Poznan University of Physical Education

TRENDS in SPORT SCIENCES

(formerly Studies in Physical Culture and Tourism)

quarterly • number 1 • volume 28 • year 2021

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Publisher
Poznan University of Physical Education
ul. Królowej Jadwigi 27/39
61-871 Poznań, Poland
tel. +48 61 835 51 96
e-mail: gronek@awf.poznan.pl
e-mail: tss@awf.poznan.pl
www.tss.awf.poznan.pl

Printed by
ESUS Tomasz Przybylak
ul. Południowa 54
62-064 Plewiska, Poland

Indexed in
SCOPUS
EBSCO Publishing, Inc.
SPORTDiscus
Ulrich's International Periodical Directory
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Index Copernicus (2017): 88.38 points
KBN/MNiSW (2019): 20 points

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REVIEW ARTICLE

TRENDS in
Sport Sciences
2021; 28(**1**): 5-10
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.1-1

Cognicise – a new model of exercise

PIOTR GRONEK, JAN ADAMCZYK, ROMAN CELKA, JOANNA GRONEK

Abstract
Many physical activity centers for geriatrics and gerontology all over the word are examining the best fitted type of exercise for older people including endurance, resistance, stretching and cognitive intervention. Pro-health training is a special area of activity on the border of health prophylaxis, rehabilitation and even sports. The modern neuroscience provides a lot of evidence that in the older people exercises enhance plasticity of the brain networks. The aim of this review is to explicate the topic of cognicise training for older people that is combining of *cogni*tive and exer*cise* tasks.

KEYWORDS: cognicise, older adults, exercise, healthy aging.

Received: 23 November 2020
Accepted: 15 December 2020

Corresponding author: gronek@awf.poznan.pl

Poznan University of Physical Education, Department of Dance and Gymnastics Sciences, Poznań, Poland

Introduction

It is predicted that in 2050 y., 40% of Poland population will be represented by people over 60 years old, and also in global view the coming 'tsunami' of aging of the society can be expected [30]. In this context, the issue of healthy aging is gaining importance since population aging is accelerating, parallel to prolonged life expectancy – especially that of the old-old aged 75--84 and the oldest-old aged over 85 – while decreasing in birth rate.

The classical view assumes that age-related decline in physical performance and cognitive deficits are irreversible as they are a consequence of changes in an aging body, including: cortical atrophy [29], neurotransmission dysfunction [28], reduced blood perfusion [45], and cognitive decline [17]. Therefore, physical and functional limitations as well as cognitive deficits must appear during aging process. However, more and more researchers indicate that physical activity (PA) and training itself cause a number of a favourable protective effect against some chronic illness or severity [6, 26].

Many centers for geriatrics and gerontology all over the word has been examining the best fitted exercise for older people, including the development of an effective training system for high-risk groups and intervention for dementia prevention [37]. Pro-health training of older people is a special area of activity on the border of health prophylaxis, rehabilitation and even sports, since the older people are much more diverse in terms of physical, cognitive and emotional condition, and are in different health conditions than young or middle-aged individuals. Moreover, the modern neuroscience provides a lot of evidence that in the older people PA enhances plasticity of the brain networks.

Thus, the aim of this short review is to look closer on one of many well designed and possible recommended propositions that is called the **cognicise** training, which is designed to improve the cognitive functions through appropriate training based on the appropriate stimulation in the form of exercise.

Multicomponent exercise intervention

According to Baar [3] exercise can be classified into three subclasses: resistance, endurance, and patterned movements. Resistance and endurance exercise is recognized as such stimulating the body that have a significant influence on muscle phenotype. In turn, patterned movement exercises concern mainly a motor program in the central nervous system (CNS) and result in relatively non-significant biochemical changes in muscles [3]. One of the well-known modifications is combined training (endurance and resistance in one single exercise) [16] that in certain cases and circumstances such combining seems adequate and thus is recommended not only as recovery or rehabilitation.

There is strong empirical evidence of the relationship between the level of PA and risk of all-cause and cause-specific mortality [6], since an asymptote exists between energy lost during PA known as metabolic equivalents (METs) and age-adjusted mortality rates. It has been shown that mortality increases at MET values below ~9 in females and >10 in males, but is independent when MET values are higher values [6].

However, parallel to physical exercise the cognitive training is well recognized as having positive effect on CNS, cognitive tasks, and therefore widely recommended especially for older people as prevention against early dementia [37].

It is customary in the prevention training of the older people to be conducted both individually at home and in nursing homes aimed at helping the elderly, where either physical training or cognitive training is used, sometimes both alternately on different days of the week.

However interesting is combining multicomponent exercise intervention composed of exercise and cognitive task. Thus, as the fourth subclass of exercise the term **cognicise** should be added, classified into one of fourth subclasses: 1. resistance, 2. endurance, 3. patterned movements and 4. cognicise. The origin of this term is ***cogni***tive and exer***cise*** [37].

Physical activity stimulates plasticity of brain network

Physical inactivity plays a pivotal role in the development of neurodegenerative disorders. It is well known that the human brain is organized into divisible functional networks that are more active during rest and varied states of activities including cognition tasks or PA. During cognitive exercise some regions of the brain automatically increase activity, whereas others routinely decrease their activity [15]. Default Mode Network (DMN), a fronto-executive network (FE), and a frontoparietal (FP) network, are the well-studied brain networks that communicate between different part of the brain and in consequence are negatively affected by aging that is associated with specific dysfunctions of the brain [41]. Voss et al. [41] demonstrated for the first time that aerobic training improves the resting functional performance of the aging brain. Moreover, the authors found strong evidence that PA increased functional connectivity within the brain networks, which seems highly significant to brain dysfunction in aging. Also among stretching group increased functional connectivity in the DMN as well as in the FP network was observed reflecting experience-dependent plasticity and these intervention are recognized as the first study that demonstrated the existence of exercise-induced functional plasticity in the aging brain. Analogous results were found by other authors [25] after comparing different exercise models i.e. aerobic, resistance, and combined exercise: resistance + aerobic.

Exercise stimulates neural plasticity

Exercise influences to the body by many pathways including upregulating of expression of important molecules such as IGF-1 [11, 40] and brain-derived neurotrophic factor (BDNF) [32].

The other pathways include moderating plasticity in the hippocampus and cortex, as well as increasing resting state perfusion in the hippocampus [27], and increasing dendritic complexity and the number of dendritic spines in the dentate gyrus (DG) [12].

Moreover, animal models showed that aerobic exercises such as voluntary wheel running can significantly reverse declining neurogenesis and memory function [21, 38], improving pattern separation during novel object recognition [7].

However, much common information about the positive influence of aerobic exercise as well as environmental enrichment on improve cognition was originated from a rodent-based model (often studying DG, a sub-region of the hippocampus).

It was Whiteman [44] who showed positive influences of aerobic exercise and environmental enrichment for cognition, in particular for learning and memory [44]. A gray matter volume in a region of the right entorhinal cortex (EC) was positively associated with aerobic fitness.

It is assumed that intervention with voluntary exercise normalized hypothalamic inflammation, neurodegeneration, and glucose metabolism in the Alzheimer's disease (AD) animal model, suggesting that exercise prevents the progression of dementia and AD.

Cognicise

The key question for designing the optimal pattern of physical activity for older individuals is which models of PA are the best fitting for healthy aging process and can support body against dementia and other age related declines. The absolute pioneering research in the era of modern science highlighted that older athletes' performance on comparable tasks was substantially better than the older sedentary individuals, and even comparable to the performance of the young sedentary adults [34]. These study of Spirduso and Clifford presented in the *Journal of Gerontology* in 1978 are real fundament of understanding the role of PA in healthy aging.

The next conclusion is that aerobic exercises decrease the risk of cognitive impairment [19] since it is assumed that exercise enhances hippocampal neurogenesis [36] and cognitive function especially learning in aging [33]. A milestone paper was prepared by Verghese and colleagues and presented in *New England Journal of Medicine*. Authors examined the relation between leisure physical activities and leisure cognitive activities with the risk of dementia. In a numerous cohort of 469 subjects between 75 and 85 years of age stated, that leisure activities such as dancing, playing board games or musical instruments, were associated with a reduced risk of dementia [39]. The conclusion may be drawn that activation of CNS in a specific manner, by physical and cognitive activity, is more advantageous than non-stimulating of the nervous system by cognitive and physical inactivity [35].

The aforementioned studies show that physical activity, especially aerobic exercise, may increase structural and functional integrity in the regions of the brain that decline with age-related dysfunction [9].

To explain in which way exercise acts as CNS 'bodyguard', the following explanations were proposed: 1) neurogenesis and synaptic neural plasticity is caused by the release of neurotrophic factors [2]; 2) exercises cause the reduction of the free radicals in the hippocampus, and increase in superoxide dismutase and endothelial nitric oxide synthase (eNOS) [20]; 3) BDNFs are stimulated to regulate energy homeostasis and mediate beneficial effects of energetic challenges, on cognition, mood, cardiovascular function and peripheral metabolism [22].

The cognicise training is designed into multicomponent exercise intervention, which was reported to have benefits on cognitive improvement and reduction of brain atrophy based on randomized controlled trials. Moreover, Suzuki et al [37] suggest that to achieve synergistic effects of exercise and cognitive stimulation, it might be recommended to design an intervention method **"cognicise"** as a multicomponent exercise program with cognitive loads, containing learning tasks during the exercises. It is well recognized that that regular physical exercise is beneficial in reducing the risk of cognitive decline in older adults [14, 18].

Cognitive stimulation such as for example learning tasks is considered as important in lowering the risk of cognitive decline. Thus, cognitive decline becomes essentially lower in individuals who are more intellectually active compare to inactive mentally individuals, and it is well proofed that multitasking positively stimulate the prefrontal cortex [18]. As a consequence according to Collette and Van der Linden [10] "cognicise" may generate synergistic effects for risk reduction of cognitive decline.

Cognicise training is programmed into multicomponent exercise in two variants that can be called Japanese and Polish models. The Japanese variant of cognicise intervention consists of physical exercise and cognitive exercise existing alternately. In turn, Polish model consists of such exercises where activity of both components are trained simultaneously in each exercise task [31]. For example during dancing, spinning, running on treadmill always exercising to the music, the cadence is adjusted to the beat of music and exercising person make some of given cognitive tasks (for instance including "shifted counting"). The idea behind this unusual way of counting consists in setting series of attentional "traps" for the individual [31] where the participant is counting from one to four, but each cycle of counting starts with a different (next adjoining) number, which means one should count:

• **1**-2-3-4, **2**-3-4-1, **3**-4-1-2, **4**-1-2-3, **1**-2-3-4 etc. instead of

• **1**-2-3-4, **1**-2-3-4, **1**-2-3-4, **1**-2-3-4, **1**-2-3-4 etc. [31].

Digits can be replaced with letters a, b, c, d or colors, which sometimes is preferred by exercising persons, especially those who do not like math.

Mind–body interventions

In the context of cognicise training it seems worthy to mention about the other techniques where empirical data that has emerged in support of the influence of mind–body interventions (MBIs) could be defined as techniques designed to enhance the mind's capacity to affect bodily function and symptoms [43].

Mind–body techniques are recognized as therapies that focus on the associations between the mind, brain, body, behavior and their influence on health and disease [42]. However, mind and behavior do not enter to the exactly same category that brain and body.

The databases are plenty of numerous evidence for the effectiveness of MBIs including Qigong, yoga, Tai Chi, relaxation response, awareness and breath regulation in improving physical and mental health [8]. However, molecular mechanisms of mentioned profits remain not fully recognized and described.

First of all, it attracts our attention that degeneration changes of basal forebrain complex (BFC) neurons are common symptom in patients with dementia and AD. It is supposed that it might be a consequence of the significant reduction in nerve growth factor (NGF), member of neurotrophin family [13]. This molecule is closely involved in work of the peripheral nervous system and the cholinergic neurons of the CNS [1].

Some medical interventions including NGF therapy are very limited because of the necessity of using extremely invasive methods. Such surgery interventions involve intracranial injection of DNA vectors that expresses human NGF. For this reason, non-pharmacological approaches of treatment always should rise our enthusiasm. Such alternative methods that should be studied including MBIs is e.g. yoga.

Well studied are variable yoga breathing (YB) techniques and salivary expressions of NGF in cognitively normal healthy volunteers [4]. Following 20 minutes practice of YB a significant increase in NGF levels was observed. This effect may suggest that yoga could be considered as adjunct method to treat dementia and AD [5]. Moreover, interestingly meditation diminished loss of brain volume with age [23, 24].

Conclusions

In conclusion, the available evidence highlights that exercise may be used in a preventative or mitigating manner for healthy aging. Moreover, it can be stated that cognicise training seems to be the promising and beneficial method, targeted especially for older individuals.

Conflict of interests

The authors declare no conflict of interest.

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ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2021; 28(1): 11-18
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.1-2

Analysis of associations between selected sports performance factors and racing performance in the youth alpine skiing category

IVANA TURKOVA[1,2], JOSEF HEIDLER[1], MARTIN NOSEK[1]

Abstract
Introduction. The research focuses on the analysis of associations between important motor skills that are essential for alpine skiing and performance in the youth category. The study came about in response to the fact that associations between individual concepts of motor abilities and performance in alpine skiing are not clearly described in the literature. Aim of Study. The research aimed to evaluate and identify possible associations between selected factors of sports performance, and actual performance of youth alpine skiers. Material and Methods. A group of 12 elite female Czech youth skiers (16-18 years old) was monitored for their training indicators, racing season performance, and selected sports performance factors (anthropometry, balance, laterality, muscle condition). To evaluate associations of monitored parameters, Spearman's correlation coefficient *r* was used. Results. The results of multiple analyses show no statistically significant correlation between anthropometric features and total FIS race performance. On the other hand, a statistically significant dependence was noted for specific training indicators (skiing hours, gate skiing) and FIS race performance. In the analysis of performance and monitored parameters (laterality, balance) of youth skiers no statistical dependence was found. Thus it may be assumed that the balance on both the dominant and non-dominant leg was the same, although muscle imbalances were identified among the skiers. Conclusions. From the obtained knowledge, we can state that alpine skiing is a complex sport, in which there is no unilateral overloading of the organism. To obtain excellent and steady results during a competition all the examined variables are more or less important for skiers. Without these abilities and skills, skiers' performance will never reach the maximum. Even though conditioning and skills are one of the main features of skiing, we should not forget about regeneration and compensation to prevent a risk of potential muscle imbalances or injuries among young athletes.

KEYWORDS: balance, anthropometrics, alpine skiing, FIS score, muscle imbalances, lower limb laterality.

