm up (15) - Soccer skills training (15) - Scrimmage (60)

During each practice, the following procedures took place in regards to sweat loss assessment and estimation. Sweat loss volume was determined by change in nude body mass from pre- to post-practice with consideration for fluid intake (no participants urinated or defecated between body mass assessments). It was assumed each kilogram of body mass change was equal to 1 liter of sweat loss volume. No corrections were made for differences of mass lost in sweat loss solutes, respiratory tract water evaporation, or metabolic related shifts in total body water. A private room with the scale platform (BWB-800, Tanita Corporation, Tokyo, Japan) located inside and digital output screen outside for an investigator to record results was used to assess body mass to the nearest 0.1 kg without unblinding players to their change in body mass.

Following measurement of pre-practice nude body mass, participants were restricted from consuming any fluids until the start of practice. Immediately prior to practice, investigators provided each participant with a chilled, manufacturer-sealed bottle of water containing 1,000 ml of water. Participants were instructed to consume the water ad libitum during the upcoming practice session and directed to avoid rinsing their mouth, spitting the water out, or spraying the water on their face or body. Participants were instructed to inform investigators if they needed a new bottle during practice. Bottles were weighed before and after practice

DOI 10.26773/mjssm.220908

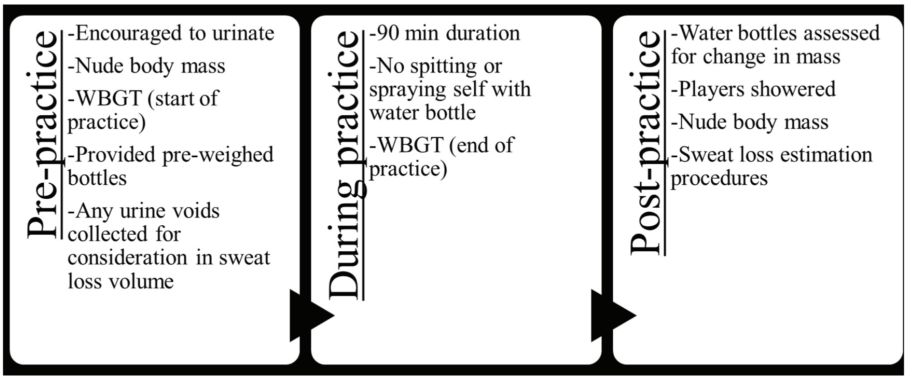


Figure 1. Schematic of data collection procedures for all practices.

using a precision scale (KD-200, Tanita Corporation, Tokyo, Japan) to determine fluid intake volume. No other beverages were provided to participants during practice sessions. Wet-bulb-globe temperature (WBGT) was monitored (HT30: Heat Stress WBGT Meter, Extech Instruments, Waltham, MA) immediately before and after the practice session and the average was recorded.

Players showered and cleaned up from practice then had nude body mass assessed in the same fashion as pre-practice. Next, players completed the sweat loss estimation procedures. This process involved the players individually being presented with a large stack of empty papers cups that each would hold ~250 mL of water. Two, 3.75-liter jugs were also on the table. Players were asked to use the water in the jugs to fill the paper cups with the volume of water equal to their sweat losses incurred during practice. The cups were then assessed for mass in front of the players and the total mass of the fluid was described to the players in terms of volume to the nearest milliliter. Participants were allowed to adjust the volume of water in the cups at this point if desired. Participants were instructed to not discuss their estimations with teammates.

Statistical Analyses

All data analyses were performed using IBM©, SPSS© Statistics version 26. Data are reported as mean ± SD. One-way repeated measures ANOVA was used to compare differences in sweat loss, fluid intake, and sweat loss estimations across practice sessions. Mauchly's test was used to determine sphericity. Greenhouse-Geisser adjustments were made if applicable when determining significance of main effects. Bonferroni corrections were used for all post hoc comparisons. Estimated sweat loss volumes and actual sweat losses for each practice were compared using paired t tests. An a priori alpha level ≤ 0.05 was considered to represent statistical significance.

Results

Sweat loss and sweat loss as percent body mass both exhibited main effects for practice sessions ($p < 0.01$) with all practices differing from each other (Table 2). Practice fluid intake was lower during the afternoon practice, but neither morning practices differed from each other (Table 2). Sweat loss accuracy did not differ among practices (Table 2). Estimated sweat losses were less than actual sweat losses for all three practices (Figure 2).

Table 2. Fluid intake and sweat loss outcomes (n = 17; mean ± SD).

	P1	P2	P3
Fluid intake			
during practice (L)	1.823 ± 0.757^{B}	0.922 ± 0.569^{A,C}	2.190 ± 0.524^{B}
Sweat loss			
loss (kg)	2.181 ± 0.693^{B,C}	1.710 ± 0.474^{A,C}	3.361 ± 0.956^{A,B}
% body mass	2.98 ± 0.88^{B,C}	2.31 ± 0.59^{A,C}	4.51 ± 1.06^{A,B}
estimated (kg)	0.804 ± 0.329^{C}	0.672 ± 0.324^{A,C}	1.076 ± 0.489^{B}
accuracy (%)	40.2 ± 21.5	40.1 ± 19.9	31.8 ± 11.6

^{A} = different from P1; ^{B} = different from P2; ^{C} = different from P3 ($p < 0.05$).

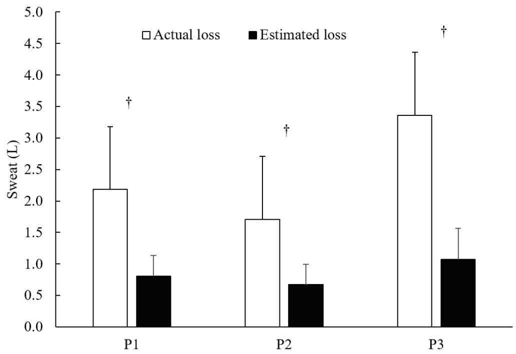


Figure 2. Comparison of absolute sweat losses to sweat loss estimates (n = 17; mean ± SD). † = ($p < 0.01$). P = practice session..

Discussion

This study was the first investigation to our knowledge that examined soccer athletes' abilities to estimate their sweat losses during hot training conditions at any level of competition. Furthermore, estimation consistency was also able to be compared during practices of the same duration but with different volumes of sweat loss due to differences in environments or training intensity. The main findings confirmed our hypotheses that players would consistently and greatly underestimate their sweat losses across practices regardless of sweat volume produced based on environmental and practice activities (Table 2 and Figure 2). It is well established that soccer training and competition in the heat can produce significant sweat losses. Professional and international level soccer competitions often take place in thermoregulatory challenging conditions. For example, the 2022 World Cup will be played in Qatar where regional soccer match environments can average temperatures of 45 °C and produce match sweat losses exceeding 3 L (Al-Jaser & Hasan, 2006). Castro-Sepulveda, Astudillo, Letelier, and Zbinden-Foncea (2016) reported over 50% of internationally competitive female soccer players arrived for practice or formal matches presented USG values exceeding 1.030 when living and training in hot climates. While training in cooler environments reduces odds of rampant team dehydration based on urinary hydration indicators (Gibson, Stuart-Hill, Pethick, & Gaul, 2012; Klimesova et al., 2022), formal collegiate soccer training and competition in the United States begin in late summer. These increased temperatures create a significant hydration challenge for many athletes. It is possible that athletes might adjust their fluid intake more adequately if they are aware of their actual sweat loss volume from training.

In this study, the mean sweat loss during the most intense and thermoregulatory challenging practice (P3) exceeded 3 L and 4% of body mass (Table 2). During P2, a cold front and thunderstorm altered environmental conditions which cut sweat losses in half even though practices were of the same duration and separated by only one week (Table 2). The positive takeaway from the sweat loss estimation of the athletes across practices is that estimated volume in absolute terms trended to match the increase or decrease of sweat loss volume (Table 2), and that the relative estimations (i.e. percentage of underestimation; Figure 2) did not change across practices. In summary, players were aware of when they were sweating more or less in relative terms. However, these sensitive adjustments in sweat loss estimation were essentially meaningless due to the vast underestimations of absolute sweat loss volume (Table 2; Figure 2).

While no comparisons can be made to female soccer players or soccer players at other competition levels, past evidence suggests extrapolation to these other populations is reasonable. Male and female, NCAA Division II basketball players underestimated their in-season practice sweat loss by ~30% and 65%, respectively (Thigpen et al., 2014). Both men's and women's NCAA Rugby Union players were found to also underestimate their practice sweat losses by 47 and 79% (Muth et al., 2019). In the only other team sport sweat loss estimation study we are aware of, Love et al. (2018) found professional rugby players exhibited some of the greatest and consistent sweat loss underestimations ever reported at 73 ± 17%. Despite greater chance of exposure to hydration education, these 38 professional, male rugby players were much less accurate estimators of their sweat losses than almost all cohorts of amateur athletes across a variety of training types (O'Neal et al., 2020).

In regards to consistency of estimations, only two studies are available in which duration and physical activity demands are similar between trials. Shaver et al. (2018) found female runners consistently underestimated sweat losses by half or more when completing two outdoor 15-km runs in similar, temperate environmental conditions. Davis and colleagues (2019) altered well-trained, male runners' sweat losses by controlling room temperature during 1-h treadmill runs of the same pace. In agreement with the current investigation, the runners estimated greater absolute sweat losses during the warmer condition, and mean estimation accuracy by percentage did not differ (62 vs 65% of actual sweat loss). Based on our extensive research history on sweat loss estimation accuracy, we do not believe that sweat loss volume is not on the forefront of athletes' minds. However, the consistency across studies suggests that when asked, athletes have a somewhat fixed, albeit incorrect, estimation volume developed.

A recent meta-analysis (Chapelle et al., 2020) concerning soccer hydration profile confirms that most research has focused on professional (Aragón-Vargas, Moncada-Jiménez, Hernández-Elizondo, Barrenechea, & Monge-Alvarado, 2009; Duffield, McCall, Coutts, & Peiffer, 2012; Kiitam et al., 2018; Voitkevica, Pontaga, Timpmann, & Ööpik, 2014) and youth (Arnaoutis et al., 2013; Phillips, Sykes, & Gibson, 2014; Silva et al., 2011; Williams & Blackwell, 2012) level soccer competitors. There is a lack of investigations examining hydration profiles for NCAA soccer players, but hydration research is expanding for both men's (Sekiguchi et al., 2019) and women's (Clarke, Carpenter, Spain-Mansmann, Taylor, & Schubert, 2021a; Mattausch, Domnik, Koehler, Schaenzer, & Braun, 2017; Wainwright et al., 2020; Wang et al., 2020) teams. Collegiate soccer players have continual contact with athletic trainers, and a growing number of universities are now employing registered sport dieticians, creating an excellent environment for hydration education interventions. A recent intervention with players preparing for United European Football Association matches found the rate of players reporting with high USG could be drastically reduced by educational seminars and alerting players to their actual pre-activity USG values (Mohr, Nólsøe, Krustrup, Fatouros, & Jamurtas, 2021). Intentional and focused hydration intervention based on pre-activity USG has also been found to be efficacious on a small scale for collegiate women soccer players (Mattausch et al., 2017). The current authors propose that if widespread dehydration is repeatedly detected for collegiate soccer players using urine color or specific gravity, athletic training and nutrition staff should consider taking steps to develop a sweat loss profile that can be shared with athletes.

This is a fairly simple process that would likely not require significant financial or human resources. An assessment of nude body mass measured before and after practice would provide pertinent information in creating individual sweat loss profiles for athletes. This process can be completed quickly by appropriate personnel (i.e. sport nutrition staff, not coaches) with a digital scale placed in a privacy room and scale reader located outside the room. Collegiate athletes almost universally drink from their own water bottles during practice, which can easily be weighed pre- and post-practice to offset fluid intake when calculating change in body mass to determine sweat losses. Players should be informed to not spit

DOI 10.26773/mjssm.220908

out or spray their bottled fluids on themselves during practice. Additionally, players should also be encouraged to complete a void prior to initial weigh-in so urinary or fecal losses do not result in calculation errors. To further simplify the process, data collection could take place with smaller groups during a practice versus trying to test all team members at once.

It is important to also consider practice conditions as environment and duration will impact sweat loss. Sweat loss estimate procedures conducted during moderate and high thermoregulatory challenging conditions based on the team's local climate could help provide fluid intake recommendations more accurately reflecting real time practice sweat losses without repeatedly completing sweat loss determination protocols. Individual player sweat loss rate profiles for time could also be easily calculated for practices of different duration. The same procedures could also be undertaken during exhibition matches early in the season with considerations based on playing time.

In summary, soccer players consistently and vastly underestimate their sweat losses across a variety of practice conditions. Soccer players training in the heat are highly susceptible to begin training in a state of dehydration. Individual hydration plans for both during and between practices can be developed by sports medicine staff without significant cost or time by devolping a sweat loss profile for players. Visually displaying sweat loss volume for each player by depicting their volume of sweat loss in terms of their practice beverage bottles might reinforce the volume of fluid athletes should attempt to consume during and between training or competition bouts. Environmental factors are the major limitation of the current study. Soccer players may have different prediction accuracy levels when training in cool or cold environments or environments with very low humidity levels, unlike those experienced in the current study. Although the literature does not support differences in estimation accuracy based on competition level of team sport athletes or on basis of sex, professional or female soccer players may not underestimate sweat losses in a similar pattern as male, collegiate soccer players. Future investigations are warranted to determine if other soccer populations experience similar underestimation values as displayed in this study and if estimations differ based on environmental conditions. Whether sweat loss estimates influence fluid intake of soccer players or if sweat loss estimation accuracy hydration education can improve individual and team hydration levels is also worth being explored.

References

Al-Jaser, T. A., & Hasan, A. A. (2006). Fluid loss and body composition of elite Kuwaiti soccer players during a soccer match. *J Sports Med Phys Fitness, 46*(2), 281-285. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/16823359

Ali, A., Gardiner, R., Foskett, A., & Gant, N. (2011). Fluid balance, thermoregulation and sprint and passing skill performance in female soccer players. *Scandinavian journal of medicine & science in sports, 21*(3), 437-445.

Aragón-Vargas, L. F., Moncada-Jiménez, J., Hernández-Elizondo, J., Barrenechea, A., & Monge-Alvarado, M. (2009). Evaluation of pre-game hydration status, heat stress, and fluid balance during professional soccer competition in the heat. *European Journal of Sport Science, 9*(5), 269-276.

Arnaoutis, G., Kavouras, S. A., Kotsis, Y. P., Tsekouras, Y. E., Makrillos, M., & Bardis, C. N. (2013). Ad libitum fluid intake does not prevent dehydration in suboptimally hydrated young soccer players during a training session of a summer camp. *Int J Sport Nutr Exerc Metab, 23*(3), 245-251. doi:2011-0189 [pii]

Castro-Sepulveda, M., Astudillo, J., Letelier, P., & Zbinden-Foncea, H. (2016). Prevalence of Dehydration Before Training Sessions, Friendly and Official Matches in Elite Female Soccer Players. *J Hum Kinet, 50*, 79-84. doi:10.1515/hukin-2015-0145

Chapelle, L., Tassignon, B., Rommers, N., Mertens, E., Mullie, P., & Clarys, P. (2020). Pre-exercise hypohydration prevalence in soccer players: A quantitative systematic review. *Eur J Sport Sci, 20*(6), 744-755. doi:10.1080/1746 1391.2019.1669716

Clarke, H. E., Carpenter, R. S., Spain-Mansmann, K., Taylor, J. K., & Schubert, M. M. (2021a). Estado de Hidratación de Jugadoras de Fútbol Universitarias Durante Días de Entrenamiento y Partidos Consecutivos. *MHSalud, 18*(1), 154-164.

Clarke, H. E., Carpenter, R. S., Spain-Mansmann, K., Taylor, J. K., & Schubert, M. M. (2021b). The Hydration Status of Female Collegiate Soccer Players Over Consecutive Training and Match Days. *MHSalud: Revista en Ciencias del Movimiento Humano y Salud, 18*(1), 1-11.

Davis, B. A., O'Neal, E., Johnson, S., & Farley, R. S. (2019). Hot Training Conditions Inhibit Adequate Ad Libitum Recovery Fluid Intake of Runners. *International Journal of Exercise Science, 12*(6), 1322-1333.

Duffield, R., McCall, A., Coutts, A. J., & Peiffer, J. J. (2012). Hydration, sweat and thermoregulatory responses to professional football training in the heat. *Journal of Sports Sciences, 30*(10), 957-965.

Edwards, A. M., Mann, M. E., Marfell-Jones, M. J., Rankin, D. M., Noakes, T. D., & Shillington, D. P. (2007). Influence of moderate dehydration on soccer performance: physiological responses to 45 min of outdoor match-play and the immediate subsequent performance of sport-specific and mental concentration tests. *Br J Sports Med, 41*(6), 385-391. doi:bjsm.2006.033860 [pii]
10.1136/bjsm.2006.033860

Gibson, J. C., Stuart-Hill, L. A., Pethick, W., & Gaul, C. A. (2012). Hydration status and fluid and sodium balance in elite Canadian junior women's soccer players in a cool environment. *Applied Physiology, Nutrition, and Metabolism, 37*(5), 931-937.

Kiitam, U., Voitkevica, L., Timpmann, S., Pontaga, I., Ereline, J., Unt, E., & Ööpik, V. (2018). Pre-Practice Hydration Status in Soccer (Football) Players in a Cool Environment. *Medicina (Kaunas), 54*(6), 102.

Klimesova, I., Krejci, J., Botek, M., McKune, A. J., Jakubec, A., Neuls, F., . . . Valenta, M. (2022). Prevalence of Dehydration and the Relationship with Fluid Intake and Self-Assessment of Hydration Status in Czech First League Soccer Players. *Journal of Human Kinetics, 82*(1), 101-110.

Love, T. D., Baker, D. F., Healey, P., & Black, K. E. (2018). Measured and perceived indices of fluid balance in professional athletes. The use and impact of hydration assessment strategies. *Eur J Sport Sci, 18*(3), 349-356. doi:1 0.1080/17461391.2017.1418910

Mattausch, N. R., Domnik, K., Koehler, K., Schaenzer, W., & Braun, H. (2017). Case study: Hydration intervention improves pre-game hydration status in female collegiate soccer players. *International journal of sport nutrition and exercise metabolism, 27*(5), 475-481.

McDermott, B. P., Anderson, S. A., Armstrong, L. E., Casa, D. J., Cheuvront, S. N., Cooper, L., . . . Roberts, W. O. (2017). National Athletic Trainers' Association Position Statement: Fluid Replacement for the Physically Active. *J Athl Train, 52*(9), 877-895. doi:10.4085/1062-6050-52.9.02

McGregor, S. J., Nicholas, C. W., Lakomy, H. K., & Williams, C. (1999). The influence of intermittent high-intensity shuttle running and fluid ingestion on the performance of a soccer skill. *J Sports Sci, 17*(11), 895-903. doi:10.1080/026404199365452

Mohr, M., Nólsøe, E. L., Krustrup, P., Fatouros, I. G., & Jamurtas, A. Z. (2021). Improving hydration in elite male footballers during a national team training camp–an observational case study. *Physical activity and nutrition, 25*(4), 10.

Muth, T., Pitchett, R., Pritchett, K., DePaepe, J., & Blank, R. (2019). Hydration Status and Perception of Fluid Loss in Male and Female University Rugby Union Players. *International Journal of Exercise Science, 12*(3), 859.

O'Neal, E., Boy, T., Davis, B., Pritchett, K., Pritchett, R., Nepocatych, S., & Black, K. (2020). Post-Exercise Sweat Loss Estimation Accuracy of Athletes and Physically Active Adults: A Review. *Sports, 8*(8), 113.

Phillips, S. M., Sykes, D., & Gibson, N. (2014). Hydration status and fluid balance of elite European youth soccer players during consecutive training sessions. *J Sports Sci Med, 13*(4), 817.

Sekiguchi, Y., Adams, W. M., Curtis, R. M., Benjamin, C. L., & Casa, D. J. (2019). Factors influencing hydration status during a National Collegiate Athletics Association division 1 soccer preseason. *J Sci Med Sport, 22*(6), 624-628. doi:10.1016/j.jsams.2018.12.005

Shaver, L. N., O'Neal, E. K., Hall, E. E., & Nepocatych, S. (2018). No Performance or Affective Advantage of Drinking versus Rinsing with Water during a 15-km Running Session in Female Runners. *Int J Exerc Sci, 11*(2), 910-920. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/30147823

Silva, R. P., Mündel, T., Natali, A. J., Bara Filho, M. G., Lima, J. R., Alfenas, R. C., . . . Marins, J. C. (2011). Fluid balance of elite Brazilian youth soccer players during consecutive days of training. *Journal of Sports Sciences, 29*(7), 725-732.

Thigpen, L. K., Green, J. M., & O'Neal, E. K. (2014). Hydration profile and sweat loss perception of male and female division II basketball players during practice. *J Strength Cond Res, 28*(12), 3425-3431. doi:10.1519/JSC.0000000000000549

Voitkevica, L., Pontaga, I., Timpmann, S., & Ööpik, V. (2014). Pre-training hydration status of well-trained soccer players in moderate temperature autumn and cool winter. *Baltic Journal of Sport and Health Sciences, 4*(95).

Volpe, S. L., Poule, K. A., & Bland, E. G. (2009). Estimation of prepractice hydration status of National Collegiate Athletic Association Division I athletes. *J Athl Train, 44*(6), 624-629. doi:10.4085/1062-6050-44.6.624

Wainwright, J. B., Wallen, J. N., Sanchez, A. M., DeAnda, N., Gonzales, X. F., Willoughby, D. S., . . . Newmire, D. E. (2020). *The Assessment of Hydration Status and Renal Markers Associated with Acute Kidney Injury in NCAA Division I Female Soccer Players During Preseason Training in South Texas: A Pilot Study.* Paper presented at the International Journal of Exercise Science: Conference Proceedings.

Wang, H., Early, K. S., Theall, B. M., Lowe, A. C., Lemoine, N. P., Marucci, J., . . . Johannsen, N. M. (2020). Effects of field position on fluid balance and electrolyte losses in collegiate women's soccer players. *Medicina (Kaunas), 56*(10), 502.

Williams, C. A., & Blackwell, J. (2012). Hydration status, fluid intake, and electrolyte losses in youth soccer players. *International Journal of Sports Physiology & Performance, 7*(4).

DOI 10.26773/mjssm.220908

REVIEW

Ancient Boxing: A Narrative Discussion from Archaeological and Historical Evidences

Muhammad Shahidul Islam[1], Anup De[2]

Affiliations: [1]Deputy Director, Office of Physical Education, Shahjalal University of Science and Technology, Sylhet, Bangladesh, [2]Former Research Scholar, Department of Physical Education and Sport Science, Visva-Bharati University, Santiniketan, West Bengal, India.

Correspondence: Dr. Anup De, Former Research Scholar, Department of Physical Education and Sport Science, Visva-Bharati University, Santiniketan, West Bengal, India. Email- anupde2013@gmail.com

Abstract

Boxing is one of the most popular and ancient striking combat sports where two athletes, generally wearing protective gloves, throw punches at each other in a boxing ring for a specified amount of time. Boxing has a golden history that dates back thousands of years, not just hundreds. The most famous evidence of fighting sporting competitions goes back to ancient civilizations: the civilizations of Mesopotamia, Egypt Civilization, Minoan Civilization, Greece Civilization, and Roman Civilization. The present investigation was designed to understand the evolution and pattern of boxing games in the ancient world. This study finds that one of the earliest ancient boxing depictions appeared in a terracotta relief based on ancient Eshnunna, a limestone plaque based on the early Dynastic periods of Sumeria, a terracotta tablet was discovered in a tomb near Larasa in southern Iraq, and many more. The study analyzes the extensive literature on the Greek statue of a sitting nude boxer and explains its existence, face, cauliflower-like ear. The study reported some distinguished observations concerning winning rules, awards, gloves, and injuries in ancient boxing. In essence, the current investigators believe that the most notable findings of this study were that no boxing ring was mentioned in literature, the majority of boxers (males) wore beards, and the majority of ancient battles were depicted on ancient Greek pottery. There was bleeding and facial injuries as the sport was very brutal at that time.

Keywords: *Boxing, Ancient civilization, Archaeological investigation, Ancient Greek pottery, Sports injury*

@MJSSMontenegro
ANCIENT BOXING
http://mjssm.me/?sekcija=article&artid=244

Cite this article: Islam, M.S., & De, A. (2022) Ancient Boxing: A Narrative Discussion from Archaeological and Historical Evidences. *Montenegrin Journal of Sports Science and Medicine*, 11 (2), 71–78. https://doi.org/10.26773/mjssm.220909

Introduction

Frequent body contacts, intermittent games, and high-intensity sports are very widespread in modern times (Islam & De, 2018). The requisite motor skills (Islam et al., 2019; Roy & De, 2018), mental skills (Liew et al., 2019), psychological skills (Birrer & Morgan, 2010), brain functions (De & Mondal, 2016), kinesthetic perception (De & Ghosh, 2016), and intelligent movements (Islam, 2020) are needed to execute these games and highly intensify sports. Boxing is one of the most recognized combat sports by the spectator in the present world. Nowadays boxing champions make more money than any other professional athletes. The biggest battle of this big money era was the Mayweather Vs Pacquiao event in 2015, which won an estimated $120 million for Mayweather and

Received: 2 April 2022 | Accepted after revision: 10 August 2022 | Early access publication date: 30 August 2022 | Final publication date: 1 September 2022

© 2022 by the author(s). License MSA, Podgorica, Montenegro. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY).

Conflict of interest: None declared.

about $80 million for Pacquiao but in order to understand the history of boxing, we must go back not only hundreds but thousands of years (Cowie, 2018).

Boxing was a popular sport prior to the birth of Jesus Christ. All day long, boxing attracted spectators, including the elites. In the ancient Near East, this was one of the most well-known competitive sports. The earliest physical boxing evidence was found in Mesopotamia. According to Murry, the origins of boxing as a sport were in ancient Mesopotamia. Ancient carvings from the third and second millennia BCE demonstrate that Mesopotamia was familiar with boxing long before ancient Egypt (Murray, 2010). Some of the ancient limestone plaques, terracotta reliefs, and terracotta tablets exist as physical evidence for the ancient boxing game, and these antiquities discussed in the next chapter.