Received: 2 October 2020
Accepted: 27 January 2021

Corresponding author: ivana.turkova@ujep.cz

[1] *Jan Evangelista Purkyně University, Department of Physical Education and Sport, Ústí nad Labem, Czech Republic*
[2] *Jan Evangelista Purkyně University, Department of Midwifery and Specific Disciplines, Ústí nad Labem, Czech Republic*

Introduction

Alpine skiing, popular all over the world, is an extremely demanding and complex sport requiring a combination of technical, tactical, physical skills as well as high physiological capabilities in strength and endurance training. These factors determine skiers' performance. As a result, no aspect of the sport should be neglected [22]. Additionally, alpine skiing is a high-intensity sport, where lactate accumulation, muscle acidosis and muscle fatigue occur and influence the performance of skiers especially in terms of balance ability [13, 30]. The problem of balance and skiing results lacks sufficient research [18, 19], and the same applies to laterality and muscle imbalances. Therefore, we would like to fill this gap and find possible associations between them.

While a number of scientific papers concerning fine motor skills can be found in Anthropometrics and Development Psychology, it is surprising that almost none of them concerns the connection between alpine skiing and laterality [28], as laterality may play an important role in balance and skiers' performance. Balance has been accepted as one of the most important abilities in alpine skiing and it involves the skier attempting to maintain the center of his/her body vertically over the base support [10, 11, 12]. Elite skiers must fulfill immense physical requirements such as the engagement of the whole body in a streamline and aerodynamic position while making quick movements to make excellent turns [5]. All of these actions require skiers to maintain balance and overall control of their bodies, which requires good coordination of muscle structures in the trunk and lower body [9, 12, 23]. The study has also shown that balance is influenced by anthropometric features [1] and that fact led us to question whether anthropometric features are positively or negatively correlated between the two. Additionally, in terms of balance ability, the authors mainly focus on the relationship with injury cases; few studies explored the correlation between balance and performance [10]. Alpine skiing is a precise sport with a lot of requirements on the skier's body and mind. By monitoring the electromyographic activity of skiers' muscle structures, the researchers concluded that the *tibialis anterior*, *erector spinae*, *gluteus maximus*, *hamstrings*, and *quadriceps muscle groups* were the most engaged structures during elite skiing [9, 23]. Several antagonist muscle structures were shown to help with the stabilization of the knee and hip joints during skiing [9]. In these cases, any single muscle imbalance may limit the development of motor abilities and other skills and as a result affect the skier's sports performance. One study concluded that the importance of stretching is often neglected in alpine skiing [2]. In order to achieve the best results in a physically and mentally demanding sport such as alpine skiing, training needs to combine several aspects. The most common training types for alpine skiers are strength and core stability training, aerobic and anaerobic endurance, coordination, and balance. Competitive skiers combine this with supplementary training, often involving cross-training in other sports [12]. Therefore, our interest was to detect whether skiers take enough time to stretch and train antagonistic muscle pairs to prevent a potential risk of muscle imbalances and injuries, and to determine associations between different types of training and racing performance.

Aim of Study

The research aimed to evaluate and identify possible associations between selected factors of sports performance, and youth alpine skiers' performance.

Material and Methods

Participants

The sample of participants included a group of 12 elite female Czech youth skiers (16-18 years old). The participants were registered competitors in the U18 category in the Czech Republic and have raced for at least 10 years. Skiers in this category compete in slalom (S) and giant slalom (GS). Most of the competitors also competed in international events. Different teams across the Czech Republic were invited to participate provided that the competitors had to be ranked among the top 30 skiers in the 2018/2019 season. All competitors voluntarily participated in the testing after being informed of the purpose of the study. A written consent had to be signed prior to the study either by the participants themselves or by their parents.

Design

This study was conducted in specialized laboratories and under outdoor conditions. In this case, the outdoor conditions were mountains in the Czech Republic, where competitors took part in individual races included in this research. The skiers were monitored for their training indicators, performance in the 2018/2019 racing season, and selected sports performance factors (anthropometry, balance, laterality, muscle condition). Training indicators and performance were evaluated based on an analysis of training diaries and ranking lists of FIS races. The measurements were performed after the racing season. All measurements were obtained according to the WMA Declaration of Helsinki. The research was also approved by the Ethics Committee of the Faculty of Education, Jan Evangelista Purkyně University in Ústí nad Labem under no. 3/2019/02 on April 25, 2019.

Procedures

The testing included measurements of anthropometric variables, balance ability, laterality, muscle imbalance status, as well as evaluation of training performance and competition results.

Anthropometric measurements included height, weight, fitness score, basal metabolism level, skeletal muscle mass and body fat content. Anthropometric variables were evaluated on an In-Body 720 machine in the anthropometric laboratory of the Faculty of Physical

Culture (FPC), Palacky University in Olomouc. Muscular imbalances were also assessed in that laboratory. The shortening and weakening of muscles in individual parts of the human body were evaluated to determine the upper (UCS) and lower (LCS) crossed syndromes, including the evaluation of the foot arch and deformations in the foot area. The muscular apparatus examination was performed according to Dostalova [3]. The examination was performed on both sides of the body by a specialized physical therapist. The following muscles were examined: *m. iliopsoas*, *m. rectus femoris*, *m. tensor fasciae latea*, *m. triceps surae*, *mm. flexor genu*, *m. pectoralis major*, *mm. flexores nuchae*, *m. rectus abdominis*, *m. erector spinae*, *m. gluteus maximus*, *m. gluteus medius et minimus*, *mm. fixatorex scapulae inferiors*, *mm. abductors membri superioris*, *m. trapezius*, while arm stretch backward, side bend and forward bend examinations were also conducted.

In the biomechanical laboratory of the FPC, Palacky University in Olomouc, lower limb laterality and balance ability were evaluated on an AMTI force platform (type OR6-5, Advanced Mechanical Technology, Inc., Watertown, MA, USA, frame rate 200 Hz). Lower limb laterality was evaluated using three tests performed twice per each lower limb. The first test was a step onto a small box, the second test was a slight unexpected push from behind, where the participant had to maintain her stability, while the last test was an aimed kick between two cones. Balance was measured on three different surfaces, namely, the rigid platform of the force platform, a soft surface, which was mediated by a foam pad (Airex Balance Pad, Airex AG, Sins, Switzerland), and an unstable pad, which was secured by a balancing segment (ClassicR25V10, VSB – Technical University of Ostrava, Ostrava, Czech Republic). Firstly, before the testing participants tried each surface to establish their balance and feel comfortable. Then the participants took an initial position on the platform, which included standing straight on a dominant/non-dominant leg, as had been determined by the laterality tests, with the other leg bent at the knee and the foot pointing back. The arms were kept to the sides of the body and the participant looked straight forward at a point on the wall. Each test was performed twice for the dominant and non-dominant leg, lasting 30 seconds, with a 2-3-minute rest between tests. The surfaces of the platform were chosen randomly, but the dominant/non-dominant legs were alternated each time. The measurements of balance ability were calculated through the center of pressure (COP) position, which is the calculated value only from the forces acting on the pad. The COP position was calculated from the reaction force and torque according to the conversion formulas provided by the platform manufacturer. The COP coordinates were further filtered by a 4-way Butterworth low-pass filter with a 10 Hz cutoff frequency. The parameters of the COP movement were calculated as follows: Sway – a standard deviation of the COP position in each direction (medio-lateral and antero-posterior), Speed – an average speed of COP movement in each direction and overall. All balance calculations were performed in the Matlab software (v2018b, Mathworks, Inc., Natick, MA, USA).

Anthropometric measurements were performed at the beginning of the testing and they were followed by imbalance testing, determining laterality and balance performance.

Physical performance was determined by observation and competitive performance. Observation included the evaluation of training diaries, with summer and winter training taken in account (number of skiing hours, number of gates, endurance training hours, gym hours, functional training hours). Competitive performance was evaluated based on the skiers' ranking at the end of the season according to the FIS scores.

Statistics

The Shapiro–Wilk test showed variables as not normally distributed. Therefore, to evaluate associations of the monitored parameters Spearman's correlation coefficient r was applied. All the variables were analyzed using the Rstudio program, version 1.2.1335. Statistical significance was pre-determined as $p < 0.05$.

Results

Among the anthropometric measurements (Table 1), no significant correlation was found between the FIS

Table 1. Spearman's correlation between In-Body measurements and FIS score (coefficient *r*)

	FIS TS	FIS S	FIS GS
Height	0.45	0.46	0.48*
Weight	0.39	0.28	0.30*
Fitness score	0.21	0.09	0.11
Metabolic rate	0.53	0.46	0.48*
Muscle mass	0.52	0.44	0.45*
Fat mass	0.08	–0.02	–0.03

Note: FIS TS – FIS total score; FIS S – FIS slalom score; FIS GS – FIS giant slalom score
* statistically significant values

total score (TS) and the FIS S score. On the other hand, there were statistically significant values for the FIS GS score, where taller skiers obtained higher FIS scores than shorter ones. The same effect was identified for the competitor's weight.

The correlation results for the training and FIS scores indicated statistically significant relationships between the number of skiing hours and the number of gates trained throughout the whole year with FIS TS and FIS GS scores (Table 2). All of the other variables were not statistically significant.

Table 2. Spearman's correlation between observed types of training and FIS score (coefficient *r*)

	FIS TS	FIS S	FIS GS
Skiing	–0.80*	–0.72*	–0.75*
Gates	–0.75*	–0.65*	–0.69*
Endurance	–0.10	–0.16	0.41
Gym	0.48	0.35	0.44
Functional	–0.55	–0.53	–0.36

Note: FIS TS – FIS total score; FIS S – FIS slalom score; FIS GS – FIS giant slalom score
* statistically significant values

The level of balance on the dominant and non-dominant leg was determined as statistically non-significant. For that reason, it was assumed that the balance on both legs was the same. Another aspect tested in the study was the association between the skier's balance and performance (FIS TS, S, GS score), where either the dominant or non-dominant leg on different surfaces (rigid surface, foam pad, balancing segment) indicated a close correlation to the skier's performance (Table 3). Statistically significant values were found in giant slalom performance in a medio-lateral movement on both the dominant and non-dominant leg on the rigid platform.

Lastly, the UCS was diagnosed in 50% of cases (shortened – ascendant part of *m. trapezius* and *m. pectoralis major*, weakened – *m. longus colli*, *m. longus capitis* and *m. rhomboideus*). Slight muscle changes were diagnosed in 30% of the study participants. On the other hand, while no one was diagnosed with the LCS (shortened – *m. iliopsoas*, *m. rectus femoris*, *m. tensor fasciae latae*, *m. quadratus lumborum* and *m. erector spinae*, weakened – *m. rectus abdominis*, *m. gluteus maximus*, *m. gluteus medius* and *minimus*), some participants were close to developing it.

Table 3. Spearman's correlation between balance on different platforms and FIS score (coefficient r)

	FIS TS		FIS S		FIS GS	
	DL	NL	DL	NL	DL	NL
Rigid Platform						
Sway 1	0.48	0.28	0.38	0.22	0.78*	0.65*
Sway 2	0.15	0.32	0.14	0.44	0.37	0.50
Speed	0.26	0.35	0.26	0.37	0.54	0.58
Foam Pad						
Sway 1	0.33	0.27	0.28	0.24	0.52	0.64
Sway 2	0.07	0.03	–0.04	0.01	0.19	0.50
Speed	0.13	–0.27	0.09	–0.36	0.35	0.21
Balancing Segment						
Sway 1	0.22	0.37	0.22	0.42	0.58	0.75*
Sway 2	0.14	0.32	0.16	0.33	0.27	0.54
Speed	–0.14	0.08	–0.12	0.03	0.12	0.12

Note: FIS TS – FIS total score; FIS S – FIS slalom score; FIS GS – FIS giant slalom score; DL – dominant leg; NL – non-dominant leg; Sway 1 – standard deviation of the COP position in medio-lateral movement; Sway 2 – standard deviation of the COP position in antero-posterior movement; Speed – total average COP speed
* statistically significant values

Figure 1 displays muscles most commonly involved in skiing and the corresponding percentages of disability (weakened muscles – 0% *m. rectus abdominis*, 20% *m. gluteus medius* and *minimus*, 50% *m. deltoideus*, 60% *m. gluteus maximus*; shortened muscles – 30% *m. triceps surae*, 40% *m. biceps femoris*, *m. semitendinosus*, *m. semimembranosus*, *m. quadriceps femoris*, 60% *m. tibialis anterior*, *m. erector spinae*). The associations

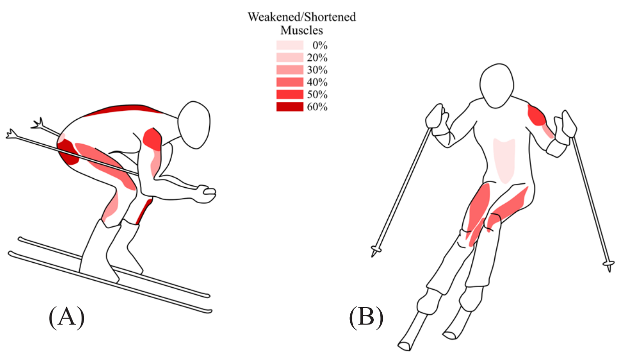

Figure 1. Overview of muscle imbalances on commonly involved muscles in skiing (A – downhill posture position, B – slalom posture position)

between the foot arch, deformations in the foot area and balance ability were not determined as statistically significant in any aspect, therefore those results are not presented.

Discussion

Regarding anthropometric variables, other studies reported different results. Lesnik and Zvan [14] aimed to determine the level of correlation between body dimensions and competitive success among 11- and 12-year old skiers and they confirmed that body weight and height parameters statistically influenced the skiers' performance. Conversely, Neumayr et al. [16] studied the anthropometric variables among skiers of the Austrian World Cup team in their mid-twenties and found no association between body height and weight, and skiers' performance. To widen the age range, our research included 16- to 18-year old skiers. We discovered an association connected to both body height and weight with skiers' GS competition performance. The results demonstrate that the heavier and/or taller a skier was the worse results she achieved. However, this may have been caused by the age of the skiers, their development, or abilities because the skiers have just gone through physical, mental, and cognitive changes. These changes might not help the skiers with their racing performance at all, because they have to adapt to new variables such as changes in coordination and overall body structures. The skiers' height may suddenly increase up to 10 cm per year and they may also gain weight. Weight gain is connected to the distribution of fat and muscle mass. Therefore, in this age category there are considerable performance differences between females and males [24, 25]. Another interesting aspect is connected with differences between slalom and giant slalom and their load intensity on the skier's organism. Slalom is the shortest event, lasting only 45–60 s with speeds ranging from 20 to 60 $km \cdot h^{-1}$. In slalom there are a total of 40–60 gates per run, with 4–13 m between gates. On the other hand, the giant slalom takes place in a relatively steep and undulating terrain. Giant slalom lasts 60–70 s with the speed range of 60–90 $km \cdot h^{-1}$, and the distance between gates of min. 10 m [17]. Hence height and weight might negatively influence giant slalom skiers' performance. Coordination for taller and heavier girls at higher speeds may be more challenging.