Boxing, one of the hardest high-intensification sports (Stevens, 2020), has been played around for thousands of years, becoming an official Olympic event in 688 B.C.E. (Before Common Era). There is still evidence of boxing in Ancient Egypt (Halperin et al., 2016; What Is Boxing?, 2003). However, boxing is mentioned in Homer's Iliad and was practiced at the Olympics beginning in the seventh century B.C. (Before Christ). The art of boxing, whereby two men enter a contest to see who can withstand the most punches from the other, dates back at least as far as the earliest civilisations and is probably one of the oldest sports of its kind in the history of fighting. Boxing throughout Ancient Crete was conducted around 1500 BC as it accompanied the spread of Egyptian society across the eastern Mediterranean.

Some of the most well-known representations of the ancient world can be found in the Bronze Age, 1700 BCE. To around 1600 BCE., frescoes from Akrotiri on the Aegean Island of Thera (wall paintings). This is a prime example of Minoan artwork. The frescoes at Akrotiri serve a purpose that is summarized by Dr. N. Marinatos as being much more than merely aesthetic works of worth. She persuasively contends that the frescoes had a connection to the function of the room in which they were painted:

The fresco, which is from Building Beta's Room B1, shows two young people engaged in ceremonial boxing rather than a match. The red coloring, which is customary when depicting men, suggests that the boxers are male. Only a belt and loincloth are worn by them, along with a boxing glove on their right hand. As a show of youth, their hair features long tresses with shaved sections. Contrary to his opponent, the boy on the left is accessorized with a necklace, earrings, bracelets, and anklets. Maybe this boxing scene is more of a ritual sport than a competitive match. It's interesting to note that the young age of the participants in the Akrotiri Boxer Fresco suggests that training for sports began quite early in life (Mark, 2014).

People all over Greece submitted their offerings to the Gods. Throughout these festivals, mass people observed the religious rituals that lasted one night and one day, and often had to be planned for three to five days for different competitions. However, the feature of these events' programs changed year after year. It is important to distinguish two categories of competitions: one dedicated to sports, and another dedicated to music and recitation. Competitive sports include horse and chariot races and combat sports involving boxing, wrestling, pankration (a mixture of boxing and wrestling) and pentathlon, a five-contest series: broad jump, foot races, discos, wrestling, and javelin. Boxing is presumably one of the most recognizable combat sports in the ancient world. So the features and attributes of ancient boxing are at present increasing the importance of investigation (Bothmer, 2010).

About a thousand years later, in 686 BC, boxing was brought to the Greek Olympic Games where the temptation of fame and riches motivated the competitors to compete (Brice et al., 1993).

The Roman historian Tacitus (c. 56–c. 118 CE) held that future generations should prioritize Roman fighting above all else; he did not want recreational training to take precedence over military preparation. On the other hand, it is known that Augustus (r. 27 BCE–14 CE) was a fan of boxing. Rome's fondness for boxing over other sports was probably brought over by the Etruscans. Contrary to Greek thinking, many Romans grew increasingly sceptical of boxing as it was perceived as a formal, sophisticated sport governed by regulations (V. Matthew, 2020). According to the Roman poet Horace, after the Romans conquered Greece in the second century BC, "Captive Greece captivated her wild conqueror" (Letters 2.1.156). Greek boxing underwent a metamorphosis as a result of Roman control. The sacred Greek games, which included boxing matches to commemorate each unique Greek polis, would now serve the new Roman emperors and meld with Roman traditions. Roman boxing (Pugilatus), which may have descended from early Etruscan versions, has been a part of athletic competitions at the Ludi (state-sponsored games) and Munera since the sixth century BC (Nakamura, 2019).

Altogether, the purpose of this study is to explain the evolution and pattern of the boxing game in the ancient world. In this investigation the researchers collected the information from archaeological findings which are written by secondary sources such as journals, research papers, books, public and official documents, websites, photographs, videos etc. The study covers the evolution of boxing of archaeological and historical literature from the first civilizations of Mesopotamia to the ancient Rome.

Foremost Representations of Ancient Boxing

Boxing has a long storied history. Its origins can be traced as far back as ancient Mesopotamia, where a terracotta relief was discovered, that depicts men boxing (Figure 1).

Though boxing, much older, has given the fact that the act of striking another with one's fist is simply a basic defensive (as well as offensive) mechanism for survival (Murray, 2010). The literary and archaeological evidence, left by the ancients, provides much detail about the boxing game.

One of the first representations of boxing in ancient times appears in a terracotta relief found of two Mesopotamians from the early third or second millennium B.C.E. that was discovered in ancient Eshnunna (now at Tell Asram, Iraq) (Murray, 2010). Researcher Murray (2010) also revealed that, the two boxers, bearing beards and carrying tunics, meet each other with bent arms and clinched fists; each is ready to deliver or withstand a strike. Neither is wearing gloves but both are equipped with some kind of band worn around the wrist, presumably for anatomical support. One of the most obvious other depictions of boxing in Mesopotamia may be a limestone plaque with three registers. It is now on display in the Iraq Museum and dates to the early Dynastic periods of Sumeria, roughly 3000–2340

 DOI 10.26773/mjssm.220909

Figure 1. Depiction of ancient boxing on Mesopotamian Terracotta relief (Circa 2000 B.C.E.) Source: https://twitter.com/hashtag/eshnunna

BCE (No. 9012). In the third register, two boxers and two musicians are seen. With the exception of gloves and cache-sex, both boxers are nude. They adopt positions that are reminiscent of modern boxing matches (Mohamed, 2020). There are various interpretations of the depictions of the delicate fragment of terracotta relief that was found in the Nintu temple in "Khafaji" and dates to the early Sumerian dynastic eras, roughly 3000–2340 BCE. The right of this tableau depicts two sportsmen facing one another and holding each other by the arms, similar to the preceding limestone plaque. The athlete on the left in the main picture looks to have been knocked off by his opponent by grabbing his leg, and he is now tumbling to the ground. According to investigator Murry, the two people on the right are boxers (Festuccia, 2016; Murray, 2010). Another ancient Babylonian-era terracotta tablet was discovered in a tomb near Larasa in southern Iraq (2000–1595 BCE). On this tablet, two men were playing boxing while dressed in hats and tunics. The boxers are using bare hands. Surprisingly, two musicians playing instruments demonstrated that ancient boxing games from the ancient Near East, like bull leaping, were accompanied by music (Mohamed, 2020).

Evolution and Pattern of Ancient Boxing Gloves

In modern times, for a number of combat sports, boxing gloves are one of the most important pieces of equipments. The gloves are both covering boxer hands from being hurt and damaging the opponent. Researchers noted that the boxing gloves trend has been evolved from the traditional gloves of the past. Traditional gloves were just bound around the palms and the fingertips were free. Binding leather strips around the hands for protection was common practice in ancient Greece. However, in Roman times, this became the gladiatorial cestus with copper being glued to the hands to cause greater damage. As we found from secondary sources that in ancient Roman times, it was common practice to tie strips (Hugh, 1911). Interestingly, boxing gloves appear on a stone plaque between 3000 and 2350 BCE on the first boxing artefact. However, no evidence of boxing gloves was found in ancient Egypt's civilization. Gloves were used in the Minoan civilizations, but boxers only had a bandage on one hand. On the other hand, there is evidence of gloves on pottery from the Mycenaean civilization (Murray, 2010). In addition, the Roman version used belts of various lengths, often to the wrist, to shield the forearm while hard hits were being guarded (Cowie, 2018). Caestus was commonly used in Roman gladiatorial combat against each other and against other weapon-wearing gladiators. While other styles of gladiators seem to intersect, a single hit from a caestus would have harmed most fighters (Hugh, 1911).

Characteristics of Ancient Roman Leather Gloves

Present researchers claimed that the combat fighting took place in ancient Roman times and it was very deadly. The oldest surviving specimen of boxing gloves dated back to about 120 anno domini (AD), originating in the shape of two non-matching leather bands were found from archaeological excavations at Vindolanda's Roman castle ("Boxing Glove," 2020). However, ancient Roman leather gloves have been found near the United Kingdom (UK) wall of Hadrian. The gloves were found by archaeologists during a summer excavation of Vindolanda, a Roman fort South of Hadrian's Wall. Unlike the modern boxing glove, the ancient examples have the appearance of a protective guard, designed to fit snugly over the knuckles protecting them from impact. According to the Vindolanda Trust, boxing was a well-documented ancient sport that proceeded the Roman era. In the context of the Roman Army, it was a recorded pursuit, a martial activity designed to increase the skills and fitness of the boxers (Borkhataria, 2018).

Boxing gloves, found at the Roman site of Vindolanda in Northumberland, England, hint at tales of soldiers increasing their battle skills, keeping up their fitness, and passing the time gambling on fights while stationed in the far northern lands of the empire (Little, 2018). The summer of 2017 was a remarkable one for Vindolanda Archaeologists. While exploring the ruins of the Roman site near Hadrian's wall, they unearthed a wealth of artifacts. But one specific finding was the undisputed champion, a pair of one of kind boxing gloves that have rolled with the punches of time (Rogers, 2018). The boxing gloves are not only noteworthy for outstanding preservation but Vindolanda Trust reports that they are an extremely rare discovery. A press release on the Roman artifacts states, "Research of the objects at Vindolanda along with the considered observations by Roman leather and other experts have indicated that these leather objects are in fact boxing gloves and probably the only known surviving examples from the Roman period." the two gloves were found in a location identified as the cavalry barracks of the Vindolanda fort. The boxing gloves date to approximately 120 AD and are a testament to sparring matches which probably took place amongst members of the garrison. Patricia Birley, former director of the Vindolanda Trust who has now focused on conservation and research at the site, has told ChronicleLive, "Boxing is an ancient sport and it was practised in the Roman army as a keep fit exercise and probably in combat contests between units, rather like the way the modern army still has its tournaments" (Bernal, 2018; Henderson, 2018).

Description of Ancient Boxer

In 1885, the bronze statue (Figure 2) 'Boxer at Rest' was excavated in Rome on the southern slope of Quirinal Hill, near Constantine's ancient baths.

The date of the statue, which is most likely between the late fourth and second century B.C., was long debated by researchers. The sculpture is an outstanding bronze work from the Hellenistic period (323-31 B.C.) and is of extraordinary artistic merit (The Boxer: An Ancient Masterpiece, 2013). Another curious feature of this statue is its sitting at all. This is a paradox in several respects. A boxer is an athlete, and should be in action. The figure is however seated and in rest. A traditional depiction of an athlete can be in action but with a broken nose and swollen spots, he shows signs of weakness (Olson, 2016).

Figure 2. The Greek sculpture of a sitting nude boxer (c. 330 to 50 B.C.E., Hellenistic Kingdom)
Source: https://www.metmuseum.org/blogs/now-at-the-met/features/2013/the-boxer

The musculature and textures are detailed and idealized but not exaggerated too much. With a furrowed brow his look on his face reveals emotion (Olson, 2016). The several wounds to his face, head, back and the primary focus of ancient Greek boxing fights make it clear that he has just finished a fight. Blood depicted by inlaid copper drips on his forehead from cuts, cheeks and ears. The right eye of boxers gets swollen and bruised. His nose is broken, and he is breathing through his mouth, presumably because blood covers his nostrils (Hemingway, 2013).

Cauliflower Ear of the Ancient Boxer

For some sports, such as boxing, rugby, judo and wrestling, a typical external ear deformity is reported, known as cauliflower ear (Noormohammadpour et al., 2015). This deformity can also take place when defensive ear guards are used. The damage or inflammation injures the cartilage of the ear, disrupts the blood flow from the eye, frequently creating a large pool of blood, called a hematoma. When the ear injury recovers, it is compress and fold in on itself and appears translucent, giving it a cauliflower-like look, hence the word ear (Cunha, 2018).

It should be remembered that the bronze statue of the ancient seated boxer had cauliflower ear. The ears certainly appear swollen and bleeding in what's generally referred to as the 'cauliflower ear' (Palmquist, 2013). The cauliflower ear represented that the ancient boxer had ear cartilage damage. In present time boxers, wrestlers, and martial artists in particular are susceptible to this type of injury. So, cauliflower ear is sometimes also called the ear of a boxer or wrestler (Cunha, 2018).

Ancient Boxing Winning Rules

Since the exact rules of boxing in antiquity are unknowable, historical evidence and archaeological photographs are used as interpretations. In the 23rd Olympic Games (688 BCE) a man called Onomastos freom Smirna drew up the rules for ancient Olympic boxing, but no description of his rules has come down to the present day (Poliakoff, 2004). Although it was not permitted to use the hands to overwhelm the eyeballs, it is reported that any kind of hand blow was allowed. At Olympia, the boxing laws imposed by the referees are nominal. Boys and adults played in different competitions much as in other disciplines. There were no weight divisions that saved the welterweight from crippling heavyweight blows. Clinching (the act of gripping the opponent's body in order to slow down a fight) was forbidden and the amphora painting revealed representations of judges using their sticks to execute these offences. The idea of a point win or a judge's opinion is new, not ancient. The defeated warrior may hold up a finger in the absence of a knockout to signify surrender, a moment sometimes

DOI 10.26773/mjssm.220909

used in Greek vase paintings (Poliakoff, 2018). Because of the few internet sources and references to the sport, the laws can only be indirect which are following:

- There was no retaining in the old boxing game, rather than Pankration (a combination of boxing and wrestling).
- No ring was used as we considered none of the photos that could show the certain boxing room and ring had been set.
- The former fighting had no frames or time limits.
- Victory was determined when one competitor quit or showed any finger or lifting index finger high, indicates giving up (c. 500 BCE) from the bout.
- Weight level classes not specified, competitors were chosen by chance.
- Fighters could choose to exchange blows without defence (Ancient Greek Olympics -The First Olympic Games in Greece, 2018).

Ancient Boxing Prizes

Danny Mack Gable (a former American wrestler and coach) stated, "Gold medals aren't really made of gold. They're made of sweat, determination, and a hard-to-find alloy called guts" (Gable, n.d.). Therefore, rewards, and prizes are not the athletes' economic benefit factor alone. The analysis of prizes and rewards is also required to learn the characteristics of hard work, dedication and athletic ability. Ancient boxing prizes can therefore play a significant role in understanding the athletic bravery. Victors' prizes were an important part of ancient athletics. Ancient people used wide mouthed, painted amphorae as decanters and were provided as prizes for combat sports. Noteworthy are the Nolan style (from Nola, Italy), some of which had triple handles common in red figure pottery; the panathenaic amphora, rendered in black-figure and shown at the Panathenaic festivals from the 6th to the 2nd century B.C. as a reward (full of olive oil and with the inscription "I am one of the prizes from Athens") (Pottery, 2010).

Significance of Ancient Greek Pottery in Boxing

A major draw was the 'strong' competitions at all Greek games - wrestling, boxing, and pankration. The pankration was a combination of boxing and wrestling that permitted virtually all techniques. This was wrong to just bit to head after an opponent's pupils. In a terracotta cup (figure-3), a couple of boxers are in a fight to the left. A pair of pancratiasts is down on the field in the middle. A discus lies in a basket above them (Olympic Games | Ancient Greece, n.d.).

Figure 3. The ancient Pankration was denoted as the mixture of boxing and wrestling (490-80 B.C.E.) Source: https://www.khanacademy.org/humanities/ancient-art-civilizations/greek-art/beginners-guide-greece/a/olympic-games

There are several ancient Greek amphorae (Figure 4) and terracotta vases which better explain how the ancient contests of boxing were fought than literatures. The participants seem to have been very bulky men in this sport (Upper 490 BC). The referee who is hitting the 'big' individual with his switch should he foul and the judge on the left announcing the win-

Figure 4. Depiction of ancient boxing on Greek Amphora (c. 332-331 B.C.E.)
Source: https://earlychurchhistory.org/entertainment/boxing-in-ancient-roman-world/

DOI 10.26773/mjssm.220909

ner (Ancient Roman Boxing, n.d.).

Black-figured amphora depicting a boxing match from Agrigento (Sicily), created in Athens around 550-500 BCE, signed by potter Nikosthenes. The boxers wearing himantes are about to exchange blows (leather thongs tied at the fist). The boxer already had a nose-bleed (Raddato, 2014) (Figure 5).

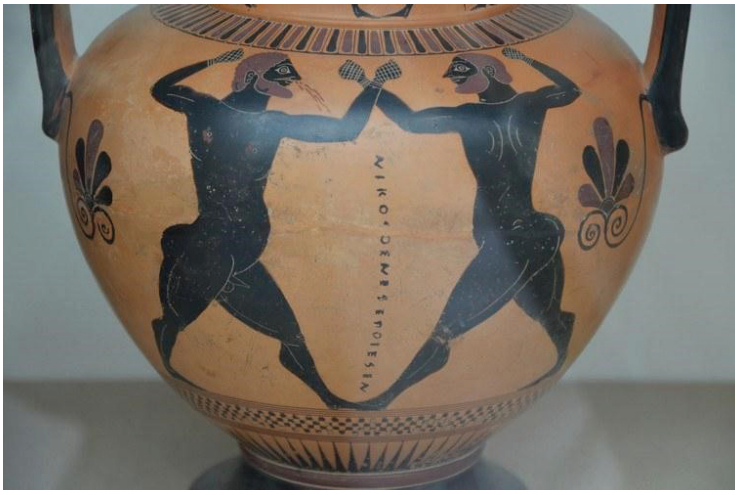


Figure 5. The nose-bleed from ancient boxer (on the left) (550-500 B.C.E., the 'Amphora' made in Athens)
Source: https://www.ancient.eu/image/2688/amphora-showing-a-boxing-contest/ Image credit Raddato, 2014

The amphorae were Panathenaic amphoraes, large ceramic vessels that contained the olive oil. This oil came from the sacred grove of Athena, and the writing of the Athenian prizes fell alongside it (Boardman, 1974). The world's leading expert on ancient Greek vases Dietrich von Bothmer (Grimes, 2009) suggested that in ancient Athens, two rival classes were distinguished; one was dedicated to athletics, and the other to recitation and music. The sports activities included horse and chariot races and athletic games, including boxing, foot races, wrestling, Pankration (a mixture of boxing and wrestling) (Bothmer, 2010). Vases in a variety of shapes that resembled boxing games were present. In his book, Poliakoff mentioned several pottery artworks that featured boxing scenes. It is assumed that the pottery was a reward to the ancient victor (Poliakoff, 2004).

Ancient Boxing Injury

The ever increasing popularity of sport around the world has made the 'sport industry' highly competitive and financially lucrative for athletes (Dhillon et al., 2017). However, sport injuries may occur through contact or non-contact mechanisms, and likely of an acute or overuse nature (Ardern et al., 2016). They may include muscle, ligaments or bone with stress fractures somewhat specific to sport and prolonged use (Dhillon et al., 2017). In boxing the injuries reflect various forms and degrees of trauma. The most vulnerable organs and tissues to this trauma bear the brunt. Boxing trauma most often affects the periorbital regions- the neck, mouth, nose, ears and hands of vulnerable and exposed areas (McCown, 1959).

Ancient combat sports showed physical ability, bravery; determination and the athlete didn't shy away from aggression or backed an opponent. Boxing, wrestling, and the Pankration were called the 'extreme events' barea athla, as the sports were dominated by tall, strong men, as in the ancient era there were no weight classes and fighters were of different dimensions (Jennings, 2016). In this period, to enhance the strength of the blow itself, boxer wrapped leather straps of rawhide leather, and/or cestus (copper being glued to the gloves) around their fists and up their arms. Probably the leather and/or cestus will cut in on the opponents face. Very often they would score a hit in the head, and blood could pour all over. Several ancient paintings of vases give a good example of the injury. Boxer could suffer a lot from the leather straps. Such paintings revealed that the boxer's face had several wounds with blood pouring from it. The thongs clearly increased the force of a blow (Murray, 2010). Indeed, the fight went on as usual until one of the protagonists succeeded in forcing his opponent to concede defeat or knock him unconscious. The Aeneid provides an in-depth description of an event between Epeus and Euryalus. The latter suffers a terrible hit that knocks him to the ground "nerveless and stretched," and Virgil paints a picture of the fighter being pulled from the ring by his buddies as follows:

"Nodding, his head hangs down his shoulder o'er:
His mouth and nostrils pour the clotted gore:
Wrapt round in mists he lies, and lost to thought;
His friends receive the bowl, too dearly bought." (Masterson, 1976).

The ancient seated boxer's bronze statue (323-31 B.C.) showed that the boxer's blow repeatedly struck both ear, nose, and face.

In addition to showing the structure and binding of the sharp thongs, The Pugilist by Apollonius, the sculpture of the ancient boxer who is seated, also depicts the wounds sustained by the boxers of the first century BC. The frontal and zygomatic bones of the skull have also been damaged at some point, and the face has scars and a broken nose. The swelling is in both ears are also visible (Gardiner, 1930; Harris, 1976; Masterson, 1976).

Similar wounds are shown on the bronze head of boxer Satyros by Silanion, but unlike the statue by Apollonius, which depicts some aristocracy, Satyros' unruly hair, beard, and sullen look are more emblematic of the cruelty to which the sport had gone by Hellenistic times (Masterson, 1976).

Highlighted Findings

At the ancient Olympic Games, only men served as judges; nevertheless, women were not allowed to compete. Another observation was that women were not even permitted to participate in sports. Therefore, the absence of female referees was

DOI 10.26773/mjssm.220909

reflected in antique pottery (Penjak & Karnincic, 2013).

On the other hand, there is something special about an ancient Greek event called the Heraea featured a footrace with young females. The race, which was staged in Olympia every four years, most likely occurred around the time of the first Olympic Games (D. Matthew, 2002).

The majority of the boxer was kept beard in the ancient Olympic game. Boxers' fingers were uncovered as though they were using some type of thong in their palm. Many of the traditional battles (boxing) were portrayed on ancient Greek pottery, especially on amphorae. Several paintings portrayed the ancient boxer's bleeding and facial injury. No archaeological discoveries support the presence of the boxing playing arena (boxing ring). Therefore, what amount of space was required for boxing fighting is a matter of debate.

Limitation

It is difficult to reconstruct ancient boxing sport on the basis of secondary sources.

Consent for Publication

Not applicable.

Funding

None.

Conflict of Interest

The authors confirm that this article content has no conflict of interest.

Acknowledgements

The present study has been developed from a number of archaeological images and literatures obtained from various electronic sources. We wish to thank the photographer for the ancient images used in this study, the documentarian and the literature writers. Without the analysis of archaeological images and valuable studies of ancient boxing, the research would have been impossible.

References

Ancient Greek Olympics -The First Olympic Games in Greece. (2018, December 20). International Olympic Committee. https://www.olympic.org/ancient-olympic-games

Ancient Roman Boxing. (n.d.). Retrieved May 3, 2020, from https://earlychurchhistory.org/entertainment/boxing-in-ancient-roman-world/

Ardern, C. L., Glasgow, P., Schneiders, A., Witvrouw, E., Clarsen, B., Cools, A., Gojanovic, B., Griffin, S., Khan, K. M., Moksnes, H., Mutch, S. A., Phillips, N., Reurink, G., Sadler, R., Grävare Silbernagel, K., Thorborg, K., Wangensteen, A., Wilk, K. E., & Bizzini, M. (2016). 2016 Consensus statement on Return to Sport from the First World Congress in Sports Physical Therapy, Bern. *British Journal of Sports Medicine*, *50*(14), 853–864. https://doi.org/10.1136/bjsports-2016-096278

Bernal, M. A. (2018, February 28). Mary Ann Bernal: Heavy Hitters: 2,000-Year-Old Boxing Gloves Suggest Roman Soldiers Used to Duke it Out. *Mary Ann Bernal*. http://maryannbernal.blogspot.com/2018/02/heavy-hitters-2000-year-old-boxing.html

Birrer, D., & Morgan, G. (2010). Psychological Skills Training as a Way to Enhance an Athlete's Performance in High-Intensity Sports: PST in High-Intensity Sports. *Scandinavian Journal of Medicine & Science in Sports*, *20*(2), 78–87. https://doi.org/10.1111/j.1600-0838.2010.01188.x

Boardman, J. (1974). Athenian Black-Figure Vases: A Handbook. *Antiquity*, *48*(192), 329–330. https://doi.org/10.1017/S0003598X00058440

Borkhataria, C. (2018, February 20). *Roman Boxing Gloves are Found Near Hadrian's Wall*. Mail Online. http://www.dailymail.co.uk/sciencetech/article-5412087/Roman-boxing-gloves-near-Hadrians-Wall.html

Bothmer, D. von. (2010). A Penathenaic Amphora. *The Metropolitan Museum of Art Is Collaborating with JSTOR to Digitize, Preserve, and Extend Access to The Metropolitan Museum of Art Bulletin*.

Boxing Glove. (2020). In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=Boxing_glove&oldid=946203081

Brice, M. J., Robins, S., Secretariat, E., Glanville, D. H., Mars, S., & Burton, L. (1993). *The Boxing Debate*. British Medical Association.

Cowie, A. (2018). *The History of Boxing: Gory Gladiatorial Origins, Back Street Venues, and Big Money* [Text]. Ancient Origins. https://www.ancient-origins.net/history-ancient-traditions/history-boxing-0010959

Cunha, J. P. (2018). *Cauliflower Ear Causes, Treatment, Draining & Surgery*. MedicineNet. https://www.medicinenet.com/cauliflower_ear/article.htm

De, A., & Ghosh, S. N. (2016). Effect of Healthy Activity Programmes on Kinesthetic Perception and Self-Concept among School Students. *International Journal of Advanced Scientific Research*, *1*(7), 29–33.

De, A., & Mondal, S. (2016). Improvement of Brain Function through Combined Yogic Intervention, Meditation and Pranayama: A Critical Analysis. *European Journal of Physical Education and Sport*, *13*(3), 89–96. https://doi.org/10.13187/ejpe.2016.13.89

Dhillon, H., Dhilllon, S., & Dhillon, M. (2017). Current Concepts in Sports Injury Rehabilitation. *Indian Journal of Orthopaedics*, *51*(5), 529. https://doi.org/10.4103/ortho.IJOrtho_226_17

Festuccia, S. (2016). Sport Representation: Transfer Images of Agonistic Contests. *Proceeding of International Congress on the Archaeology*, *1*, 99–110.

Gable, D. (n.d.). *Dan Gable Quotes*. BrainyQuote. Retrieved May 4, 2020, from https://www.brainyquote.com/quotes/dan_gable_198628

Gardiner, E. N. (1930). *Athletics in the Ancient World*. Oxford University Press.