Another selected variable that affects racing performance is training. According to the skiers' training diaries, they trained frequently, focusing on different components. Even though skiers underwent most of the training types suggested by Hydren et al. [12], we still found no association between individual types of training and skiers' performance. The reason is that all types of training are part of the performance. Without these certain types of training, the skiers would not be able to obtain such results. For that reason, alpine skiing is identified as a complex sport.

The research on the Training of Olympic Alpine Ski Racers presents the number of training sessions for functional training, endurance training and the gym. Gilgien et al. [7] stated that functional training is performed most frequently throughout the week (average 8 sessions per week), followed by endurance training and the gym. This confirms our findings that functional training may be considered the most efficient training method for alpine skiers. Our youth skiers participate in functional training on average 3 times per week. It must be taken into consideration that our participants were not elite professional competitors, therefore they did not train as many hours as Olympic athletes. It is crucial to point out that during functional training most of the muscles work intensively and dynamically, which is one of the features of skiing. Consequently, it appears to be an effective way to train in alpine skiing.

Also endurance training is essential for skiers. It consists of numerous short training runs [7, 21], as it helps to recover faster between each run and sessions. Without advanced endurance abilities skiers reach their limits quickly and fatigue can severely limit the training and learning process. Also, fatigue decreases performance in terms of physical and technical aspects [21].

Additionally, Olympic alpine skiers train and compete for approximately 130-150 days a year. The total volume of their training is distributed according to the disciplines, in which the skier specializes [7]. In our case, the youth skiers trained and competed for 100-130 days of the year. Our participants mainly trained the technical disciplines, i.e. slalom and giant slalom, as for safety reasons these are the only disciplines performed in their age category.

The study also tried to identify possible associations between balance on the dominant and non-dominant leg and skiers' performance. Firstly, balance needed for skiing is difficult to evaluate in laboratories, because athletes frequently make adjustments due to internal and external forces. It is a challenging task to choose the appropriate testing technique [17]. As previously mentioned, it is difficult to create real snow conditions in a laboratory. For that reason, we tested our participants on different platforms to see if there was any association. Secondly, it is challenging to evaluate and calculate results from one competition in alpine skiing, as not all skiers might finish the race [8, 27]. Accordingly, we took into consideration the results from the entire season (total FIS score). Thirdly, studies have shown that balance is influenced by anthropometric features. Therefore, skiers who lack balance probably quit the competitive environment, because there were already unsuccessful in lower age categories [1].

Another factor in this study was laterality. Surprisingly, alpine skiing laterality was only examined in terms of knee injuries [28], while Vaverka and Vodickova investigated it as an aspect of ski turning by [29]. In our research, we took into consideration all of the facts mentioned above. In our findings, we confirmed that there was no correlation between the dominant and non-dominant leg. Also, no such relationship was confirmed in balance ability. It would be worthwhile to evaluate more participants, potentially adding dynamic testing on the platform to see whether in some situations balance can help skiers. For athletes with a history of injuries or those who suffer from some sort of chronic injury, good balance and the accompanying training are an essential part of recovery. However, it is not always easy for skiers to incorporate this into their busy training schedule [4, 6].

Other issues related to injuries include stretching and muscle imbalance. Studies concluded that the importance of stretching is often neglected in alpine skiing. Research showed that stretching is a crucial tool for skiers to improve flexibility and elasticity, which helps with a range of motion in the joints, injury prevention (cold and unstretched muscles are more likely to tear) and fluid body movement (it promotes dissipation of lactic acid in muscles) [2, 26]. It was proven in a longitudinal study that the risk of ACL injury is greater in female athletes. This finding suggests that core strength is a predominant critical factor for ACL injuries in young ski racers [20]. Another common injury is caused by overusing the muscles of the lower back. It is caused by the volume of mechanical overloading and the specific sports patterns where skiers are involved in forward, backward, and sideways bending, as well as torsion in the pre-load spine [15].

Overall, we can confirm that certain muscle imbalances may lead to future injuries if they are not compensated. All of the study participants were girls and interestingly none of them had problems with core strength. Hopefully, this means they are unlikely to experience any ACL injuries in the future. When we talk about mechanical overloading of the skier's body, it applies to the required posture of the skier while racing or training. Fifty percent of our participants were diagnosed with the upper crossed syndrome that comes from this specific posture when the stretching and exercising were inappropriate. Twenty percent of the participants were diagnosed with no muscle imbalance changes, whereas the remaining 30% were diagnosed with slightly weakened and shortened muscles. On the other hand, we cannot talk about the lower crossed syndrome, as it was not diagnosed in any of the participants. Nevertheless, most of the skiers have weakened *m. gluteus maximus* and shortened *m. rectus femoris*, *m. tensor fasciae latae* and *m. erector spinae*. This resulted from the bending position, where these muscles are overloaded and not compensated enough. Therefore, compensation should be applied as soon as possible to prevent the skiers from developing the lower crossed syndrome.

Conclusions

Based on the obtained data we can state that alpine skiing is a complex and challenging sport, in which many variables can play a role. Within the anthropometrics and performance correlation, we identified a negative correlation between achieved results and both the weight and height of the skier. This means that the heavier and/or taller the skier was, the worse results she achieved. The analysis also showed that among the observed skiers functional training is considered as the most efficient training method for alpine skiers' performance. No correlation was observed between measures of balance and laterality with performance. Lastly, we found that half of the tested skiers had the upper crossed syndrome, which can be explained by poor stretching and muscle overload in the skiing position.

Funding

The research was realized with the support of the Specific University research grant SGS in Jan Evangelista Purkyně University in Ústí nad Labem, no. of the grant 43212 15 2002.

Acknowledgements

The research findings were presented on the Quality of Life in Interdisciplinary Approach, 2nd World Scientific Congress on November 5-7, 2019, in Kochcice, Poland.

Conflict of Interests

The authors declare no conflict of interest.

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ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2021; 28(**1**): 19-27
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.1-3

Electromyographic evaluation of spine and lower extremity muscles during repeated and sustained bodyweight deep-squat

BELA MANISH AGARWAL[1], ROBERT VAN DEURSEN[2], RAJANI PRASHANT MULLERPATAN[1]

Abstract
Introduction. Squat is a preferred exercise included in strengthening and rehabilitation protocols due to its ability to recruit large muscles of the spine and lower extremities. Speed of performing movement and regular practice are known to influence muscle activation. However, muscle activation during fast-repeated bodyweight deep-squat and sustained deep squat remains less explored. Aim of Study. This study aimed at exploring muscle activation during fast and sustained bodyweight squat and observing the effect of habitual squat exposure on spine and lower extremity muscle strength and activation. Material and Methods. Forty healthy adults (30-45 years), with varying daily squat exposure, were recruited for this cross-sectional study following an institutional ethical approval. Superficial electromyography of the erector spinae, rectus abdominis, gluteus maximus, gluteus medius, vastus lateralis, biceps femoris and the gastrocnemius was recorded during a single controlled squat, repeated fast squat and sustained squat. Muscle strength was evaluated using a trunk-leg dynamometer. Results. Higher muscle activity was observed during the ascent phase (81-240% MVC) and the descent phase (76-292% MVC) of a single squat, whereas the sustaining squat demanded low muscle activity (27-58% MVC). Repeated fast squatting elicited 2.5--10 times greater muscle activation than sustained squat. Muscle activity did not vary significantly among people with varying squat exposure. A moderately strong negative correlation was observed between deep squat repetitions and age ($r = -0.710$, $p \leq 0.001$), whereas a moderate positive correlation was observed between deep squat repetitions and force developed during trunk and leg dynamometry ($r = 0.610$, $p < 0.001$, $r = 0.654$, $p < 0.001$, respectively). Substantial co-activation of the erector spinae–rectus abdominis, biceps femoris–vastus lateralis and gluteus maximus–gluteus medius was observed during fast repeated squat. Conclusions. Repeated, dynamic, bodyweight deep-squatting exercises elicited greater muscle activation compared to sustained squat. Exercises over and above habitual activities of daily living involving sustained squatting are essential to obtain greater benefits in muscle strength.

KEYWORDS: electromyography, muscle strength, squat, strength training, physical conditioning.

Received: 11 November 2020
Accepted: 29 December 2020

Corresponding author: rajani.kanade@gmail.com

[1] *MGM Institute of Health Sciences, MGM School of Physiotherapy, Navi Mumbai, India*
[2] *Cardiff University, School of Healthcare Sciences, Cardiff, United Kingdom*

Introduction

Squat exercises are an important component of strengthening protocols especially in sports training and musculoskeletal rehabilitation [5, 12, 19, 23, 24]. Deep squat is a triple flexion movement, which moves the hip, knee and ankle joints over an almost full range of motion, simultaneously activating several muscles of the spine and lower extremities [12, 13, 24].
Superficial electromyography (sEMG) is an established, non-invasive, electrophysiological recording technique used to detect electric potential generated due to muscle excitation [30]. Muscle activation patterns during exercises, the level of activation and a comparison against maximum voluntary contraction, enables a comparison of capacity versus performance of an individual during

an activity. Based on observations during EMG studies, exercises can be prescribed to enhance activation of specific muscles as well as determine the intensity of activity required to elicit the desired strengthening effect.

Several studies have reported the muscle activation pattern during deep squat. Squat is initiated by the deactivation of the erector spinae to bring about trunk flexion. Further, hip-knee flexion and ankle dorsiflexion are brought about by the activation of the tibialis anterior and hamstring muscles [13, 16]. As the knee flexion progresses, a strong knee extensor activity is generated to counterbalance the external flexor torque and maintain balance. Knee flexion beyond 70º results in an increased muscle activity of the vastus lateralis, gastrocnemius and gluteus maximus [7]. At full depth of squat, the thigh-calf contact results in a reduction of torque [27]. However, biarticular muscles such as hamstrings and quadriceps co-contract to maintain knee stability [21]. Although EMG activity during the eccentric and concentric phase of squat is reported, muscle activity during sustained, bodyweight deep squat and fast repeated, bodyweight deep squat is poorly explored. This information would be particularly useful while prescribing squat exercises to obtain a maximal strengthening effect, using bodyweight, in healthy adults and people with weak spine and lower extremity muscles.

Secondly, people from the Asian and African subcontinents are already habituated to spending a varying duration of time in the deep-squat posture to perform activities of daily living and occupational tasks [14]. Physical activity involving deep squat can serve as a beneficial exercise stimulus inducing physiological adaptation in muscles of lower extremities [20]. It was hypothesized that static-dynamic muscle activations while performing ADL would lend greater muscle strength and muscle activation in people with high squat exposure.

Therefore, the objectives of this study were to explore muscle activation of lower extremities and spine muscles during repeated and sustained deep squat and to identify whether habitual squat exposure leads to differences in muscle activation and strength of spine and lower extremity muscles. The information gained would be useful for prescribing tailor-made squat exercise programs for healthy people and people with movement dysfunctions.

Aim of Study

This study aimed at exploring muscle activation during fast and sustained bodyweight squat and observing the effect of habitual squat exposure on spine and lower extremity muscle strength and activation.

Material and Methods

An observational, cross-sectional, electromyography-based study was undertaken to explore muscle activation during repeated and sustained deep squat. Ethical approval was sought from the Ethical Committee for Research on Human Subjects (MGMIHS/RS/2015--16/190). Participants were tested at the Centre of Human Movement Sciences. Forty healthy adults, not engaged in formal strength training or physical activity programs, were recruited. People with known musculoskeletal, cardiovascular, respiratory, metabolic or neurologic disorders, musculoskeletal injury or pain in the past year or any discomfort that prevented participation were excluded. A written informed consent was obtained from all participants as per the Declaration of Helsinki guidelines.

Participants

Participants were grouped based on squat exposure into non-squatters (people with nil squat exposure, n = 15; 7 male, 8 female) and habitual squatters who were further classified as activity of daily living (ADL) squatters (i.e. people who adopt squatting to perform self-care activities and household chores, n = 14; 7 male, 7 female) and occupational squatters (i.e. people who adopt squatting for occupational tasks and ADL, n = 11; 5 male, 6 female). People with squat exposure for self-care and household chores were classified as ADL squatters, while people with squat exposure for occupational activity in addition to ADL were classified as occupational squatters.

Procedure

Squat exposure was quantified using a reliable and validated tool, i.e. the MGM Ground Level Activity Questionnaire [3]. Habitual physical activity was quantified using the International Physical Activity Questionnaire – Short Form (IPAQ) [9].

Muscle activity was recorded during single squat, repetitive squat, sustained deep squat and maximum voluntary contraction (MVC) using wireless superficial electromyography (sEMG) 8 channel system (Trigno Wireless EMG System; Delsys, Inc., Boston, MA, USA) at a sample rate of 2,000 Hz, with a bandwidth of 20-450 Hz, common mode rejection ratio >80 dB, and noise <0.75 μV. Muscle activity was evaluated on the right side of the body as previous studies have demonstrated that deep squat is a symmetrical activity [22].

Bipolar sensors were placed on the skin over seven muscles, namely the erector spinae, rectus abdominis (as prime movers of the trunk), gluteus maximus, gluteus medius, vastus lateralis, biceps femoris and the medial head of the gastrocnemius (as primary muscles controlling motion at the hip, knee and ankle joints during squat activity) [11]. Electrodes were placed as per SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles) recommendations [24]. Following skin preparation by shaving, peeling and cleaning the electrodes were positioned as described by researchers in previous studies [1, 24, 25, 26, 27]. Electrodes were secured with adhesive tape to prevent displacement during exercise.

EMG was recorded while performing a 10-second maximum voluntary contraction (MVC), targeting each muscle using standard methods, in order to normalize and compare muscle activity between the different activities and groups. The sEMG signal of MVC was recorded using functional test positions described previously [5, 6, 18, 19, 20]. Maximum manual resistance was opposed by the researcher in a direction opposite to the motion being tested [4].

Electromyography data from mid-8 seconds of the 10 second MVC were analysed using the EMG analysis software (National Instruments, Austin, TX). Raw EMG data were band-pass filtered at 20 to 450 Hz and smoothed using a root mean square sliding window function with a time constant of 20 milliseconds, window length of 0.125 sec and window overlap of 0.0625 sec. Data was inspected for artifacts and power spectral analysis was performed. Data corrupted with motion artifacts and high signal noise were excluded from the analysis.

Muscle activity was evaluated while participants performed a single deep squat. Participants were requested to keep hands stretched forwards, adopt a comfortable stance, descend to deep squat (150° knee flexion), sustain the position for 5 seconds and ascend to stand.

For evaluation of muscle activity during sustained deep squat, participants were requested to keep hands stretched forwards, adopt a comfortable stance, descend to deep squat, sustain the position for 30 seconds and ascend to stand. Participants were given a 5-minute rest period following the test.

Patterns of muscle activity during fast repetitive squat were evaluated using the 30-second deep-squat test. Participants were instructed to perform as many deep squat repetitions as fast as possible, in a period of 30 seconds. The number of complete squat-stand repetitions was recorded. A higher number of repetitions indicated greater muscle strength-endurance. sEMG was recorded continuously during the test. No participant reported any discomfort during the test. Participants were given a 5-minute rest time following the test.

Muscle strength of lower extremity and trunk muscles was evaluated using a calibrated Back-Leg-Chest Dynamometer (Model SH5007, Saehan Corporation, Korea). The dynamometer measured isometric muscle strength, recorded in kilograms (kg) of force. Vertical upward force was applied to a handle attached to an adjustable chain. Participants were instructed to stand on the base of dynamometer with knees flexed to 30° and pull handle upwards with maximal force while extending the spine and to maintain the isometric hold for 10 seconds. During measurement of leg strength participants maintained a 110° knee flexion and simulated the action of rising from a chair while exerting maximal force on the handle of the dynamometer [28].

Statistical analysis

Statistical analysis was performed using the SPSS Version 24 software. Normality of data was tested using the Shapiro–Wilk test. As the data followed normal distribution, parametric tests were used for further analysis. Measures of central tendency and dispersion were calculated. RMS of muscle activity normalised with RMS of MVC was used for analysis. Muscle activity during single squat, sustained squat and fast repetitive squat was compared using ANOVA. BMI and IPAQ scores were used as covariates while comparing muscle strength between the three groups using ANCOVA. Correlations between variables were analysed using Spearman's correlation coefficient.

Results

Demographic characteristics of the three groups are presented in Table 1.

All three groups were matched on marginal distributions for age and gender. However, it was difficult to match the three groups on body mass due to inherent lifestyle variations in groups. Daily deep-squat exposure was nil in non-squatters, moderate in ADL-squatters (mean exposure 33 min/day) and high in occupational squatters (mean exposure 104 min/day).

Habitual physical activity was scored using the International Physical Activity Questionnaire – Short Form. Large standard deviations were observed in habitual physical activity with habitual squatters reporting higher levels of physical activity than non-squatters (Table 1).

Table 1. Demographic characteristics, habitual physical activity and daily squat exposure in non-squatters, ADL squatters and occupational squatters

Variable	Non-squatters n = 15 Mean (SD)	ADL squatters n = 14 Mean (SD)	Occupational squatters n = 11 Mean (SD)	*p-value* using ANOVA/ANCOVA
Age (years)	36.3 (3.4)	36.7 (5.2)	39.3 (5.7)	0.221
Height (cm)	157.9 (8.8)	161.1 (10.9)	155.2 (8.3)	0.117
Body mass (kg)	65.9 (11.6)	60.4 (16.6)	51.2 (10.1)	<0.001*
BMI (kg/m^2)	26.4 (3.8)	22.9 (4.4)	21.2 (4.0)	<0.001*
IPAQ score (MET min/week)	326.3 (605.4)	1048.3 (2722.0)	1943.8 (4219.8)	0.193
Daily squat exposure (min)	0	33.7 (28.6)	104.5 (96.8)	<0.001*
Muscle strength				
Trunk dynamometry (kg)	61.5 (27.4)	63.1 (33.9)	78.2 (35.2)	0.485
Leg dynamometry (kg)	42.6 (15.8)	46.6 (19.38)	54.3 (19.35)	0.368

Note: ADL – activity of daily living
* level of significance $p < 0.05$

Table 2. Performance on 30-second deep squat test and muscle activity of seven prime movers of trunk and lower extremities during 30-second repeated deep squat and 30-second sustained squat in non-squatters, ADL squatters and occupational squatters

Variable	Non-squatters Mean (SD)	ADL squatters Mean (SD)	Occupational squatters Mean (SD)	*p-value* using ANOVA
30-sec DST reps	13.8 (3.0)	13.7 (3.1)	14.0 (5.5)	0.857
RMS % MVC during 30-sec repeated deep squat				
Erector spinae	320.6 (240.2)	249.6 (168.2)	261.6 (178.7)	0.712
Rectus abdominis	213.6 (118.6)	175.2 (118.3)	214.1 (292.9)	0.843
Gluteus maximus	187.6 (169.4)	122.0 (86.4)	114.8 (77.4)	0.391
Gluteus medius	245.1 (474.3)	144.1 (189.2)	95.9 (34.2)	0.606
Vastus lateralis	245.9 (171.8)	232.6 (202.6)	128.9 (54.8)	0.404
Biceps femoris	337.5 (384.8)	534.9 (571.8)	115.6 (45.5)	0.160
Gastrocnemius	482.7 (452.0)	218.3 (197.0)	177.9 (100.2)	0.597
RMS % MVC during 30-sec sustained deep squat				
Erector spinae	38.7 (19.5)	57.8 (49.8)	65.1 (45.5)	0.559
Rectus abdominis	62.3 (70.5)	83.1 (115.3)	114.3 (124.4)	0.532
Gluteus maximus	39.4 (61.0)	49.0 (46.5)	39.3 (41.1)	0.907
Gluteus medius	20.0 (19.2)	14.9 (9.8)	33.2 (44.2)	0.378
Vastus lateralis	31.6 (19.4)	63.7 (83.4)	46.8 (42.5)	0.590
Biceps femoris	36.1 (39.0)	28.6 (30.6)	30.5 (23.5)	0.900
Gastrocnemius	43.8 (55.1)	14.2 (8.6)	35.3 (45.2)	0.458

Note: ADL – activity of daily living; DST – deep squat test
Level of significance $p < 0.05$

A single deep squat elicited substantial activation of all tested prime movers of the trunk and lower extremities in all the three groups of healthy adults. The average time taken to perform a single squat was 4.5 sec, with the mean speed of 0.226 m/s. The average speed of descent was 0.209 m/s, whereas the speed of ascent was 0.247 m/s in a single squat.

During the 30-second repeated fast deep squat test, participants could perform on average 13.7 squats (SD 3.9). Mean time taken to perform one squat during fast repeated squatting was 2.3 sec, while the speed was 0.447 m/sec, which was 2 times the speed of a single squat. Therefore, it was not surprising that repeated deep squat elicited 2.5-10 times greater muscle activity compared to a 30-second sustained squat ($p < 0.05$--0.001). Non-squatters demonstrated muscle activity equivalent to 1.87-4.82 times MVC, ADL squatters 1.22-5.32 times MVC and occupational squatters presented 0.95-2.21 times MVC during repeated squats. In turn, during sustained squatting lower muscle activation

Table 3. Comparison of muscle activity during descent, sustained and ascent phases of single squat among non-squatters, ADL squatters and occupational squatters

	Non-squatters Mean (SD)	ADL squatters Mean (SD)	Occupational squatters Mean (SD)	*p-value* using ANOVA
	RMS % MVC during descent phase of squat			
Erector spinae	147.8 (202.9)	143.1 (160.3)	137.6 (99.3)	0.992
Rectus abdominis	101.0 (71.3)	64.6 (40.2)	64.3 (72.1)	0.405
Gluteus maximus	118.6 (172.2)	58.8 (43.6)	140.8 (122.7)	0.744
Gluteus medius	45.0 (43.3)	52.5 (48.9)	134.5 (260.1)	0.409
Vastus lateralis	112.3 (54.7)	64.2 (24.6)	77.9 (44.1)	0.072
Biceps femoris	287.7 (564.7)	268.2 (249.4)	322.8 (559.0)	0.968
Gastrocnemius	167.4 (101.2)	34.7 (33.1)	135.5 (88.2)	0.228
	RMS % MVC during sustained phase of squat			
Erector spinae	38.4 (23.3)	56.6 (45.4)	59.5 (22.1)	0.377
Rectus abdominis	64.4 (78.6)	55.7 (44.7)	33.2 (39.6)	0.573
Gluteus maximus	23.3 (30.4)	30.4 (29.4)	48.8 (33.9)	0.478
Gluteus medius	15.5 (15.3)	22.8 (27.4)	43.7 (84.5)	0.503
Vastus lateralis	26.9 (14.9)	22.3 (17.3)	37.0 (19.1)	0.246
Biceps femoris	99.3 (135.6)	52.7 (109.3)	22.4 (15.8)	0.390
Gastrocnemius	98.4 (99.5)	13.4 (4.4)	22.7 (21.7)	0.073
	RMS % MVC during ascent phase of squat			
Erector spinae	196.3 (202.7)	118.5 (65.3)	217.2 (175.9)	0.418
Rectus abdominis	94.3 (88.4)	81.4 (86.8)	69.4 (55.6)	0.826
Gluteus maximus	103.5 (86.9)	93.2 (73.9)	290.3 (183.9)	0.327
Gluteus medius	82.6 (125.1)	71.6 (68.5)	243.0 (196.2)	0.408
Vastus lateralis	146.1 (81.8)	87.1 (43.2)	75.3 (58.0)	0.070
Biceps femoris	345.6 (357.6)	166.3 (165.0)	210.7 (161.9)	0.265
Gastrocnemius	201.7 (178.3)	127.5 (96.3)	147.8 (50.3)	0.909

Note: ADL – activity of daily living
Level of significance $p < 0.05$

equivalent to 0.20-0.62 times MVC was observed in non-squatters, 0.14-0.83 times MVC in ADL squatters and 0.30-1.14 times MVC in occupational squatters.
The number of repetitions performed during a 30-second DST and muscle activity were not significantly different between the three groups (Table 2, Figure 1).

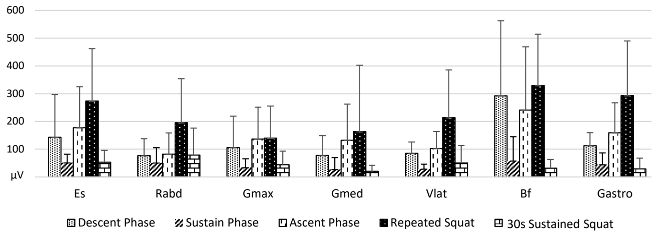

Figure 1. Average muscle activity of seven prime movers of trunk and lower extremity during descent, sustain, ascent phases of single deep squat, repeated deep squat and sustained deep squat

A moderately strong negative correlation was observed between deep-squat repetitions and age ($r = –0.710$, $p \leq 0.001$), whereas a moderate positive correlation was observed between deep-squat repetitions and force developed during trunk and leg dynamometry ($r = 0.610$, $p < 0.001$, $r = 0.654$, $p < 0.001$, respectively).
Secondly, we observed variations in muscle activity among the three groups of people with varying quantum of daily deep-squat exposure. Discernibly, people with varying squat exposure demonstrated varying patterns of movement during deep squat. Most non-squatters could not perform a foot-flat squat. Squat was initiated with trunk flexion, hip-knee flexion and raising heels off the ground at full depth of squat. Greater trunk flexion was observed at full squat depth. In contrast, ADL and occupational squatters could perform a foot-flat deep-squat while maintaining an erect trunk. Participants were allowed to perform a natural squat, as it was hypothesized that controlling the squat movement would influence the muscle activation pattern. Despite variations in movement pattern, no significant difference was observed in the activity of the sampled muscles, which could be due to large standard deviations in RMS (Table 3).
Additionally, force generated during trunk and leg dynamometry did not differ significantly between the groups. There was a relatively marked negative correlation between strength measures and age ($r = –0.381$, $p = 0.01$ and $r = –0.405$, $p = 0.006$ respectively) (Table 1). A very strong positive correlation was observed between trunk and leg muscle force ($r = 0.810$, $p < 0.001$). No influence of the habitual level of overall physical activity or BMI was observed on trunk-leg dynamometry force when the IPAQ scores and BMI were used as covariates.

Discussion

The current study explored activation of spine and lower extremity muscles during single squat, sustained and repeated deep squat using electromyography along with a comparison of muscle activity and muscle strength in people with varying squat exposure.
Although numerous muscles are recruited during deep squat, only the prime movers of the spine and lower extremities were evaluated in this study due to the technical limitation of available EMG channels. Bodyweight deep squat activated all seven selected muscles. Greater activation was observed during the ascent (81-240% MVC) and descent phases (76-292% MVC) compared to the sustaining phase of squat (27-58% MVC). Higher EMG activity during repeated squatting may be attributed to greater angular speed compared the sustained static phase of a sustained squat. Dynamic squatting demands greater muscle activation in order to maintain joint stability and a satisfactory execution technique [4, 17, 18]. Non-squatters demonstrated greater activation of the erector spinae (3.2 times MVC), vastus lateralis (2.4 times MVC), biceps femoris (3.3 times MVC), vastus lateralis (2.4 times MVC) and the gastrocnemius (4.8 times MVC), which may be attributed to the greater forward flexion of the trunk, need for greater stabilization of the knee and the plantar flexed foot during squat. Comparatively, ADL and occupational squatters required lower muscle activation during repeated squat as they were habituated to performing squat. The lower recruitment of the erector spinae (2.4-2.6 times MVC), vastus lateralis (1.2-2.3 times MVC) and the gastrocnemius (1.7 -2.1 times MVC) in ADL and occupational squatters may be a result of motor engrams formed during the habitual activity associated with a reduced synergistic muscle activity, greater stability of the knee, enhanced postural control leading to lower proximal hip and distal ankle muscle activation. Compared to dynamic squatting, lower muscle activation was observed in all the three groups during sustained squat. Sustaining the squat posture brought about contact between the posterior thigh-calf and anterior abdominal wall-thigh, which offered passive stability to the trunk and pelvis and reduced overall muscle activity required to sustain the posture.
Secondly, substantial co-activation of the erector spinae–rectus abdominis, biceps femoris–vastus lateralis and the gluteus maximus–gluteus medius was

observed during deep squat. Similar findings are reported while performing partial and parallel squats to varying depth [12]. During repeated squat, the muscle activity ratio of the erector spinae : rectus abdominis pair was 1.3, whereas during sustained squat it was 0.6, indicating that the erector spinae was activated to a greater extent during dynamic squatting, whereas its activity reduced during sustained squat due to the passive anterior support. In contrast, the ratio between the vastus lateralis : biceps femoris pair was 0.7 during repeated squat and 1.5 during sustained squat, indicating that a greater activation of the hamstring muscles was required to maintain knee stability to sustain the posture. Thus, repeated squat emerges as an effective exercise bringing about activation of dynamic stabilisers of the spine, hip and knee.