Grimes, W. (2009, October 15). Dietrich von Bothmer, Curator and Art Historian, Dies at 90. *The New York Times*. https://www.nytimes.com/2009/10/15/arts/15bothmer.html

Halperin, I., Hughes, S., & Chapman, D. W. (2016). Physiological Profile of a Professional Boxer Preparing for Title Bout: A Case Study. *Journal of Sports Sciences*, *34*(20), 1949–1956. https://doi.org/10.1080/02640414.2016.1143110

Harris, H. A. (1976). *Greek Athletes and Athletics*. Hutchinson. London.

Hemingway, S. (2013, June 17). *The Boxer: An Ancient Masterpiece Comes to the Met*. Curator, Department of Greek and Roman Art. https://www.metmuseum.org/blogs/now-at-the-met/features/2013/the-boxer

Henderson, T. (2018, February 20). *Knock Out as Roman Boxing Gloves are Discovered in North East*. Nechronicle. https://www.chroniclelive.co.uk/news/north-east-news/knock-out-find-roman-boxing-14311448

Hugh, C. (1911). Cestus: Encyclopædia Britannica. In *Wikipedia* (11th ed.). Cambridge University Press. https://en.wikipedia.org/w/index.php?title=Cestus&oldid=952111580

Islam, M. S. (2020). Introducing Drone Technology to Soccer Coaching. *International Journal of Sports Science and Physical Education*, *5*(1), 1–4. https://doi.org/10.11648/j.ijsspe.20200501.11

Islam, M. S., & De, A. (2018). Functional Hamstring to Quadriceps Strength Ratio (H:Q) and Hamstrings Injury of Soccer Players: A Qualitative Analysis. *Orthopedics and Sports Medicine Open Access Journal*, *2*(2), 126–132. https://doi.org/10.32474/OSMOAJ.2018.02.000133

Islam, M. S., Kundu, B., & Saha, S. (2019). Relationship between Repeated Sprint Ability and Accuracy of Soccer Shooting Performance in Young Players. *European Journal of Physical Education and Sport Science*, *5*(11), 95–104. https://doi.org/10.5281/ZENODO.3381127

Jennings, L. A. (2016). The Bloody, Deadly, Heavy Fights of Ancient Greece. *Fightland*. http://fightland.vice.com/blog/the-bloody-deadly-heavy-fights-of-ancient-greece

Liew, G. C., Kuan, G., Chin, N. S., & Hashim, H. A. (2019). Mental Toughness in Sport: Systematic Review and Future. *German Journal of Exercise and Sport Research*, *49*(4), 381–394. https://doi.org/10.1007/s12662-019-00603-3

Little, B. (2018). *Only Known Boxing Gloves From Roman Empire Discovered*. HISTORY. https://www.history.com/news/only-known-boxing-gloves-from-roman-empire-discovered

Mark, C. (2014). Akrotiri Frescoes. *World History Encyclopedia*. https://www.worldhistory.org/article/673/akrotiri-frescoes/.

Masterson, D. W. (1976). The ancient Greek origins of sports medicine. *British Journal of Sports Medicine*, *10*(4), 196–202. https://doi.org/10.1136/bjsm.10.4.196

Matthew, D. (2002). *Girls and Women in Classical Greek Religion* (1st ed., p. 448). Routledge.

Matthew, V. (2020). Boxing in the Roman Empire. *World History Encyclopedia*. https://www.worldhistory.org/article/1641/boxing-in-the-roman-empire/

McCown, I. A. (1959). Boxing injuries. *The American Journal of Surgery*, *98*(3), 509–516. https://doi.org/10.1016/0002-9610(59)90545-8

Mohamed, F. A. (2020). Early Evidence of Boxing in Ancient Egypt and Mesopotamia: A Comparative Study. *Shedet*, *7*(7), 74–86. https://doi.org/10.21608/shedet.2020.137664

Murray, S. R. (2010). Boxing Gloves of the Ancient World. *Journal of Combative Sport*. https://ejmas.com/jcs/2010jcs/jcsart_murray_1007.html

Nakamura, B. J. (2019). Boxing in the Ancient World. In G. Early (Ed.), *The Cambridge Companion to Boxing* (1st ed., pp. 22–33). Cambridge University Press. https://doi.org/10.1017/9781107415355.003

Noormohammadpour, P., Rostami, M., Nourian, R., Mansournia, M. A., Sarough Farahani, S., Farahbakhsh, F., & Kordi, R. (2015). Association Between Hearing Loss And Cauliflower Ear in Wrestlers, a Case Control Study Employing Hearing Tests. *Asian Journal of Sports Medicine*, *6*(2). https://doi.org/10.5812/asjsm.6(2)2015.25786

Olson, C. (2016, March 30). *The Seated Boxer*. Art 230: Ancient Art Digital Exhibit. https://scholarexchange.furman.edu/art231/48

Olympic Games | Ancient Greece. (n.d.). Khan Academy. Retrieved May 4, 2020, from https://www.khanacademy.org/humanities/ancient-art-civilizations/greek-art/beginners-guide-greece/a/olympic-games

Palmquist, C. (2013, July 25). *Ancient Roman Statue of Fighter Shows Cauliflower Ear Being Drained*. The Underground. https://www.mixedmartialarts.com/news/Ancient-Roman-statue-of-fighter-shows-cauliflower-ear-being-drained

Penjak, A., & Karnincic, H. (2013). Sport and Literature: An Overview of the Wrestling Combats in the Early Literary Texts. *International Journal of Humanities and Social Science*, *3*(5), 49–55.

Poliakoff, M. B. (2004). Ancient Combat Sports. *Archaeology Odyssey*, *7*(4). https://www.baslibrary.org/archaeology-odyssey/7/4/8

Poliakoff, M. B. (2018, August 26). Ancient Combat Sports. *Biblical Archaeology Society*. https://www.biblicalarchaeology.org/daily/ancient-cultures/daily-life-and-practice/ancient-combat-sports/

Pottery, A. (2010). *Amphora | Pottery*. Encyclopedia Britannica. https://www.britannica.com/art/amphora-pottery

Raddato, C. (2014, June 15). *Amphora Showing a Boxing Contest*. Ancient History Encyclopedia. https://www.ancient.eu/image/2688/amphora-showing-a-boxing-contest/

Rogers, J. (2018, February 20). *Ancient Roman Boxing Gloves Discovered near Hadrian's Wall* [Text.Article]. Fox News. https://www.foxnews.com/science/ancient-roman-boxing-gloves-discovered-near-hadrians-wall

Roy, D., & De, A. (2018). Effect of Aging on Psycho-Motor Components in Relation to Perceived Stress among Healthy Citizens. *International Journal of Movement Education and Social Science*, *7*(1), 1–6.

Stevens, E. C. (2020). *Why Boxing is the Toughest Sport*. Breaking Muscle. https://breakingmuscle.com/fitness/why-boxing-is-the-toughest-sport

The Boxer: An Ancient Masterpiece. (2013). The Metropolitan Museum of Art. https://www.metmuseum.org/exhibitions/listings/2013/the-boxer

What is Boxing? - Definition & Rules. (2003). Study.Com. https://study.com/academy/lesson/what-is-boxing-definition-rules.html

 DOI 10.26773/mjssm.220909

ORIGINAL SCIENTIFIC PAPER

Handball players' training profile and its relation to potential injuries

Dimitrios Hatzimanouil[1], Vasilis Skandalis[1], Ioannis Terzidis[1,2], Efthymios Papasoulis[2], Giorgos Mavromatis[1]

Affiliations: [1]Aristotle University of Thessaloniki, Faculty of Physical Education and Sports Science, Laboratory of Biological Evaluation Human Performance, Thessaloniki, Greece, [2]Thessaloniki Minimally Invasive Surgery (The-MIS), Orthopaedic Center St. Luke's Hospital, Thessaloniki, Greece.

Correspondence: D. Hatzimanouil, Aristotle University of Thessaloniki, Faculty of Physical Education and Sports Science Laboratory of Biological Evaluation of Human Performance New Campus Thermi, Thessaloniki. E-mail: xatjiman@phed.auth.gr

Abstract

Although injuries in handball show high frequency and severity, the training profile of handball players and its relationship to injuries has not been extensively investigated. The purpose of the study was to describe this relationship between players' training profile and injuries. In total, 216 male and female players from A1 Division teams and players from U19 and U17 teams answered a relevant questionnaire. The statistical analysis, including descriptive and inductive statistics (correspondence analysis, one-way analysis of variance [ANOVA], multivariate analysis of variance [MANOVA], chi-square test), revealed that injured players mainly had ligament injuries of the lower extremities, especially the knee, while the mechanism most frequently reported by the players was an unfortunate moment. The frequency of injuries was higher in the game than in training, especially in attack, resulting in many serious injuries (return-to-play [RTP] ≥ 4 weeks). In most cases diagnosis was made by doctors while the therapeutic methods were different for each athlete. Correspondence analysis revealed that injured players were differentiated in terms of their training content and daily training, as well as competition level. The ANOVA showed that the severity of the injury was independent of all quantitative and qualitative variables examined, while the chi-square test indicated that the frequency appeared to be related to engaging in another sport prior to handball, to the playing position, and to prevention training. Further research is needed to clarify this issue.

Keywords: *Training load, Exposure, Impacts of handball training and competition*

@MJSSMontenegro
HANDBALL PLAYERS' TRAINING PROFILE AND INJURIES
http://mjssm.me/?sekcija=article&artid=245

Cite this article: Hatzimanouil, D., Skandalis, V., Terzidis, I., Papasoulis, E., &, Mavromatis G. (2022) Handball players' training profile and its relation to potential injuries. *Montenegrin Journal of Sports Science and Medicine*, 11 (2), 79–85. https://doi.org/10.26773/mjssm.220910

Introduction

Modern handball is a fast-paced sport, with a high pace in defense and attack (Karcher & Buchheit, 2014). Injuries in this sport appear to show high frequency and severity in both men and women. The frequency of injuries in handball ranges between 4.1-12.4/1000 hours of training or competition, with 3-10 times more injuries during games, especially (85%) in official competitions (Bere et al., 2015; Luig & Henke, 2010; Mónaco et al., 2019). Many studies also show a high percentage of high severity, which leads to abstinence from training and competition for a long time (Bedo et al., 2019; Rafnsson et al., 2017). Raya-González et al. (2020) reported that male senior handball players had the highest values of incidence for injuries during training and matches. The same authors stated that male players suffered from ankle and knee injuries while female players suffered from knee injuries. Male players main-

Received: 19 April 2022 | Accepted after revision: 25 August 2022 | Early access publication date: 30 August 2022 | Final publication date: 1 September 2022

© 2022 by the author(s). License MSA, Podgorica, Montenegro. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY).

Conflict of interest: None declared.

ly seem to have a high incidence of strains while female players seem to have contusions and sprains. Although in general injuries last fewer than seven days, it seems that female players have more serious injuries (Raya-González et al., 2020). This is because female players suffer mainly and especially from anterior cruciate ligament (ACL) injuries.

Furthermore, Mónaco et al. (2019) stated that regarding injury incidence there are no statistically significant differences between youth vs adult categories. The same authors also reported no statistically significant differences between immature vs mature players. Immature players have more apophysitis injuries than all the other players. Adults presented more ankle, muscle and head injuries than youth players, because in competitions adults play at a higher level than youths (Mónaco et al., 2019).

A review of the literature shows that, although handball injuries have been extensively analyzed, references to the players' training load and its relationship to injuries are lacking (Bjørndal et al., 2021). More specifically, although training elements such as warm-up, individual technique, stretching, general physical condition of a player, team tactics followed by the team, participation of the team in friendly matches and prevention training seem to be important factors in the occurrence or non-occurrence of injuries, they have not been extensively analyzed and need further investigation (Raya-González et al., 2020). In the present study we regarded the terms "training load" and "training profile" of a handball player as equivalent. Thus when we refer to the training profile of a handball player we mean the training load: all the elements (warm-up, individual technique, stretching, etc.) included during training.

It appears from the above that injuries and their relationship to the players' "training profile" are poorly described in the literature and there is a lack of information on this issue. This led to the goal of the present study, which was to describe the relationship between the training profile of handball players and the injuries that occur.

Methods

The study sample consisted of 216 handball players in A1 division teams and U19 and U17 players. Of the 216 players of our sample, 166 (76.9%) were males and 50 (23.1%) were females. Their mean age was 21.07 ± 5.16 years. Players' mean height was 180.64 ± 9.21 cm. Mean body weight was 79.71 ± 13.1 kg. The mean starting age of playing handball was 10.56 ± 2.53 years, while the total years of playing were 10.51. ± 5.13 years. Of our sample, 148 (68.5%) had played another sport before playing handball. Of those, 31.9% were back players, 31.9% wings, 20.4% pivots and 15.7% goalkeepers. Also 133 (61.6%) participated in more than 4 trainings per week, 62 (28.75%) in 2-4 trainings and 21 (9.7%) in less than 2 trainings. Moreover, 191 (88.4%) followed the whole basic stage of preparation and physical condition trainings, during the pre-season and before the start of the in-season obligations of the team. Of the sample, 137 (63.4%) had a participation of more than 50% in team games, 42 (19.5%) 25-50%, and 36 (16.7%) less than 25%.

All participants completed a questionnaire related to the training process and their injury history. The questionnaire included demographic and anthropometric characteristics, questions related to the training, and questions on the injuries suffered by the players in the previous season.