Additionally, published reports indicate that muscle activity equivalent to 10-25% MVC is effective in stabilizing the spine during functional activities of daily living [5]. Observations from this study demonstrated that repeated squats elicited substantial activation of prime stabilisers of the spine, namely the erector spinae and rectus abdominis, which was 1.3-5.3 times greater than in the case of sustained squat. Fast, repetitive activity of short duration could result in post-activation potentiation and enhancement of muscle performance due to an increased excitability of α–motoneurons and recruitment of fast-twitch muscle fibres [15, 26, 29]. Thus, dynamic deep squat training at progressive speeds may be useful in strengthening programs for people with trunk and lower extremity muscle weakness.

While repetitive, dynamic squat results in greater muscle recruitment, sustaining squat would result in the passive stretch of soft tissues, thereby influencing the lower extremity joint range of motion [2]. Hence, sustained squat would provide benefits in terms of joint motion, whereas a repetitive dynamic loading stimulus may be of greater benefit in strengthening programs targeting lower extremity and spine muscles. Previous studies have established that strength training of spine and lower limb muscles is beneficial for people with degenerative disorders such as knee osteoarthritis [10], low back pain and osteoporosis [8], thus making it imperative to address muscle dysfunction and imbalance prophylactically. Specifically, weakness of knee extensor muscles is associated with increased risk of developing symptomatic and functional deterioration in people with knee OA and weakness of spine muscles in people with low back pain. Hence, bodyweight exercises such as squat that target muscle strength can be included as an integral component of rehabilitation and health promotion programs.

Furthermore, we explored differences in muscle strength among people with varying habitual squat exposure. Although muscle strength increased with daily squat exposure, the difference was not significant. This may be due to the fact that habitual squatters were required to largely sustain deep squat posture for a prolonged duration of time rather than perform repeated dynamic squats. High duration exposure to static squat probably did not provide a sufficient stimulus to bring about physiological adaptations characteristic to dynamic, repetitive high intensity training [6, 14]. On a positive note, even people who had given up adopting squat for performing ADL, could perform both repeated squats and sustained squat, although with slight alterations in movement patterns. These observations indicate that dynamic squat training can be safely initiated by both non-squatters and habitual squatters, and included into daily routine to obtain benefits such as greater mobility and muscle strength.

Certain limitations of the study cannot be overlooked. Deep squat is a large range of motion activity, involving contact between body segments resulting in movement artefacts. These limitations were addressed by accurate positioning of electrodes, visual inspection of raw and processed data for artifacts, deletion of corrupt data and outliers from analysis. However, sEMG results may be interpreted with caution for such muscles as the biceps femoris, which was prone to greater artefacts.

Conclusions

Deep squat resulted in substantial activation of spine and lower extremity muscles. Repeated squatting elicited highest activity levels, which was 2.5-10 times greater muscle activation than sustained squat. Muscle activity and strength were similar in people with varying squat exposure, suggesting that engaging in a dynamic squat activity, over and above habitual activities of daily living involving sustained squatting, is essential to obtain greater benefits in muscle strength.

Conflict of Interests

The authors declare no conflict of interest.

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ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2021; 28(**1**): 29-35
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.1-4

Cluster analysis of selected biomechanical variables related to backwards running in soccer

UDAY CH HASAN[1], FILIPE MANUEL CLEMENTE[2,3]

[1] *Al-Kitab University, Department of Physical Education and Sports Sciences, Kirkuk, Iraq*
[2] *Escola Superior Desporto e Lazer, Instituto Politécnico de Viana do Castelo, Viana do Castelo, Portugal*
[3] *Instituto de Telecomunicações, Delegação da Covilhã, Lisboa, Portugal*

Abstract
Introduction. **Running, of which backwards running (BR) is one type, is a basic skill that has to be maintained at a high level by athletes.** Aim of Study. **Use cluster analysis to evaluate some kinematic variables for BR. This analysis is applied to classify players and identify differences in their classification to determine relevant dynamic solutions to raise players' performance levels.** Material and Methods. **Twelve volunteer university soccer players (age: 20.8 ± 0.83 years old; experience: 4.7 ± 0.78 years; height: 175.6 ± 6.01 cm; body mass: 68.63 ± ± 5.06 kg) participated in the present study. The participants tried two 10-m BR, in which the best attempt based on the shortest time was analysed.** Results. **The study showed that cluster analysis may be used to classify and divide participants into two groups via evaluations of selected biomechanical variables. The first group, which consisted of 7 participants, represents the indistinctive performance level, while the second group, which consisted of 5 participants, represents the distinctive performance level. Statistically significant differences were found between the classifications of the participants. The second group excelled regarding certain biomechanical variables, including average stride length, average speed, angular velocity of the arms, peripheral velocity of the arms, angular velocity of the legs, peripheral velocity of the legs, instantaneous force and time of achievement.** Conclusions. **This classification ensures the correct selection and full consideration of practical training to achieve the ideal biomechanical characteristics for BR in soccer.**

KEYWORDS: biomechanics, motion analysis, football, performance, backwards running.

Received: 28 October 2020
Accepted: 25 January 2021

Corresponding author: dr_udayhasan@yahoo.com

Introduction

Soccer is considered an intense multi-directional and intermittent field sport [22]. The play efficiency depends on the player's ability to perform certain movements of varying intensity in different directions and in different sections of the field [11]. Players should exhibit well-developed basic and specific motor abilities [15]. One of the basic skills that has to be performed at a high level is running. A specific type of running is backwards running (BR), which Uthoff et al. (2018) defined as "any form of locomotion in a reverse direction where movement is accomplished through a single leg of support throughout foot-ground contact and both feet simultaneously in the air between contralateral foot strikes" [35].

There is a likely interplay of factors that influence running performance during soccer matches. Some of the most important factors include the player's characteristics, match location, field position, phase of the season, recovery period, competition strength and the match results [8, 32].

Match analyses revealed that elite soccer players usually cover 9-12 km during a 90-minute game [14, 17, 21]. About 58% of a game is spent standing (15%) and

walking (43%), whereas about 30% of a game is spent running at 7-14 km/h. Meanwhile, about 8% of a match is spent running at a moderate speed (15-19 km/h), 3% is spent running at a high speed (20-25 km/h), and only about 1% is spent sprinting at maximum speed [1].
Reports have also revealed that BR accounts for approximately 5% of the total competition performance [31]. Recently, BR has been proposed as a means to enhance athletic performance due to its unique acute and longitudinal adaptations [35]. Including BR when preparing players for the demands of competition reduces injury rates [29, 34] and enhances performance [16, 36].
In American football a defensive back who employs BR, for instance, can keep both the receiver and the quarterback in their field of vision. Once the player turns to run forward, he loses sight of one or both of these players, placing him at a disadvantage since both the quarterback and the receiver know where the ball is going. Athletes in sports such as soccer and basketball often run forward while on offence and backwards while on defence. Thus, superior BR speed is advantageous for players in these sports, as it allows players to better defend against attacks [3].
Recently, there has been an increasing interest in examining and analysing many soccer skills (e.g. kicking, throwing, and goalkeeper's skills). Unfortunately, BR has not been sufficiently investigated. Even when studies investigated BR, it was considered merely as a training tool or for rehabilitation. As far as the researchers know, no study has applied cluster analysis of the kinematic variables that are investigated in the present work. Thus, our study aims to use cluster analysis to evaluate selected kinematic variables for BR to evaluate applicability of this analysis to classify players and identify differences in players' classifications to propose relevant dynamic solutions to raise players' skill levels.

Methods

Participants
A total of 12 voluntary university soccer players (age: 20.8 ± 0.83 years old; experience: 4.7 ± 0.78 years; height: 175.6 ± 6.01 cm; body mass: 68.63 ± 5.06 kg) participated in the present study. The players belonged to the same team, which at the time of the study was training three times a week (for a total of 6 hours of training per week) and was playing one official match every week. All participants were informed of the study design and protocol; accordingly, each participant signed a free informed consent before the testing procedure. The study protocol was approved by the university ethics committee, while all the procedures followed the ethical standards of the Declaration of Helsinki for the study on humans.

Experimental approach to the problem
This study followed a cross-sectional design. The data collection occurred over four weeks after the beginning of the 2018/2019 academic year. The participants performed two BR trials, with the best attempt selected based on the shortest time taken to cover 10 metres. None of the participants reported any previous injuries. The tests were performed on the same day at the same time on the same field with natural grass. Each participant was asked to avoid any strenuous activity for 12 hours before the test. They were also instructed to follow their regular diet as closely as possible before the test. It was ensured that each participant reached the recovery stage before performing their second attempt.

Testing procedure
Before starting the basic test, the players warmed up for 10 minutes by running on a treadmill at 5 km/h and then stretching. The participants wore soccer boots with all the equipment required for soccer players as determined by FIFA. During the main session, each participant performed a BR test for 10 metres. One of the most important tests was to run backwards as fast as possible. After all participants performed one trial, a second trial was carried out. The best attempt (i.e. the shortest time) of each participant was chosen for analysis.
The data were collected using a mobile phone (Huawei Y9 prime 2019, China) with a frequency of 120 FPS. The mobile was placed 14 metres away from the middle of the test area and from the player's movement field, with a height of 125 cm between the centre of the lens and the surface of the ground to correspond to approximately the centre of the mass of the participants. Then the video clips were transferred to the Kinovea software program (2D motion analysis software under the GPLv2 license, version 0.8.27) to perform motion analysis and extract biomechanical variables.

Biomechanics variables
1. Time of achievement (TA): The BR time during the test distance of 10 meters.
2. Stride number (SN): Number of the participant's BR strides to finish the 10-meter test.
3. Average stride frequency (ASF): The rhythm for the stride's movement at a specific period of time (stride number per second).
4. Average stride length (ASL): The distance between

the point of initial contact of one foot and the point of initial contact of the opposite foot during the 10-m test distance.
5. Average speed (AS): The test distance of 10 meters divided over the time of achievement.
6. Angular velocity of the arms (AVA): The angular velocity of the arms is extracted by counting the number of degrees from the end of the back swing to the forward swing end of the time unit.
7. Peripheral velocity of the arms (PVA): The arms' circular distance during a specified period of time.
8. Angular velocity of the legs (AVL): The angular velocity of the legs is extracted by counting the number of degrees from the end of the back swing to the forward swing end of the time unit.
9. Peripheral velocity of the legs (PVL): The legs' circular distance during a specified period of time.
10. Instantaneous force (IF): The rate of change of linear momentum with respect to time.

Statistical procedures

The statistical package for Social Sciences (SPSS for Windows, version 22.0, IBM Corp., Armonk, NY, USA) was used for the statistical processing to calculate the mean, standard deviation (SD), and to perform the cluster analyses. Significant statistical changes were set at $p < 0.05$. Practical differences were assessed by calculating Cohen's d effect size (ES) [10]. The interpretation of inference's magnitudes was used by following [6]: <0.2 = slight; 0.2-0.6 = small; 0.6-1.2 = = moderate; 1.2-2.0 = large; 2.0-4.0 = very large; and >4.0 = extremely large.

Results

Cluster analysis for the measured biomechanical variables was used to classify the participants into two groups as shown in Table 1.

Table 1 clearly shows the possibility of dividing the participants into two groups using cluster analysis according to the measured biomechanical variables: the first group, which consists of 7 participants, represents the indistinctive performance level, while the second group, which consists of 5 participants, represents the distinctive performance level.

For comparison and to acquire accurate information about these groupings, one-way analysis of variance

Table 1. Classification of participants into two groups using cluster analysis

Player No.	1	2	3	4	5	6	7	8	9	10	11	12
TA (sec)	2.74	2.62	2.81	2.78	2.64	2.71	2.79	2.73	2.66	2.63	2.60	2.68
Cluster No.	1	2	1	1	2	1	1	1	2	2	2	1

Note: TA = time of achievement

Table 2. Biomechanical parameters (mean ± standard deviation, F values, and effect size) during BR

Biomechanical variables	Distinctive performance	Indistinctive performance	F(p)	Effect size	Magnitude
SN (number)	13.40 ± 0.55	15.14 ± 1.22	8.809(0.014)	1.735	Large
ASF (number/sec)	5.07 ± 0.16	5.50 ± 0.37	5.898(0.036)	1.422	Large
ASL (cm)	74.55 ± 3.03	66.25 ± 4.16	14.281(0.004)	2.213	Very large
AS (m/sec)	3.78 ± 0.06	3.63 ± 0.07	15.549(0.003)	2.309	Very large
AVA (degree/sec)	4.69 ± 0.30	4.21 ± 0.25	8.827(0.014)	1.740	Large
PVA (m/sec)	2.39 ± 0.17	1.99 ± 0.17	16.21(0.002)	2.357	Very large
AVL (degree/sec)	3.12 ± 0.16	2.88 ± 0.15	6.808(0.026)	1.528	Large
PVL (m/sec)	3.21 ± 0.20	2.88 ± 0.15	11.161(0.007)	1.956	Large
IF (N)	2627.06 ± 297.12	1943.81 ± 214.73	21.62(0.001)	2.723	Very large
TA (sec)	2.63 ± 0.02	2.75 ± 0.05	27.182(<0.001)	2.539	Very large

Note: SN = step number; ASF = average step frequency; ASL = average step length; AS = average speed; AVA = angular velocity of the arms; PVA = peripheral velocity of the arms; AVL = angular velocity of the legs; PVL = peripheral velocity of the legs; IF = instantaneous force; TA = time of achievement

(ANOVA) was used. It is part of the classification method to determine the statistical differences between the two groups in the biomechanical variables as shown in Table 2. Significant differences were found between the two groups under investigation in all the biomechanical variables ($p < 0.05$). A very large effect size was also observed for the differences between the two the groups in: (i) ASL ($d = 2.213$); (ii) AS ($d = 2.309$); (iii) PVA ($d = 2.357$); (iv) IF ($d = 2.723$); (v) TA ($d = 2.539$). Large ES was found for differences in: (i) SN ($d = 1.735$); (ii) ASF ($d = 1.422$); (iii) AVA ($d = 1.740$); (iv) AVL ($d = 1.528$); (v) PVL ($d = 1.956$).

Discussion

Cluster analysis was used to reduce the amount of interference between the two groups according to the measured biomechanical variables, not according to just one variable. As such, the treatment and distinction between the two groups were simplified when BR is practised. This is because cluster analysis is a classification method, by which a class of data reduction methods is used to sort cases, observations, or variables of a given data set into homogeneous groups that differ from each other. Using just one standard for classification cannot provide a classification that is free from criticism [2].

A crucial distinctive skillful performance factor is the player's application of proper mechanical principles that are suitable for an accomplished skill based on the situation the player is in by relying on the extensive range of motion that he has acquired for this skill [19]. Appropriate motor coordination, which is considered the most important factor in starting a run, affects the amount of force generated by the legs at the right time and for the optimal duration [7].