Descriptive and inductive statistics were used for the statistical analysis of the present study. More specifically, the frequency of the values and their corresponding percentage, as well as the mean value and standard deviation (SD) were used. Correspondence analysis was also applied in order to verify the differentiation of the injured individuals, in terms of their training content and their daily training on the one hand and their competitive level on the other. We divided the sample into injured and uninjured players. In order to determine the relationship between the severity of the injury and the competition level with all the qualitative and quantitative variables of the study, one-way analysis of variance (one-way ANOVA) was applied. Multivariate analysis of variance (MANOVA) was applied to find significant differences between injured and uninjured players. A chi-square test was used to identify the relation of severity with the quality variables. The significance level was set at 0.05. The statistical processing of the data was carried out using SPSS 22.

Results

In the previous season, 106 players were injured. The remaining 110 players did not suffer any injuries in the previous season. The MANOVA showed a borderline differentiation between injured and uninjured players while univariate analy-

Table 1. Statistically significant differences between injured and uninjured players

Variables	Last season injuries	N	Mean Rank	p
Warm-up	Yes	106	101.80	0.173
	No	110	114.96	
	Total	216		
Stretching	Yes	106	102.66	0.173
	No	110	114.13	
	Total	216		
Individual Technique	Yes	106	104.32	0.251
	No	110	112.53	
	Total	216		
Team Tactics	Yes	106	108.75	0.976
	No	110	108.26	
	Total	216		
Physical Condition	Yes	106	102.21	0.128
	No	110	114.56	
	Total	216		

(continued on next page)

DOI 10.26773/mjssm.220910

(continued from previous page)

Variables	Last season injuries	N	Mean Rank	p
Friendly Games	Yes	106	96.83	0.004
	No	110	119.75	
	Total	216		
Prehab Training	Yes	106	96.78	0.005
	No	110	119.80	
	Total	216		

sis showed two variables which differentiate injured from uninjured athletes: "friendly games" and "prehab training". Table 1 shows the statistically significant differences between injured and uninjured players.

In players who had at least one injury, the most frequent injuries were 36.8% ligament injury and 22.6% muscle rupture. Regarding the location (injury point), the point with the most injuries (76 cases) was the lower extremities. More specifically, 27 players suffered injuries to the knee, 22 to the ankle, 10 to the tibia, 11 to the thigh, 3 to the hip and 3 to the toes. Regarding the mechanism of injury, the possible causes of injury reported by the players were mainly an unfortunate moment (44.3%), overtraining (33%) and collision with an opponent (22.6%).

The chi-square test showed that the situation (training or game) was independent of the time at which the players were injured (chi-square = 3.155 and p=0.207). Table 2 shows the frequency and the corresponding percentage of players in terms of the situation (training or game) and the time at which they were injured.

Table 3 presents the situation in which the injury occurred both in training and in the game, the place and time of the diagnosis, the person who made the diagnosis, the treatment and the therapeutic means followed by injured players, and the players' return to the previous playing activity.

Table 2. Situation and time of injury in training and in game (game minute of injury)

	Number of players	Start – game minute of injury	Middle – game minute of injury	End – game minute of injury
Training	49	11 (22.4%)	29 (59.2 %)	9 (18.4%)
Game	57	18 (31.6%) 0-20′	25 (43.8%) 20-40′	14 (24.6%) 40-60′
Total	106	29 (27.3%)	54 (50.9%)	23 (21.6%)

Table 3. Situation which the injury occurred, place, time and person of diagnosis, therapeutic means and return of the players to the previous playing activity

	Situation of Injuries		Place of diagnosis		Person of diagnosis		Therapeutic means		RTP	
		%		%		%		%		%
Defense	21	19.8								
Attack	44	41.5								
Counter attack	11	10.4								
Other	30	28.3								
Total	106	100								
Sports hall			11	10.4						
Hospital			25	23.6						
Private doctor's office			66	62.2						
Other			4	3.8						
Total			106	100						
Coach					1	1				
Physiotherapist					12	11.3				
Doctor					93	87.7				
Total					106	100				
Physiotherapy							73	68.6		
Kinesiotherapy							25	23.5		
Medical treatment							34	32		
Operation							18	16.9		
Other							12	11.3		
Total							106			
Immediately									1	1

(continued on next page)

(continued from previous page)

	Situation of Injuries	Place of diagnosis	Person of diagnosis	Therapeutic means	RTP	
1st week					16	15.1
2nd week					20	18.9
3rd week					18	16.9
4th week					13	12.3
> 4th week					38	35.8
Total					106	100

The correspondence analysis showed that the injured individuals in this study were differentiated in terms of their training content and their daily training. Thus, injured players were divided according to the volume of daily training into injured who competed with satisfactory training content and injured who competed with unsatisfactory training content. On the right of Figure 1, with the low values, is the incomplete training content, while on the left of the chart, where high values are observed, is the adequate training content. The injured were also distinguished according to competitive level, on the vertical axis of the diagram. They were divided into players (men/women) competing in the first divisions, shown in Figure 1 around a circle with the variables "A1" and "Seniors", and players (men/women) competing in the lower divisions, in the upper circle with the variables U19 and U17. Here it is important to mention that in the higher divisions line players are injured the most (the variable "pivot" is in the center of the lower circle), while in the lower divisions all the other playing positions are injured.

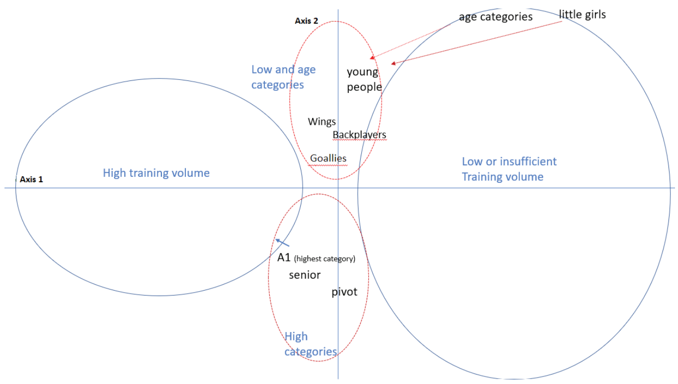


Figure 1. Correspondence analysis of injured players

The correspondence analysis revealed that the competitive levels of the injured players do not seem to affect the severity of the injury.

The one-way ANOVA showed that the severity of the injury measured in hospitalization time (no hospitalization, a week, between 1 and 2 weeks, between 2 and 3 weeks, between 3 and 4 weeks, over 4 weeks) is independent of all the other quantitative variables, such as the players' height ($p = 0.881$), weight ($p = 0.475$), age of starting handball ($p = 0.723$), and years of involvement in the specific sport ($p = 0.132$). Table 4

Table 4. Relationship between severity of injuries and other variables

Variables	Severity of injuries
	p
Category level	p=0.566
Team level	p=0.489
Previous sport	p=0.641
Playing position	p=0.721
Training frequency	p=0.547
Preparatory phase	p=0.612
Game frequency	p=0.283
Warm up	p=0.689
Stretching	p=0.479
Individual technique	p=0.114
Team tactic	p=0.136
Physical condition	p=0.647
Friendly game	p=0.556
Prehab training	p=0.750

DOI 10.26773/mjssm.220910

shows the relationship between severity of injuries and the other variables.

The chi-square test showed that the injury as a fact (injury/no injury) is independent of all the variables measured, except the variables of involvement in another sport before handball (previous sport), playing position (position) and prevention training (prehab).

More specifically, in players who were involved in another sport before handball, there were more injured than non-injured. Table 5 shows the injury as a fact (injury/no injury) and the chi-square test values.

Figure 2 shows the relationship of injured and uninjured with the playing position. Back players and line players (pivot) had more injuries than the other positions. Furthermore, it seems that the "status" (injured/uninjured) and the relationship with the playing position is statistically significant, and the significance is found mainly in the wings (with adjusted residual = 2) and secondarily in the pivots (with adjusted residual = 1.85).

Table 5. Injury as a fact (injury/non-injury) and chi-square test values

Injury during previous season	
Variables	p
Previous sport	p=0.038
Play Position	p=0.036
Play percentage	p=0.069
Friendly games	p=0.065
Prehab training	p=0.046

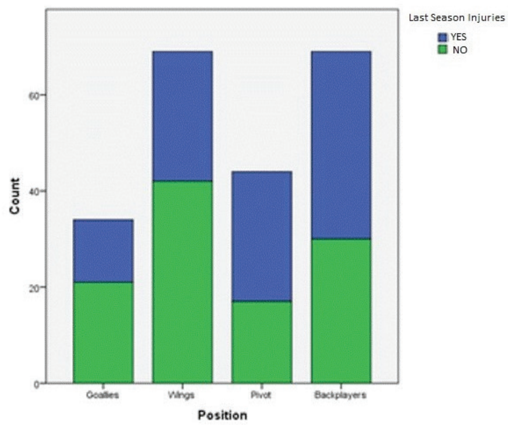


Figure 2. Relation of injured and uninjured players with playing position.

Concerning the relationship between injured/uninjured and prevention training, as shown in Figure 3, the less prevention training the more injuries. The high point is no prevention training, which means that everyone was injured, with an adjusted residual=2.3 and n = 5.

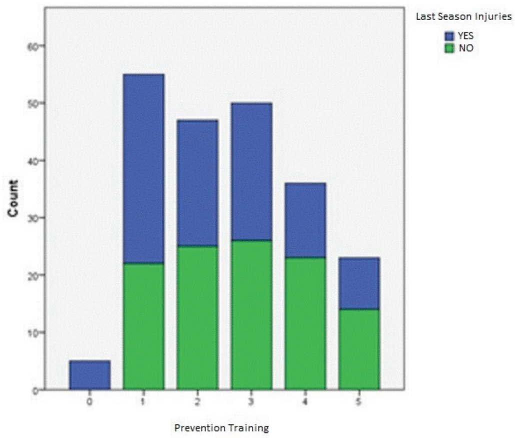


Figure 3. Relation of injured and uninjured players with prevention training.

Discussion

In the present study we had a borderline differentiation between injured and uninjured players, while it seems that two variables distinguish injured from uninjured athletes: "friendly games" and "prehab training". Regarding friendly matches, the results showed that the majority of players participate in friendly matches a little to moderately. This makes sense, since the number of friendly matches decreases during the season (Kniubaité, 2020). Regarding prevention training, it appeared that 35.8% and 20.8% respectively did not use prevention training at all or did it moderately. Players should make use of basic prevention through preventive exercise programs (Instrumental or Physical-Exercise Rehabilitation – IPER). The main reasons preventing use of these exercises are lack of knowledge about injury risk and the benefits of prevention, lack of motivation, and coaching approaches and "policies" (Moller et al., 2018).

Regarding the type and location of injuries, the results of the present study are in line with the international literature (Mónaco et al., 2019). More specifically, in the sample of injured players, ligament injuries (36.8%) and muscle fractures (22.6%) are most frequent. The types of injuries to the lower extremities are usually sprains, bruises and fractures, as well as ligament injuries which occur mainly in the knee and ankle (Luig & Henke, 2010). Concerning the location of the injuries, 76 players suffered injuries in the lower extremities: 27 knee injuries and 22 ankle injuries. The injury mechanisms most frequently reported by the players were an "unfortunate moment" (44.3%) and "contact with an opponent" (40.5%), Handball, as a contact sport, has a high probability of injuries due to the frequent collisions between players (Tyrdal & Bahr, 1996).

The results of the present study also agree with those of other research stating that the frequency of injuries is higher in the game than in training, especially in attack (Mónaco et al., 2019; Luig et al., 2020; Laver et al., 2018). Moreover, the results are partly in line with another study (Luig et al., 2017) which found that injuries occur in the last ten minutes of each half. In our results this was only verified in the first half, in line with Bere et al. (2015). However, although there is a tendency for injuries to occur in the second half, this differs in the female population (Laver et al., 2018).

The results also showed that the situation of injury was mainly in attack, in accordance with the literature (Mónaco et al., 2019; Luig et al., 2020; Laver et al., 2018). Physicians are responsible for diagnosing injuries in a team (Mónaco et al., 2019). The results of the present study agree with the above, since in most cases the diagnosis was made by doctors. Various therapeutic methods were used, since they should be individualized according to the requirements of each player, the current situation, the functionality, the type and the severity of injury, the requirements of the sport, etc. (Laver et al., 2018). Regarding the time of return to the same competitive activity, most of the sample returned at 4 weeks or later. This classifies these injuries in terms of severity as very serious (Laver et al., 2018; Rafnsson et al., 2017).

The correspondence analysis revealed low values for the incomplete training content and high values for the adequate training content. This is logical because in the sample of the present study there were players who competed at a high level but also players in younger age teams. The same analysis showed that the injured were distinguished based on their competitive level. In our study the injury rate appears to be higher in the higher competition levels, probably due to the greater intensity of the game at this level (Mónaco et al., 2019). Raya-González et al. (2021) found no significant differences between divisions in terms of injury frequency; however, a higher rate of injuries was observed in the lower divisions during training and a higher incidence of injuries in the higher divisions during game. Our results also showed that in the top competitive levels, the line players (pivots) are injured the most, while in the low competitive levels all the other playing positions are affected. These results are in contrast to research stating that elite back players present the highest percentage of ACL ruptures (Laver et al., 2018). Furthermore, the correspondence analysis revealed that the severity of the injury does not seem to be associated with the competition level of the injured players. A recent study of Brazilian handball players found that handball has many acute and serious injuries resulting in players being out of training and games for a long time (Bedo et al., 2019; Rafnsson et al., 2017).