The difference in the SN variable is due to the influence of the ASL variable; this is the case because any SL will reduce the SN in the specified distance. Some studies claim that ASF is the most significant variable affecting AS [26, 28], whereas others claim that ASL is the most significant [38]. Some researchers indicated that the interaction between ASL and ASF is important for maximising AS [24]. However, Murphy et al. (2003) examined the difference between faster and slower field sport athletes (including soccer players) and found that the faster group had greater ASF [27].

The AS increase could be explained by the significant increase in SL when compared with ASF and SN, which allowed the participants to better coordinate the actions of their body parts to accomplish the requirements of the technique acceleration. Babić et al. (2011) defined ASL as a very complex kinematic variable that depends on many factors apart from the morphological characteristics (leg length), such as muscle structure, reflex mechanisms, and ground force in the propulsion phase, as they are of particular importance in speed development [4]. Optimal ASL has been recommended for both the sub-maximal and maximal phases of FR [20].

It is believed that the increases in ASF lead to maximal sprint running performance [35]. Therefore, AS is considered as the result of an interaction between SF and SL [13]; greater speeds are achieved through large ground reaction forces that are produced during short ground contact times [37]. The results of many studies have revealed that stride length is a biomechanical variable that is related to running economy [5, 9]. It would be worthwhile to conduct an in-depth study of joint kinematic and kinetic variables to understand the mechanisms that cause such a relationship. Usually, sprint running at maximal velocity is considered the most important part of a race [12]. The most apparent general performance description in the sprint is horizontal velocity (i.e. the athlete who can produce the most horizontal velocity will be the most successful) [25].

The arms actively contribute to balance the rotary momentum of the legs. They are also vital to sprint BR performance and contribute to propulsive forces [23]. The arms act as passive mass dampers that move by the lower part of the body [30]. When a push is made by the right leg, for instance, the body rushes backwards and rotates around its centre of gravity to the left direction. To stop body rotation, the participant has to move the opposite arm of the driving leg with the same speed and force. As for the AVL during the swing, the significant mechanic basis that the participant has to meet is to let the leg's parts approach the rotation axis and any means that could reduce the moment of inertia while increasing the angular velocity amount. This is accomplished by bending the hip and knee joint angles.

One of the mechanical bases in the BR is to control the leg's length (turning radius) during the performance period, by which the knee joint angle plays a significant role in determining the leg's peripheral velocity. This, in turn, affects the force production, and, consequently, the body velocity. Force production during multi-joint leg extension depends on the combined effects of angle and angular velocity [18]. Slawinski et al. (2010) were of an opinion that improved synchronisation between the upper and lower limbs can increase the efficiency of the pushing phase [33]. Thus, faster participants are probably able to achieve higher running speed by striking the ground with greater force and much faster than the slower ones. This might be due to another mechanical element that distinguishes fast participants from the slower ones. Accordingly, one could say that maximum running speed is largely determined by how much force a participant can apply on the ground during each stride [24].

As far as we know, this is a pioneering study in that we classified the players using cluster analysis according to several biomechanical variables. Nevertheless, one should acknowledge that, as with any study, this study faced some limitations. For one, the test that participants completed during BR did not include all aspects of an official match, such as the psychological, physical and physiological pressure. Therefore, a test that mimics match situations should be designed. Undoubtedly, analysing 2D movement would reveal some significant and essential issues concerning soccer players' BR skills. As such, the 2D study has set the basis to evaluate this skill. Nevertheless, we cannot be sure that the 2D analysis can accurately describe the movement of the entire body without losing some significant characteristics. Hence, additional studies need to be conducted using other techniques, such as 3D analysis.

We recommend the extensive use of cluster analysis to include the physical, skillful, planned and psychological aspects of sports, since such an analysis can organise observations and divide them into homogeneous groups that share some characteristics. We also recommend that soccer coaches adopt the mechanical bases and rules that are essential during the soccer players' training while providing an environment that mimics that of a real match.

Conclusions

Cluster analysis can be used to classify and divide the participants into two groups by evaluating some biomechanical variables for the BR skill. Statistically significant differences were found between the classifications of participants regarding the biomechanical variables of BR. A very large effect size was also found for the differences between the two groups in variables: ASL, AS, PVA, IF and TA. Large ES was recorded for differences in such variables as SN, ASF, AVA, AVL and PVL. It has become evident that the second group (i.e. the group with the distinctive skillful performance) excelled in terms of certain biomechanical variables, including ASL, AS, AVA, PVA, AVL, PVL and IF. Hence, we can say that this classification ensures correct selection and fully considers practical training to achieve the ideal biomechanical characteristics for the BR skill in soccer.

Funding

This work is funded by Fundação para a Ciência e Tecnologia/Miniestrério/Ministério da Ciência, Tecnologia e Ensino Superior through national funds and when applicable co-funded EU funds under the project UIDB /50008/2020.

Acknowledgements

We gratefully acknowledge the support of proof-reader Dr. Kusay Abdul-Munim Ahmad and the participants who were essential for the success of this research paper.

Conflict of Interests

The authors declare no conflict of interest.

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ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2021; 28(**1**): 37-44
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.1-5

Arrowhead agility test in elite U-19 soccer players: positional differences and relationships with other performance tests

YIANNIS MICHAILIDIS[1], CHRISTOS KARYDOPOULOS[1], DIMITRIOS KAPRALOS[1], MICHALIS MITROTASIOS[2], IOANNIS ISPIRLIDIS[3], KONSTANTINOS MARGONIS[3], THOMAS METAXAS[1]

Abstract

Introduction. **Change of direction (COD) is an important prerequisite in soccer. Therefore, a large number of tests have been developed aiming to assess the COD of athletes. The test most commonly used in soccer include the Illinois test (ICODT), the T test, the 505 test, and the Arrowhead COD test (ACODT).** **Aim of Study.** **The aim of this study was to investigate relationships between ACODT and other field tests (ICODT, 0-10 m sprint, 0-30 m sprint, countermovement jump, squat jump) in Greek elite under-19 soccer players. Comparisons were also drawn between different field positions (central defenders, side defenders, central midfielders, side midfielders, forwards).** **Material and Methods.** **Forty Greek elite male soccer players (under 19; U-19) participated in this study and were classified into the following groups: forwards, central-midfielders, side-midfielders, central-defenders, and side-defenders. Anthropometric variables of participants (height, weight, body mass index (BMI), % body fat) and anaerobic physiological parameters (10 m and 30 m sprint, squat jump, countermovement jump, Illinois COD test, Arrowhead COD test) were measured.** **Results.** **There were no significant differences between the position groups for any of the performance tests or the anthropometric measurements. There were significant correlations between ACODT for both sides (left and right) and 0-10 m time, 0-30 m time, and ICODT time. There were no significant correlations between ACODT and any of the jump performance tests.** **Conclusions.** **The lack of differences between positional roles is in contrast with other studies that addressed professional older soccer players. This fact indicates that the specification of the training may produce differences between positional roles as the performance level of the players is increasing. Greater sprinting and acceleration speed could augment ACODT performance.**

KEYWORDS: anthropometrics, change of direction, playing position, anaerobic profile.

Received: 30 July 2020
Accepted: 29 December 2020

Corresponding author: ioannimd@phed.auth.gr

[1] *Aristotle University of Thessaloniki, Department of Physical Education and Sports Sciences, Laboratory of Evaluation of Human Biological Performance, Thessaloniki, Greece*
[2] *National and Kapodistrian University of Athens, Department of Sport Science, Athens, Greece*
[3] *Democritus University of Thrace, Department of Physical Education and Sports Sciences, Komotini, Greece*

Introduction

Soccer is an intermittent-type of sport that incorporates actions with low and high intensity and duration. A soccer player during a match covers on average about 9 to 14 km, and performs considerably more than 1.000 activities in a match, such as e.g. accelerations, decelerations, jumps, changes of direction, etc. [20]. The ability to move at high speed and quickly execute changes of direction (COD) is crucial for successful match performance [14]. Therefore, in soccer training numerous COD drills are included, which help players to become more economical in such actions.

Previous researchers mentioned the significance of COD for performance and they proposed a model to improve this ability. More specifically, Lloyd et al. [15] suggested that COD should be targeted during both prepubescence and adolescence. They mentioned that neural plasticity, which is associated with prepubescence, offers an ideal opportunity to develop motor control programs inclusive of a basic change of direction techniques. Recently, a group of researchers proposed a model for the development of agility during childhood and adolescence. They mentioned that during pre-puberty 25% of the training time should be focused on COD training, during circum-puberty 40%, and during post-puberty 20% of the time [15].

The use of a global positioning system (GPS) greatly facilitates the assessment of each athlete's physical demands (distance at specific speed ranges, average speed, acceleration, decelerations, and a maximum number of sprints) during matches and training sessions. Previous studies in soccer have noted that different field positions (e.g. defenders, midfielders, and forwards) encounter different dynamic actions during a match [3]. More specifically, it has been reported that in a high-level match the midfielders cover significantly more distance and make considerably fewer turns than defenders or strikers [3, 7, 30]. It has also been found that strikers do significantly more sprints than defenders and midfielders, while defenders cover the shortest distance of all players with the ball [7].

It is also stated that anthropometric characteristics, such as body weight, height and body mass index, may vary depending on the position of the soccer player [31]. As regards the changes of direction, in a study carried out in the Premier League it was established that players perform on average more than 700 changes of direction [3]. This high frequency shows the important role of the ability to change direction in soccer performance. The same study also found that there is a difference in direction changes depending on the players' position with midfielders performing the least compared to the other pitch positions [3].

Characteristics such as age, biological maturity, coaching age and anthropometric characteristics can affect the physical performance of players [5]. At younger developmental ages, the match rate is lower [29], and therefore it affects all the other variables such as the total distance covered.

The COD seems to depend on many factors such as strength, power, technique and anthropometric characteristics [15, 17]. Recent studies in developmental age players have shown that strength and power training programs have also improved performance in the COD. More specifically, Keiner et al. [10] reported that after a long program of strength training, the COD ability improved. Michailidis et al. [19] mentioned that after a 6-week plyometric training program the COD ability improved. In addition, previous studies have reported significant correlations between anthropometric characteristics and performance in the ability to change direction [17].

As mentioned above, COD is an important prerequisite in soccer. Therefore, a large number of tests have been developed aiming to assess the COD in athletes and most of them have been applied to soccer players. Distances in these tests ranged from 10 to 60 m including 1 to 9 directional changes of 45° to 270° [1]. The tests most commonly used in soccer include the Illinois test (ICODT), the T test, the 505 test and the Arrowhead COD test (ACODT). A recent study showed that ACODT is reliable to measure COD in soccer players [22].

Therefore, this study investigated relationships between ACODT and other field tests (ICODT, 0-10 m sprint, 0-30 m sprint, countermovement jump, squat jump) in Greek elite under-19 soccer players. Comparisons were also drawn between different field positions (central defenders, side defenders, central midfielders, side midfielders, forwards).

Material and Methods

Subjects

Fifty-three soccer players from elite male U-19 soccer teams were approached to participate in this study, but only 44 accepted the invitation (age 18.2 ± 0.8 years). The inclusion criteria to participate in the study were as follows: 1) not to have musculoskeletal injuries for ≥6 months prior to the study, 2) having participated in ≥95% of training sessions, 3) not to be taking any medication. Forty soccer players met the inclusion criteria and completed the study. All participants and their parents were informed about the potential risks and benefits of the study and signed consent was obtained. The local Institutional Review Board approved the study, in accordance with the Helsinki Declaration.

Experimental approach to the problem

In order to study the correlation of the ACOD with the selected field tests and to study potential differences between the different filed positions, the following design was followed. Field players were stratified into central defenders (n = 8), side defenders (n = 7), central midfielders (n = 11), side midfielders (n = 5), and forwards (n = 9). The players performed the subsequent field tests: the ACOD test, the Illinois test, 0-10 m sprint, 0-30 m sprint, countermovement jump and squat jump. The dependent variables for this study were: 0-10 m and 0-30 m sprint times; ACODT time from the left and from the right side, Illinois test time, as well as CMJ and SJ height.

Procedures

All players were familiar with the tests, because these tests were previously used by the teams' training staff to evaluate players' performance. Testing was incorporated within the team's gym (jump tests) and field (running field tests) training sessions that were held across two weeks in a season. At the beginning of each testing session, soccer players performed a 10-minute warm-up and at the end a 10-minute cool-down period. In the gym, after the warm-up, the players executed the CMJ test and then the SJ test. In the field, the players executed the sprint tests, followed by the ACODT and Illinois tests. Each test was performed twice and the best performance was used for statistical analysis. A 3-minute period was provided between trials. Testing was performed under identical conditions and the players avoided intense exercise in the preceding 24 hours. The field tests were performed on a soccer field with synthetic grass. Before the first gym testing session, the player's body mass, height, body fat and age were recorded.

Anthropometric measurements

Body mass was measured accurate to the nearest 0.1 kg using an electronic digital scale with the participants in their underclothes and barefoot. Standing height was measured to the nearest 0.1 cm (Seca 220e, Hamburg, Germany). Body fat percentage was estimated based on the sum of four (biceps, triceps, suprailiac, subscapular) skinfold thicknesses measured with a specific caliper (Lafayette, Ins. Co., Indiana) on the right side of the body by the equation of Siri (1956) [25].

Speed testing

A 30 m sprint test with 10 m splits (0–10 m was measured as well) was used to measure speed performance. After a 5-second countdown the participants ran in front of three infrared photoelectric gates (Microgate, Bolzano, Italy) that recorded times at each gate. The participants sprinted from a standing starting position with the toe of the front foot approximately 0.3 m behind the first gate. Photocells were placed 0.6 m above the ground (approximately at the hip level) to capture the movement of the trunk rather than a false signal due to a limb motion. The coefficient of variation for test–retest trials was 3.2%.

Vertical jump testing

The participants performed two jump tests: (a) SJ: participants, from a stationary semi-squatted position (90° angle at the knees), performed a maximal VJ; (b) CMJ: participants, from an upright standing position, performed a fast preliminary motion downwards by flexing their knees and hips followed by an explosive upward motion by extending their knees and hips. Both tests were performed with the arms akimbo. The VJ height was measured with Chronojump Boscosystem (Chonojump, Spain). The coefficients of variation for test–retest trials were 2.9 and 3.7% SJ and CMJ, respectively.

Arrowhead COD test

The participants stood behind the starting line in a sprint starting position. At their discretion, each subject ran as fast as possible from the starting line to the middle marks (A), turned to run through the side marks (C), through the far marks (B), and back through the start/finish line (Figure 1A). The participants completed two trials, one to the left and one to the right, having at least 5 minutes of recovery between them. The time was recorded in seconds to the nearest two decimal places for each direction. The coefficient of variation for test–retest trials was 4.3%.

Illinois COD test

The ICODT was set up with four markers forming a square area of 9.3 × 7.2 m. The start and finish gates were positioned at two consecutive angles of a square area, while two markers were positioned on the opposite side to indicate the two turning points. Four other markers were in the center, with an equal distance apart (3.1 m). Each participant had to run as quickly as possible from the start gate, follow a planned route, and slalom through the markers without knocking them down or cutting over them. From a standing position, each athlete sprinted 9.3 m on command and returned to the starting line, then had to swerve in and out of the markers, perform another sprint of 9.3 m, and complete the test by running to the finish gate. The photocells at the start and finish gates recorded the test time. The better time of two attempts was considered the ICODT score. A graphic representation of the test is shown in Figure 1B.

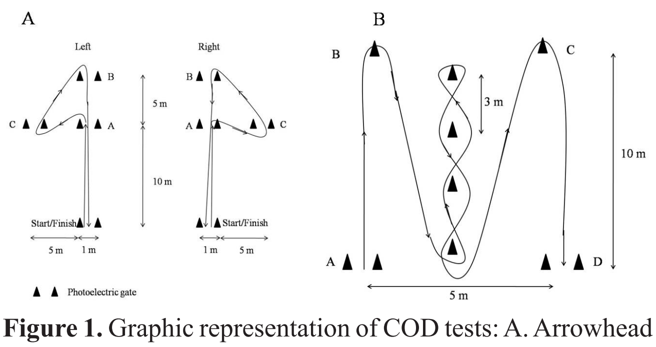

Figure 1. Graphic representation of COD tests: A. Arrowhead change of direction test (ACODT); B. Illinois change of direction test (ICODT)

Statistical analysis

Descriptive statistics (mean ± standard deviation, SD) were calculated for each parameter. Data normality was verified with the Kolmogorov–Smirnoff test. A one-way analysis of variance (ANOVA) was used to compute any differences in the subject characteristics and the performance test data between the position groups (central defenders, side defenders, central midfielders, side midfielders, forwards). Pearson's two-tailed correlation analysis determined relationships between ACODT and ICODT, CMJ, SJ, 0-10 m sprint test, and 0-30 m sprint test. The level of significance was set at $p = 0.05$. A power analysis was performed to estimate the smallest acceptable number of participants to analyze the interaction between groups and time points of measurements. The SPSS version 18.0 was used for all analyses (SPSS Inc., Chicago, IL, USA).

Results

Anthropometric characteristics are presented in Table 1. There were no significant differences in age, body mass,

Table 1. Participants' anthropometric characteristics

	F	CD	CM	SD	SM
Age (y)	18.4 ± 0.8	18.6 ± 0.9	17.9 ± 0.6	17.8 ± 1.1	18.2 ± 0.5
Height (m)	1.80 ± 0.05	1.79 ± 0.07	1.76 ± 0.06	1.77 ± 0.04	1.76 ± 0.09
Weight (kg)	72.8 ± 6.9	72.6 ± 8.8	69.4 ± 5.7	69.8 ± 4.7	69.1 ± 7.2
BMI	22.4 ± 1.2	22.5 ± 1.7	22.5 ± 1.3	22.2 ± 1.5	22.2 ± 0.8
Body fat (%)	11.7 ± 3.8	11.1 ± 2.2	13.5 ± 3.7	11.3 ± 2.8	9.7 ± 3.1

Note: Data are presented as means ± SD; F – forward; CD – central defender; CM – central midfielder; SD – side defender; SM – side midfielder

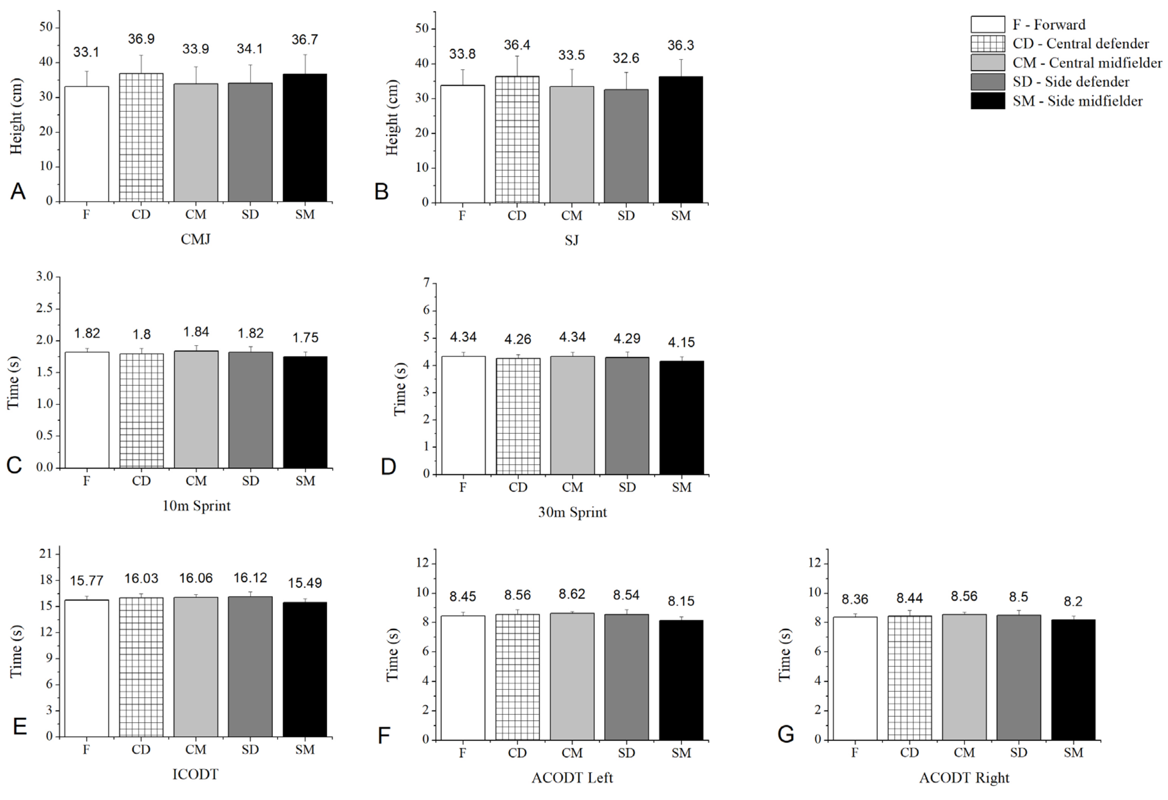

Figure 2. The comparison of obtained results according to playing positions: A – countermovement jump; B – squat jump; C – acceleration times (10 m); D – sprint times (30 m); E – Illinois COD test times; F – arrowhead COD times for the left side; G – arrowhead COD times for the right side

Table 2. Correlation between performance and anthropometric variables

		Height	Weight	BMI	% BF	SJ	CMJ	10 m	30 m	ICODT	ACODT left	ACODT right
% BF	r	–0.199	–0.152	0.474		–0.352	–0.352	0.181	0.355	0.325	0.330	0.209
	p	0.219	0.348	0.002**		0.026*	0.026*	0.262	0.025*	0.041*	0.077	0.195
SJ	r	0.159	0.142	0.052	–0.352		0.944	–0.267	–0.541	–0.397	–0.227	–0.159
	p	0.326	0.381	0.748	0.026*		0.001**	0.096	0.001**	0.011*	0.158	0.327
CMJ	r	0.092	0.091	0.048*	–0.352	0.944		–0.312	–0.594	–0.317	–0.218	–0.104
	p	0.574	0.578	0.771	0.026*	0.001**		0.050	0.001**	0.046*	0.177	0.521
10 m	r	0.268	0.152	–0.062	0.181	–0.267	–0.312		0.759	0.539	0.490	0.441
	p	0.094	0.350	0.703	0.262	0.096	0.050		0.001**	0.001**	0.001**	0.004**
30 m	r	0.240	0.066	–0.162	0.355	–0.541	–0.594			0.588	0.592	0.400
	p	0.136	0.684	0.319	0.025*	0.001**	0.001**			0.001**	0.001**	0.011*
ICODT	r	0.141	0.050	–0.095	0.325	–0.397	–0.317				0.869	0.800
	p	0.385	0.758	0.559	0.041*	0.011*	0.046*				0.001**	0.001**
ACODT left	r	0.141	0.022	–0.134	0.330	–0.227	–0.218					
	p	0.386	0.892	0.409	0.077	0.158	0.177					
ACODT right	r	0.225	0.141	–0.044	0.209	–0.159	–0.104					
	p	0.162	0.386	0.788	0.195	0.327	0.521					

Note: BMI – body mass index; % BF – percentage of body fat; SJ – squat jump; CMJ – countermovement jump; ICODT – Illinois change of direction test; ACODT – arrowhead change of direction test
* significance level <0.05; ** significance level <0.01

height, body fat and BMI between the positional groups. The performance test data are shown in Figure 2. The one-way ANOVA analysis indicated no significant differences between the positional groups for any of the performance tests.

The correlations between the ACODT and the other field performance tests are presented in Table 2. There were significant correlations between ACODT for both sides (left and right) and 0-10 m time, 0-30 m time, and ICODT time. All the correlations were positive, indicating that a lower time in the above tests was related to a lower time in ACODT. There were no significant correlations between ACODT and any of the jump performance tests.

Discussion

The aims of this study were a) to investigate relationships between ACODT and other field tests (ICODT, 0-10 m sprint, 0-30 m sprint, countermovement jump, squat jump), and b) to establish the anthropometric and anaerobic profile of Greek elite under-19 soccer players according to their playing positions (central defenders, side defenders, central midfielders, side midfielders, forwards). The major finding of this study is that anthropometric characteristics did not differ depending on playing positions. Additionally, there are no positional differences in anaerobic performances.

No differences were observed between the different playing positions in the two COD tests (ICODT and ACODT). This is in agreement with previous studies in collegiate soccer players [16]. However, previous researchers mentioned that agility could be used to distinguish elite from non-elite players within all positions [23]. Furthermore, elite Belgian male soccer forward players were faster in a shuttle-run COD speed test when compared to all the other position groups [4]. In view of the above, we find that in developmental ages and early adulthood there are no differences in the COD ability between playing positions as opposed to high-level adult soccer players. However, it should be noted that studies investigating the above relationship are limited. These findings suggest that when a young soccer player manages to compete at a high level, the long and specialized training followed when playing on a particular position could differentiate the player's performance in specific physical condition tests compared to the other positions. More simply, the specialization of the playing position probably causes differentiation in the tests' results.

The anthropometric characteristics and vertical jump performances did not correlate with the ACODT performance. It was surprising for us that, contrary to a previous study where minor relationships were found between CMJ and CODS ($p > 0.05$) [18], none of the vertical jump performances correlated with ACODT performance. However, both SJ and CMJ performances correlated with 30 m performance and Illinois COD test performance. Other earlier studies mentioned strong correlations between jumps and maximal velocity [18]. However, the correlations of ACODT with the sprint test and ICODT indicate that the use of ACODT is sufficient to evaluate the change of direction performance as it is with the Illinois test. It should be mentioned that the distance covered in ACODT is about 40 m, while in the ICODT it is about 60 m. This difference in the distance covered may make the ACODT a more appropriate test to assess the COD ability at developmental ages under 13 years of age, as the greater distance of the ICODT may adversely affect the COD ability of the participants. Weaker correlations ($r = 0.346$) were mentioned by Little and Williams (2005) [14] between 10 m performance with zig-zag agility test performance in a sample of professional male soccer players. Noted differences between the studies' results likely reflect the use of different COD tests and the different performance levels of participants.

The specialization of young soccer players in specific playing positions – concerning technical and tactical abilities – starts from the age of 13-14 years. However, the physical condition at these ages develops globally without differentiating between playing positions. In the last decade with the help of technology it has been found that during the match at the professional level there are differences in the running performance between playing positions. This differentiation probably indicates the need for personalized physical condition programs depending on the playing positions (e.g. SM runs more km than CD). This practice could lead to a greater improvement in the players' performance.

Numerous studies mentioned that professional soccer players exhibit positional differences regarding anthropometrical aspects such as body mass, height, body fat and body mass index [13]. More specifically, previous studies showed that CD were the heaviest and tallest players, while SD, SM, and F were the lightest and shortest [13]. Furthermore, the midfielders had a lower percentage of body fat than the other positional roles (defenders) [28]. However, other researchers mentioned no differences between positional roles [24]. This controversy in the literature could be due to the competitive level differences between soccer players. Another explanation for the differences between the results reported in various studies could be related with the design of individual studies, because some of them classified the players into three groups (defenders, midfielders, forwards) and others into five groups (CD, SD, CM, SM, F) except for goalkeepers. In our study we found no differences in anthropometric characteristics between the positional groups, but observed a trend for the CD and F to be heavier and taller than SD, CM, and SM.

It is known that vertical jump tests such as SJ and CMJ can determine the muscle power of the lower limbs in soccer players [26]. In the present study no positional differences were found in SJ and CMJ heights. These results are in agreement with previous studies [8, 13]. However, other researchers showed that explosive power is an important discriminate factor between the elite attackers from the other field positions [6], and in the case of underage soccer players it was mentioned that midfielders had the lowest jump height compared with forwards and defenders [29].

This study is in agreement with previous studies, which found no differences in running speed (10 m and 30 m sprint times) between soccer players depending on their playing positions [13]. In contrast, other studies showed that forwards were faster than defenders [8]. This contradiction could be explained by the competitive level of participating soccer players. As the competitive level increases and the trainings become more specific to a given soccer position, positional differences are observed and forwards seem to be faster than players of the other positions [27].

The percentage of body fat was negatively correlated with performance in SJ and CMJ and positively with the performance in 30 m sprint and the Illinois COD test. A recent study showed similar results for the relationship between speed performances and the percentage of fat mass [21].

The COD tests include accelerations and decelerations, therefore the use of the stretch-shortening cycle (SSC) phenomenon is crucial in this performance. The SSC is typically characterized by an eccentric muscular contraction followed immediately followed by a concentric one. Utilizing a stretch immediately before a concentric contraction has been shown to augment the concentric phase, resulting in increased force production and power output [11]. The importance of the SSC in sprinting and jumping performance is well established [12]. It was mentioned that stronger correlations between SJ and acceleration may be due to the fact that an adequate starting strength is necessary to initiate acceleration and overcome inertia and it does not rely as heavily on the SSC due to a static starting position [9]. Before sprinting soccer players are usually already in motion, so the SSC is already contributing to force generation during a moving start. This means that the assistance of stored elastic energy in the CMJ is more similar to a maximal sprint. This could be an explanation why jump performances were correlated with ICODT, but not with ACODT. Perhaps the distance of the tests (60 m vs 37.07 m) is crucial for this difference. However, SSC effectiveness is influenced by the stiffness of the muscle tendon, the rate and magnitude of the stretch, as well as other factors [2].