The one-way ANOVA and the chi-square test revealed that the severity of the injury was independent of all the quantitative and qualitative variables of the present study. The chi-square test showed that the fact of injury (injury/ no injury) was independent of all the variables measured, except the variables of involvement in another sport before handball (previous sport), playing position and prehab training. Engaging in other sport activities results in an additional burden that leads to health problems (Bjørndal et al., 2021). This is probably due to additional school sport activities, since in our sample there were a certain number of school students. Regarding the injuries per position in the present study, we found that back players and line players (pivots) suffer injuries more frequently than the other playing positions. This is in line with the findings of another study (Luig & Henke, 2010). Finally, regarding prevention training, the present study found a relationship between prevention training and injuries. This result is consistent with a meta-analysis study which showed that there was a significant reduction in the overall incidence of ACL ruptures in both the total number (50%) and the number of non-contact injuries (75%) in female players who followed prevention programs (Webster & Hewett, 2018). Moreover, one review states that prevention programs in team sports are effective in avoiding lower limb injuries, particularly knee, ACL, and ankle injuries (Brunner et al. 2019).

Although the strong point of the present study is the large sample examined for the relationship between injuries and training profile, the results have some limitations in terms of overall research. The first limitation is that our sample included both adult players (men and women) and younger players. This was due to the fact that the questionnaires were answered in the preparation period, when higher division teams include players of younger ages in order to give them the opportunity to participate with the men's or women's team and gain additional experience. Further research is needed on each individual age group in order to ensure the representativeness of the sample in the general population and make the results of the statistical analysis specific to each age group. The second limitation of the present study is the absence of previous research on this issue. Therefore, the purpose of this study was to develop a completely new research approach to the topic and to identify this gap in the literature, meaning that further research is needed.

Conclusions

In conclusion, we would say that although there was a borderline differentiation between injured and uninjured players, "friendly games" and "prehab training" differentiate injured from uninjured athletes. Injured players mainly had ligament

DOI 10.26773/mjssm.220910

injuries in the lower extremities, especially the knee, while the mechanism most frequently reported by the players was an unfortunate moment. The frequency of injuries was higher in the game than in training, especially in attack. In most cases diagnosis was made by doctors while the therapeutic methods were different for each athlete. Regarding the time of return to the same competitive activity, the highest percentage of the sample returned at 4 weeks or later. The injured individuals in this study were differentiated in terms of their training content and daily training, and also according to their competitive level. Another important finding was that the severity of the injury did not seem to be associated with the competitive level of the injured players. The severity of the injury was independent of all quantitative and qualitative variables of the study, while the chi-square test showed that the fact of injury (injury/no injury) was independent of all the variables measured, except the variables of involvement in another sport before handball (previous sport), playing position and prehab training. From the above it seems that although the training profile is related to injuries, further research is needed to clarify this issue.

References

Bedo, B. L. S., Manechini, J. P. V., Nunomura, M., Menezes, R. P., & Silva, S. R. D. D. (2019). Injury frequency in handball players: a descriptive study of injury pattern in São Paulo state regional teams. *Motriz: Revista de Educação Física*, *25*(1), 1–6. http://dx.doi.org/10.1590/S1980-6574201900020020.

Bere, T., Alonso, J. M., Wangensteen, A., Bakken, A., Eirale, C., Dijkstra, H. P., ... & Popovic, N. (2015). Injury and illness surveillance during the 24th Men's Handball World Championship 2015 in Qatar. *British Journal of Sports Medicine*, *49*(17), 1151–1156. https://doi:10.1136/bjsports-2015-094972.

Bjørndal, C. T., Bache-Mathiesen, L. K., Gjesdal, S., Moseid, C. H., Myklebust, G., & Luteberget, L. S. (2021). An examination of training load, match activities, and health problems in Norwegian youth elite handball players over one competitive season. *Frontiers in Sports and Active Living*, *3*, 1–12. https://doi.org/10.3389/fspor.2021.635103.

Brunner, R., Friesenbichler, B., Casartelli, N. C., Bizzini, M., Maffiuletti, N. A., & Niedermann, K. (2019). Effectiveness of multicomponent lower extremity injury prevention programmes in team-sport athletes: an umbrella review. *British Journal of Sports Medicine*, *53*(5), 282–288. https://doi:10.1136/bjsports-2017-098944.

Karcher, C., & Buchheit, M. (2014). On-court demands of elite handball, with special reference to playing positions. *Sports Medicine*, *44*(6), 797–814. http://DOI 10.1007/s40279-014-0164-z.

Kniubaitė, A. (2020). *Modeling of coaching in high-performance female handball player* (Doctoral dissertation, Lithuanian Sports University, Kaunas). Retrieved from: https://vb.lsu.lt/object/elaba:69578784/.

Laver, L., Landreau, P., Seil, R., & Popovic, N. (Eds.). (2018). *Handball Sports Medicine: Basic science, injury management and return to sport*. Berlin: Springer. https://doi.org/10.1007/978-3-662-55892-8.

Luig, P., Krutsch, W., Henke, T., Klein, C., Bloch, H., Platen, P., & Achenbach, L. (2020). Contact—but not foul play—dominates injury mechanisms in men's professional handball: a video match analysis of 580 injuries. *British Journal of Sports Medicine*, *54*(16), 984–990. http://doi:10.1136/bjsports-2018-100250.

Luig, P., Bloch, H., Burkhardt, K., Klein, C., & Kühn, N. (2017). *VBG-Sportreport 2017. Analyse des Unfallgeschehens in den zwei höchsten Ligen der Männer: Basketball, Eishockey, Fußball und Handball*. Hamburg: VBG. Retrieved from: https://www.vbg.de/SharedDocs/Medien-Center/DE/Broschuere/Branchen/Sport/VBG-Sportreport%202017.pdf?__blob=publicationFile&v=8).

Luig, P., & Henke, T. (2010). *Safety in Sports*. Retrieved from: https://www.sicherheit.sport/app/uploads/2015/01/Burden_Report_Handball.pdf.

Møller, M., Ageberg, E., Bencke, J., Zebis, M. K., & Myklebust, G. (2018). Implementing Handball Injury Prevention Exercise Programs: A Practical Guideline. In L. Laver, P. Landreau, R. Seil, N. Popovic (Eds.), *Handball Sports Medicine* (pp. 413–432). Berlin, Heidelberg: Springer

Mónaco, M., Rincón, J. A. G., Ronsano, B. J. M., Whiteley, R., Sanz-Lopez, F., & Rodas,

G. (2019). Injury incidence and injury patterns by category, player position, and maturation in elite male handball elite players. *Biology of Sport*, *36*(1), 67–74. https://doi.org/10.5114/biolsport.2018.78908.

Rafnsson, E. T., Myklebust, G., Bahr, R., Frohm, A., Valdimarsson, O., & Arnason, A. (2017). Overuse problems in Icelandic male handball. *British Journalof Sports Medicine*, *51*(4), 376–376. http://dx.doi.org/10.1136/bjsports-2016-097372.234.

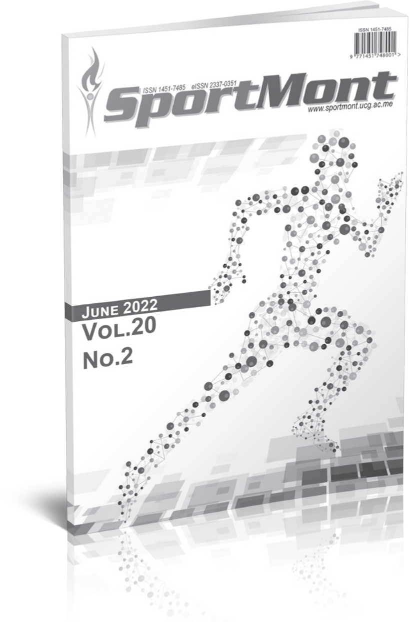
Raya-González, J., García-Esteban, S., de Ste Croix, M., Manuel Clemente, F., & Castillo, D. (2021). Longitudinal differences in the injury profile of professional male handball players according to competitive-level. *Research in Sports Medicine*, *29*(1), 90–102. https://doi.org/10.1080/15438627.2020.1800465.

Raya-González, J., Clemente, F. M., Beato, M., & Castillo, D. (2020). Injury profile of male and female senior and youth handball players: A systematic review. *International Journal of Environmental Research and Public Health*, *17*(11), 1–13. doi:10.3390/ijerph17113925.

Tyrdal, S. & Bahr, R. (1996). High prevalence of elbow problems among goalkeepers in European team handball - 'handball goallie's elbow'. *Scandinavian Journal of Medicine and Science in Sports*, *6*(5), 297–302. https://doi.org/10.1111/j.1600-0838.1996.tb00474.x.

Webster, K. E., & Hewett, T. E. (2018). Meta-analysis of meta-analyses of anterior cruciate ligament injury reduction training programs. *Journal of Orthopaedic Research®*, *36*(10), 2696–2708. https://doi.org/10.1002/jor.24043.

ISSN 1451-7485 eISSN 2337-0351
SportMont
www.sportmont.ucg.ac.me



ISSN 1451-7485

Sport Mont (SM) is a print (ISSN 1451-7485) and electronic scientific journal (eISSN 2337-0351) aims to present easy access to the scientific knowledge for sport-conscious individuals using contemporary methods. The purpose is to minimize the problems like the delays in publishing process of the articles or to acquire previous issues by drawing advantage from electronic medium. Hence, it provides:

- Open-access and freely accessible online;
- Fast publication time;
- Peer review by expert, practicing researchers;
- Post-publication tools to indicate quality and impact;
- Community-based dialogue on articles;
- Worldwide media coverage.

SM is published three times a year, in February, June and October of each year. SM publishes original scientific papers, review papers, editorials, short reports, peer review - fair review, as well as invited papers and award papers in the fields of Sports Science and Medicine, as well as it can function as an open discussion forum on significant issues of current interest.

SM covers all aspects of sports science and medicine; all clinical aspects of exercise, health, and sport; exercise physiology and biophysical investigation of sports performance; sport biomechanics; sports nutrition; rehabilitation, physiotherapy; sports psychology; sport pedagogy, sport history, sport philosophy, sport sociology, sport management; and all aspects of scientific support of the sports coaches from the natural, social and humanistic side.

Prospective authors should submit manuscripts for consideration in Microsoft Word-compatible format. For more complete descriptions and submission instructions, please access the Guidelines for Authors pages at the SM website: http://www.sportmont.ucg.ac.me/?sekcija=page&p=51. Contributors are urged to read SM's guidelines for the authors carefully before submitting manuscripts. Manuscripts submissions should be sent in electronic format to sportmont@ucg.ac.me or contact following Editors:

Dusko BJELICA, *Editor-in Chief – sportmont@t-com.me*
Zoran MILOSEVIC, *Editor-in Chief – zoranais@eunet.rs*
Borko KATANIC, *Managing Editor – borkokatanic@gmail.com*
Nedim COVIC, *Managing Editor – nedimcovic@gmail.com*

Publication date: Autumn issue – October 2022
Winter issue – February 2023
Summer issue – June 2023

Montenegrin Sports Academy welcomes you to *Dubrovnik, Croatia*

KEY DATES

- **1st of July 2022, 24:00 CET**
  Abstract submission opening and opening of registration
- **1st of December 2022, 24:00 CET**
  Abstract submission deadline
- **15th of January 2023, 24:00 CET**
  Notification to authors about acceptance
- **1st of February 2023, 24:00 CET**
  Deadline for early-bird registration for presenting authors
- **15th of February 2023, 24:00 CET**
  Deadline for late registration for presenting authors

* CET = Central European Time

CONTACT

Montenegrin Sports Academy
Đoka Miraševića 1/10 | 81000 Podgorica
Phone: +382 67 615 090
+382 69 040 150
(Available Mo-Fr 9-12 AM local Time)

E-Mail: conference@csakademija.me
www.csakademija.me

www.csakademija.me/conference

MSA Dubrovnik 2023

20th Annual Scientific Conference of Montenegrin Sports Academy "Sport, Physical Activity and Health: Contemporary Perspectives"

MSA Dubrovnik 2023

20th - 23th April 2023

CONFERENCE VENUE

Hotel Croatia Cavtat, situated across the bay from the historic walls of Dubrovnik, Hotel Croatia Cavtat is a leading five-star resort and conference hotel on the southern part of Adriatic. Hotel Croatia's architecture blends seamlessly with its natural surroundings. Shaded by a pine tree forest, while offering spectacular sea views, all 487 accommodation units feature balconies which overlook the Adriatic Sea or Cavtat Bay. State-of-the-art facilities include numerous gourmet restaurants, a spa centre, and private beaches. Hotel Croatia is ideal for a broader experience of the Dubrovnik Riviera. Suited for business and relaxation alike, Hotel Croatia serves as an excellent base for exploring the city of Dubrovnik and the Dubrovnik Riviera.

WELCOME TO DUBROVNIK

Regardless of whether you are visiting Dubrovnik for the first time or the hundredth, the sense of awe never fails to descend when you set eyes on the beauty of the old town. Indeed it's hard to imagine anyone becoming jaded by the city's white limestone streets, baroque buildings and the endless shimmer of the Adriatic, or failing to be inspired by a walk along the ancient city walls that protected a civilised, sophisticated republic for centuries.

LANGUAGE

The official Conference language is English.

FIRST ANNOUNCEMENT

Dear Friends and Colleagues,

Montenegrin Sports Academy will mark its 20th Anniversary by organising the 20th Annual Scientific Conference during 20.-23. April 2023 in Dubrovnik Croatia. The 20th Anniversary Conference will be held in Hotel Croatia, Cavtat.

Reserve your calendars, let us gather in person after these turbulent times and make our conference even more prestigious. Guarantee for our further prosperity is our international partners and Montenegrin Sports Academy. See you in Dubrovnik next spring!

We look forward to seeing you in spring 2023,

Prof. Duško Bjelica, Conference President

Conference sub-themes include:

Adapted Physical Activity; Anthropology; Architecture and Urbanism; Biochemistry; Biomechanics; Coaching; Economics; Health and Fitness; History; Molecular Biology; Motor Learning; Neuromuscular Physiology; Nutrition; Olympism; Philosophy and Ethics; Physical Education and Pedagogics; Physiology; Physiotherapy; Psychology; Rehabilitation; Sociology; Sport Management and Law; Sport Statistics and Analyses; Sport Technology; Sport Tourism; Sports Medicine and Orthopaedics; Training and Testing; Traumatology; and other Multi- & Interdisciplinary Themes.

Look inside!

Montenegrin Journal of Sports Science and Medicine

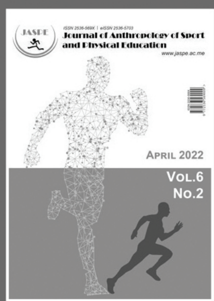
Volume 11, 2022, 2 issues per year;
Print ISSN: 1800-8755, Online ISSN: 1800-8763

www.mjssm.me

Sport Mont

Volume 20, 2019, 3 issues per year;
Print ISSN: 1451-7485, Online ISSN: 2337-0351

www.sportmont.ucg.ac.me



Journal of Anthropology of Sport and Physical Education

Volume 6, 2022, 4 issues per year;
Print ISSN: 2636-569X, Online ISSN: 2536-5703

www.jaspe.ac.me

CALL FOR ABSTRACTS

Research scholars and students are invited to present their original work in any of the conference sub-themes. The list of the conference sub-themes is not exhaustive and, therefore, authors should not feel limited by them. Authors can submit their original work in the form of an ABSTRACT, free of charge. An author may submit only one abstract as the first author and two abstracts as the co-author. After undergoing the reviewing process, all authors will be notified about the condition of their submission (accepted or rejected). Presenters (= the first authors) must be registered and have paid registration fees for the conference to secure their oral or poster (not debated) presentation during the conference and the publication in Montenegrin Journal of Sports Science and Medicine that is abstracted/indexed in Emerging Sources Citation Index, SCOPUS and other database, under the condition that the first author has paid registration fee.

CALL FOR PAPERS

Full-length manuscripts may be submitted for publishing in the Sport Mont journal (see at HYPERLINK "http://www.sportmont.ucg.ac.me" www.sportmont.ucg.ac.me), an international peer-reviewed scientific journal, indexed in Scopus, DOAJ, SPORTDiscus, Index Copernicus, ERIH PLUS, et cetera. Full-length paper submission is free of charge but author(s) has to pay additional 50 euros per accepted full-length paper to cover publication costs. Full manuscripts should be submitted for consideration of publication by the 15th of March, 2023 and prepared according to the guidelines for authors.

REGISTRATION FEES

For participants 260 EUR (220 EUR early-bird)
For students 190 EUR (160 EUR early-bird)
For accompanying persons 140 EUR (110 EUR early-bird)

MONTENEGRIN SPORTS ACADEMY

Founded in 2003 in Podgorica (Montenegro), the Montenegrin Sports Academy (MSA) is a sports scientific society dedicated to the collection, generation and dissemination of scientific knowledge at the Montenegrin level and beyond.

The Montenegrin Sports Academy (MSA) is the leading association of sports scientists at the Montenegrin level, which maintains extensive co-operation with the corresponding associations from abroad. The purpose of the MSA is the promotion of science and research, with special attention to sports science across Montenegro and beyond. Its topics include motivation, attitudes, values and responses, adaptation, performance and health aspects of people engaged in physical activity and the relation of physical activity and lifestyle to health, prevention and aging. These topics are investigated on an interdisciplinary basis and they bring together scientists from all areas of sports science, such as adapted physical activity, biochemistry, biomechanics, chronic disease and exercise, coaching and performance, doping, education, engineering and technology, environmental physiology, ethics, exercise and health, exercise, lifestyle and fitness, gender in sports, growth and development, human performance and aging, management and sports law, molecular biology and genetics, motor control and learning, muscle mechanics and neuromuscular control, muscle metabolism and hemodynamics, nutrition and exercise, overtraining, physiology, physiotherapy, rehabilitation, sports history, sports medicine, sports pedagogy, sports philosophy, sports psychology, sports sociology, training and testing.

The MSA is a non-profit organization. It supports Montenegrin institutions, such as the Ministry of Education and Sports, the Ministry of Science and the Montenegrin Olympic Committee, by offering scientific advice and assistance for carrying out coordinated national and European research projects defined by these bodies. In addition, the MSA serves as the most important Montenegrin and regional network of sports scientists from all relevant subdisciplines.

The main scientific event organized by the Montenegrin Sports Academy (MSA) is the annual conference held in the first week of April.

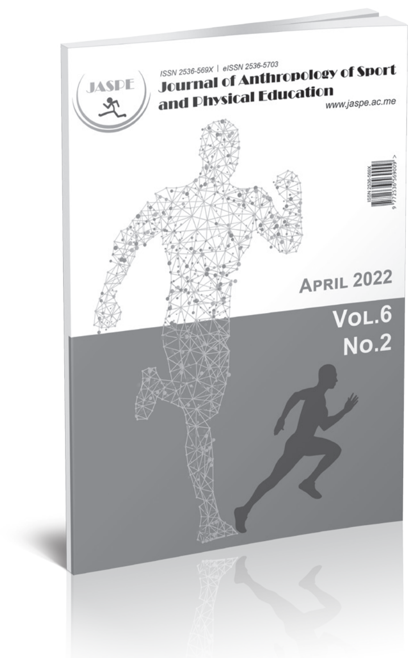
Annual conferences have been organized since the inauguration of the MSA in 2003. Today the MSA conference ranks among the leading sports scientific congresses in the Western Balkans. The conference comprises a range of invited lecturers, oral and poster presentations from multi- and mono-disciplinary areas, as well as various types of workshops. The MSA conference is attended by national, regional and international sports scientists with academic careers. The MSA conference now welcomes up to 200 participants from all over the world.

It is our great pleasure to announce the upcoming 19th Annual Scientific Conference of Montenegrin Sports Academy “Sport, Physical Activity and Health: Contemporary Perspectives” to be held in Dubrovnik, Croatia, from 7 to 10 April, 2022. It is planned to be once again organized by the Montenegrin Sports Academy, in cooperation with the Faculty of Sport and Physical Education, University of Montenegro and other international partner institutions (specified in the partner section).

The conference is focused on very current topics from all areas of sports science and sports medicine including physiology and sports medicine, social sciences and humanities, biomechanics and neuromuscular (see Abstract Submission page for more information).

We do believe that the topics offered to our conference participants will serve as a useful forum for the presentation of the latest research, as well as both for the theoretical and applied insight into the field of sports science and sports medicine disciplines.

Journal of Anthropology of Sport and Physical Education



ISSN 2536-569X

Journal of Anthropology of Sport and Physical Education (JASPE) is a print (ISSN 2536-569X) and electronic scientific journal (eISSN 2536-5703) aims to present easy access to the scientific knowledge for sport-conscious individuals using contemporary methods. The purpose is to minimize the problems like the delays in publishing process of the articles or to acquire previous issues by drawing advantage from electronic medium. Hence, it provides:

- Open-access and freely accessible online;
- Fast publication time;
- Peer review by expert, practicing researchers;
- Post-publication tools to indicate quality and impact;
- Community-based dialogue on articles;
- Worldwide media coverage.

JASPE is published four times a year, in January, April, July and October of each year. JASPE publishes original scientific papers, review papers, editorials, short reports, peer review - fair review, as well as invited papers and award papers in the fields of Anthropology of Sport and Physical Education, as well as it can function as an open discussion forum on significant issues of current interest.

JASPE covers all aspects of anthropology of sport and physical education from five major fields of anthropology: cultural, global, biological, linguistic and medical.

Prospective authors should submit manuscripts for consideration in Microsoft Word-compatible format. For more complete descriptions and submission instructions, please access the Guidelines for Authors pages at the JASPE website: http://www.jaspe.ac.me/?sekcija=page&p=51. Contributors are urged to read JASPE's guidelines for the authors carefully before submitting manuscripts. Manuscripts submissions should be sent in electronic format to jaspe@ucg.ac.me or contact JASPE's Editor:

Fidanka VASILEVA, *Editor-in Chief – vasileva.jaspe@gmail.com*

Publication date: Autumn issue – October 2022
Winter issue – January 2023
Spring issue – April 2023
Summer issue – July 2023

CRNOGORSKA SPORTSKA AKADEMIJA • MONTENEGRIN SPORTS ACADEMY

Sports Science and Medicine Journals

from Montenegrin Sports Academy

We have expanded the quality of our journals considerably over the past years and can now claim to be the market leader in terms of breadth of coverage.

As we continue to increase the quality of our publications across the field, we hope that you will continue to regard MSA journals as authoritative and stimulating sources for your research. We would be delighted to receive your comments and suggestions, mostly due to the reason your proposals are always welcome.

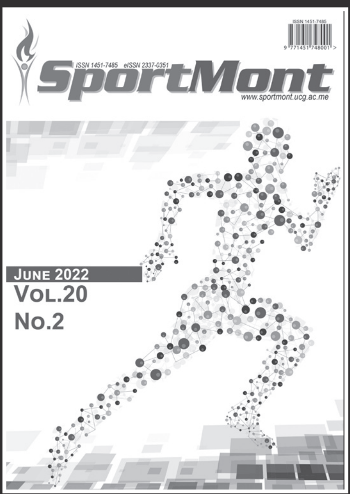
USEFUL CONTACTS

Editorial enquiries and journal proposals:
Dusko Bjelica
Damir Sekulic
Editors-in-Chief
Email: **damirsekulic.mjssm@gmail.com**

Selcuk Akpinar
Executive Editor
Email: **office@mjssm.me**

Marketing enquiries:
Fidanka Vasileva
Marketing Manager
Email: **damirsekulic.mjssm@gmail.com**

Look Inside!



Sport Mont Journal

Editors-in-Chief: **Dusko Bjelica**, Montenegro; **Zoran Milosevic**, Serbia
Managing Editor: **Borko Katanic**, Montenegro; **Nedim Covic**, Bosnia and Herzegovina

Volume 20, 2022, 3 issues per year; Print ISSN: 1451-7485, Online ISSN: 2337-0351

Sport Mont Journal is a scientific journal that provides: Open-access and freely accessible online; Fast publication time; Peer review by expert, practicing researchers; Post-publication tools to indicate quality and impact; Community-based dialogue on articles; Worldwide media coverage. SMJ is published three times a year, in February, June and October of each year. SMJ publishes original scientific papers, review papers, editorials, short reports, peer review - fair review, as well as invited papers and award papers in the fields of Sports Science and Medicine, as well as it can function as an open discussion forum on significant issues of current interest.

www.sportmont.ucg.ac.me

Montenegrin Journal of Sports Science and Medicine

Editors-in-Chief: **Dusko Bjelica**, Montenegro; **Damir Sekulic**, Croatia
Executive Editor: **Selcuk Akpinar**, Turkey
Associate Editors: **Mehmet Uygur**, USA; **Catalina Casaru**, USA; and **Predrag Bozic**, Serbia

Volume 11, 2022, 2 issues per year; Print ISSN: 1800-8755, Online ISSN: 1800-8763

Montenegrin Journal of Sports Science and Medicine (MJSSM) is published biannually, in September and March of each year. MJSSM publishes original scientific papers, review papers, editorials, short reports, peer review - fair review, as well as invited papers and award papers in the fields of Sports Science and Medicine, as well as it can function as an open discussion forum on significant issues of current interest. MJSSM covers all aspects of sports science and medicine; all clinical aspects of exercise, health, and sport; exercise physiology and biophysical investigation of sports performance; sport biomechanics; sports nutrition; rehabilitation, physiotherapy; sports psychology; sport pedagogy, sport history, sport philosophy, sport sociology, sport management; and all aspects of scientific support of the sports coaches from the natural, social and humanistic side.

www.mjssm.me

CRNOGORSKI OLIMPIJSKI KOMITET
MONTENEGRIN OLYMPIC COMMITTEE

CIP – Каталогизација у публикацији
Централна народна библиотека Црне Горе, Цетиње

796:61 (497.16)

MONTENEGRIN journal of sport science and medicine / urednik Duško Bjelica. – Vol. 1, no. 1 (2012) - . – Podgorica (Džordža Vašingtona 445) : Crnogorska sportska akademija, 2013 (Nikšić : Art grafika). – 30 cm

Polugodišnje.
ISSN 1800-8755 = Montenegrin journal of sports science and medicine (Podgorica)
COBISS.CG-ID 17824272

MSA Conference 2023

20th Annual Scientific Conference
of Montenegrin Sports Academy

"Sport, Physical Activity and Health: Contemporary perspectives"

http://www.csakademija.me/conference/

CRNOGORSKA SPORTSKA AKADEMIJA
MONTENEGRIN SPORTS ACADEMY

20th - 23th April 2023,
Dubrovnik - Croatia