Certain study limitations should be acknowledged. The sample for this study was relatively small (n = 40). Also, the heterogeneity was small, because only two U-19 Greek elite squads were tested. Additionally, the distribution of subjects between the positional groups was not equal, and this may have influenced the lack of significant differences found between positional groups.

Conclusions

The lack of differences between positional roles indicates that as the competitive level of the players increases, the specification of the training may produce differences between positions. More specifically, because the professional players reveal different positional profiles, U-19 soccer players have to participate in more position-oriented training sessions.

When we use tests to assess physical abilities it should be adequate to the soccer players' age. Although ACODT is proposed as a reliable and valid test to measure COD in soccer players, the data for similar young populations are limited. Additionally, there are no data for the relationships between ACODT and other field tests.

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ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2021; 28(**1**): 45-53
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.1-6

Influence of different 1v1 small-sided game conditions in internal and external load of U-15 and U-12 soccer players

FERNANDO JORGE SANTOS[1,2], CÁTIA CALDEIRA FERREIRA[1,3],
TERESA PALMIRA FIGUEIREDO[1,2], MÁRIO CUNHA ESPADA[1,2]

Abstract

Introduction. **Soccer is a complex team sport, in which moments of 1v1 during the game may decide the outcome. Despite this evidence, studies on this particularity are scarce, particularly involving young players.** Aim of Study. **The purpose of this study was to evaluate variations of internal and external loads in U-15 and U-12 soccer players associated to different small-sided game (SSG) conditions, in the 1v1 context.** Material and Methods. **Eight male soccer players participated in the study, integrating two groups, U-15 (n = 4) and U-12 (n = 4), monitored in different SSG models (2 minutes duration / 3 minutes interval rest, different pitch size SSG1 = 5 × 10 m; SSG2 = 10 × 15 m; SSG3 = 15 × 20 m). Soccer players carried GPS devices (WIMU PROTM, RealTrack System, Almería, Spain) operating at a sampling frequency of 10 Hz. The Mann–Whitney U test was used to compare groups in each SSG and the Kruskal–FWallis test was applied to compare the different SSGs. The significance level was adopted at $p < 0.05$.** Results. **Differences between the groups were observed mostly in HR_{mean} and $HR_{95\text{-}max}$. The distance covered (different between the groups, SSG1 197.7 ± ± 14.0 vs 162.3 ± 9.0 and SSG3 261.4 ± 10.6 vs 217.1 ± 27.4, respectively, for U-15 and U-12) and maximal velocity always increased with the increase of the pitch size. Explosive distance and accelerations were also different between the groups in SSG1 and SSG2, respectively. Differences throughout the SSGs were mainly recorded in terms of external load.** Conclusions. **This research suggests that the implemented 1v1 SSG model is relevant from the internal and external load perspective. Nevertheless, the internal and external loads in U-15 and U-12 soccer players present differences and specificities, which should be considered in exercise prescription and individualized evaluation of young soccer players.**

KEYWORDS: soccer, internal load, young players, external load, small-sided game.

Received: 28 August 2020
Accepted: 26 January 2021

Corresponding author: mario.espada@ese.ips.pt

[1] Polytechnic Institute of Setúbal, Department of Science and Technology, Setúbal, Portugal
[2] Quality of Life Research Centre, Rio Maior, Santarém, Portugal
[3] Universidad de Extremadura, Facultad de Ciencias del Deporte, Training Optimization and Sports Performance Research Group, Cáceres, Spain

Introduction

Soccer is a team sport of great technical-tactical complexity, in which individual actions can determine the result at a given moment in the game. It is physically a highly demanding sport, that requires an efficient collective organization and simultaneously a specific development of each player based on the individual and group perspective [3]. It is also a team sport, which is associated with complexity in collective and individual actions by the players, which individual characteristics potentially determining the success/ outcome of the game [13].
During a match, players typically cover a distance of 10-13 km, performing 150-250 intense actions (e.g. accelerations/decelerations, changes of direction) interspersed with short recovery periods [4]. Moreover, soccer players perform between 1000 and 1400 movements of 2 to 4 seconds in duration [30]. The

physical conditioning for soccer players is of utmost importance. Soccer is nowadays more intense and physically demanding compared to the beginning of the 21st century and players need to cover about 30% greater distances above the high-intensity threshold [5]. Nowadays in team sports small-sided game (SSG) tasks have become a useful resource in player training at all ages and competitive levels [12], namely because the training process in team sports must provide stimuli to a wide range of physical, tactical and technical components [1]. Consequently, SSGs are often used during training to develop both the physical and technical performance of soccer players [16, 18].

Considering the effects of SSGs in terms of technical actions, it has been consistently found that an increase in the number of technical actions individually performed by players occurs in smaller formats of the game [10]. Moreover, SSGs may offer additional advantages, improving essential neuro-muscular and cognitive skills such as reaction time, decision-making and change-of-direction speed [31], all of which are determinants of success in the soccer game.

These drills facilitate the development of technical-tactical aspects together with relevant physical capacities such as specific endurance, strength-power qualities and agility in a realistic match-related context [26]. Therefore, SSGs are developed under special rules, which basically involve the participation of a reduced number of players interacting in a smaller space compared to the competition format [24].

The implications of different task conditions and their concurrency contribute to changes in acute responses in terms of both internal and external loads [29]. Interestingly, altering playing conditions (e.g. game rules or objectives) and game formats (e.g. the number of players per team and/or pitch size) may change physical (external load) and physiological (internal load) demands imposed on players [8].

At the same time, the intensity of SSGs can widely vary, being higher on larger pitches and with a smaller number of players [16], although the optimal design remains to be determined, particularly in young soccer players near the pubertal phase. Typically, small-to-medium formats (2 vs 2 to 6 vs 6) promote heart rates (HR) between 85 and 90% of the HR_{max} and blood lactate concentrations [La^{-}] between 4 and 8 $mmol/L^{-1}$ [10]. Moreover, distances covered may vary between 80 and 100 m/min^{-1} at running distances between 6 and 10 m/min^{-1} [11].

Recently, it was stressed that in a soccer academy not only players with greater physical performances should be promoted, but also those with lesser physical performances, particularly when exhibiting greater abilities and skills to play soccer [23], which in our opinion leads to the need for individual evaluation of the training process.

Typically, studies concerning SSGs are predominantly related to small-to-medium formats and do not consider the one that possibly is more predominant in a soccer game and may be a determinant in the outcome of the game, the 1v1 soccer actions. The literature on this subject is scarce and there is no previous research that compares age-group differences between different SSG conditions.

Aim of Study

To evaluate variations of internal and external loads in under 15 and under 12 (U-15 and U-12) soccer players, associated to different SSG conditions in the 1v1 context.

Material and Methods

Eight male soccer players participated in the study, integrating two distinct groups, U-15 (n = 4) and U-12 (n = 4), both including three SSG formats composed of 2-minute play and 3-minute rest in the 1v1 context, with changes in the pitch size between SSGs. The participating players belonged to a training club, catalogued by the Portuguese Football Federation, awarded three stars in the club certification model implemented in Portugal, assuming a zero to top three stars scale by the Portuguese Football Federation evaluation for clubs with only youth teams training and competing, not the senior level.

The club comprises teams from different age-groups competing in the final stages of national championships, together with the best teams in Portugal. In recent years the club may also boast the regular presence of athletes in national youth teams (which compete for international titles at club and national team levels with the best soccer teams in Europe), as well as transfers of athletes to some of the most prestigious Portuguese clubs.

All the players participating in this study usually train four times a week plus one match every weekend. The U-15 training sessions lasted 90 minutes and those for U-12 – 60 minutes. The official games of U-15 consisted in an 11 a-side game with two periods of 35 minutes and the U-12 ones were 7 a-side games with 30 minutes in each of the two periods. This study followed the guidelines indicated in the Helsinki declaration and international ethical standards for sport and exercise science research [17]. Before starting the investigation, the object of the study was explained to the club officials and coaches, authorizations were guaranteed. Parents and players were also informed and their written consent was obtained. Table 1 presents the soccer players' characteristics.

Table 1. Characteristics of soccer players

	U-15 (n = 4)	U-12 (n = 4)
Age (years)	14.71 ± 0.48	11.69 ± 0.52
Height (cm)	1.71 ± 0.04	1.56 ± 0.07
Total body mass (kg)	58.0 ± 7.20	43.98 ± 4.61
Body fat (%)	12.74 ± 0.81	11.95 ± 0.52
Experience (years)	6.5 ± 0.6	9.5 ± 0.5

The study was conducted in the middle of the 2018/2019 competitive season. The tasks were performed on a synthetic grass floor under very good conditions. The training session started with a 20-minute standardized warm-up, consisting of 5 minutes of slow jogging, and strolling locomotion followed by 7 minutes of specific soccer drills, and finishing with 3 minutes of progressive sprints and accelerations. Agility and speed drills were also conducted and a 5-minute ball possession game within a space of 20 × 20 m was also performed.
The participants were free from injury and medical conditions and had not been involved in any type of other physical exercises within 2 days prior to the study. Twenty-four hours prior to the experimental session the players and parents were instructed to maintain their usual habits, which included 8 hours of sleep the night before the data collection session and to maintain the nutritional routine, since it was previously stated that factors such as dehydration may contribute to the development of fatigue in soccer [4].
The SSGs took place with the goal objective on a 1v1 player basis, with mini training goals (2 m width signalized with training cones). Throughout the SSGs colleagues and coaches were around the pitch with soccer balls in their hands to quickly replace the ball each time it left the pitch, ensuring playing time to be completed and identical in all the games. The research team had digital stopwatches to monitor the real time of play in each SSG. During the recovery time periods of the SSGs the players could drink fluids.
Soccer players carried GPS devices (WIMU PRO™, RealTrack System, Almería, Spain) operating at a sampling frequency of 10 Hz. The technology used to collect the GPS data had been previously validated and was shown to be reliable for monitoring soccer players [6]. Participants wore fitted body vests and the GPS device was inserted in a purpose-built harness prior to SSGs.
Before being placed on the players, the GPS devices were calibrated and synchronized following the manufacturer's recommendations [6]. The procedures were as follows: (a) turn on the devices, (b) wait approximately 30 seconds after turning them on, (c) press the button to start recording once the device's operating system is initialized and (d) analyze the data obtained from the devices using the SPRO™ software (RealTrack Systems, Almería, Spain).
The WIMU SPRO calculates the external load indicator used in our study, i.e. player load. Player load is derived from triaxial accelerometers (*x*, *y* and *z*), being used to evaluate neuromuscular load in different athletes.

$$PL_n = \sqrt{\frac{(x_n - x_{n-1})^2 + (y_n - y_{n-1})^2 + (z_n - z_{n-1})^2}{100}}$$

$$Accumulated\ PL = \sum_{n=0}^{m} PL_n \times 0{,}01$$

Players were randomly assigned in the SSGs. During all the games the coach was giving some feedback to the players to encourage them. All the SSGs were conducted in a 1v1 context with 2 minutes of play and 3 minutes of rest (density: work × rest = 1 : 1.5). The pause between the performed SSGs was passive, while the objective during the playing time was always to defend the small goals marked with cones (2 m) in one side and to score

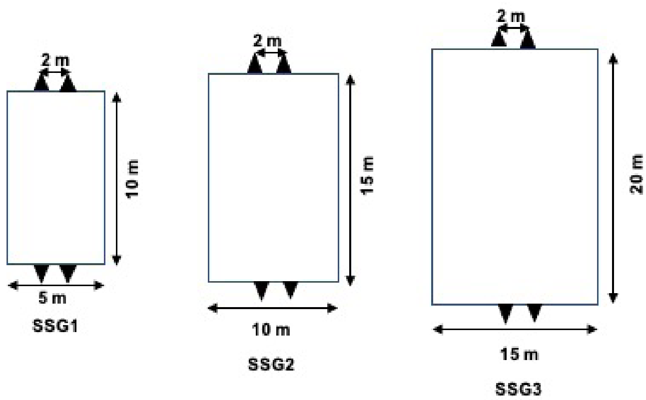

Figure 1. Schematic representation of the experimental protocol

goals in the opposite side. SSG1 presented a 5 × 10 m of pitch dimension (width × length) with an area per player of 25 / 16.66 m^2, SSG2 was characterized by pitch dimensions of 10 × 15 m (width × length) with an area per player of 75 / 50 m^2 and SSG3 was 15 × 20 m pitch dimensions (width × length) with an area per player of 150 / 100 m^2. Figure 1 presents schematically the SSG models used in this study.

The studied variables were distance (total meters covered); explosive distance (distance travelled at more than 12 km/h); player load (effort metric that accumulates tackles, jumps and other non-running activities, enabling visualization of the total amount of movement accumulated during a session); number of accelerations and decelerations; number of impacts (measures G force, to which the body is subject in the different actions of the game) and jumps; maximum velocity and mean velocity.

The normality of the distributions was assessed with the Shapiro–Wilk test. Parametric and nonparametric statistics were selected accordingly. Standard statistical methods were applied to calculate means and standard deviations. The Mann–Whitney U test was used to compare groups in each SSG and the Kruskal–Wallis test was applied to compare SSGs. The significance level was adopted at $p < 0.05$. The data analysis was carried out using the Statistical Package for Social Sciences (SPSS 25.0, SPSS Inc., Chicago, IL, USA).

Results

Under the different SSG conditions for the U-15 and U-12 soccer players differences were mostly observed in HR_{mean} and $HR_{95\text{-}max}$ compared to lower HR zones. Table 2 present the internal load values recorded for the players.

As expected, lower percentages of HR zones (50-60% and 60-70%) were not very evident during the SSGs. In turn, significant differences between the age-groups were recorded in SSG1 in % $HR_{60\text{-}70}$ and in % $HR_{70\text{-}80}$ in SSG2. HR_{mean} was also significantly different between the age-groups in SSG2 and SSG3 and $HR_{>95}$ in all the performed SSGs.

The tendency throughout all the performed SSGs was for the U-15 to show lower values of the HR zone when compared to the U-12, except for $HR_{95\text{-}max}$ and HR_{mean}. Only in HR_{max} significant differences were found between SSG1 and SSG3 ($p < 0.05$).

Another interesting fact was to observe that the $HR_{95\text{-}max}$ and HR_{mean} stabilized or even decreased between SSG1 and SSG2, to increase in SSG3, which reveals that the duration of the different SSGs and the recovery time

Table 2. Internal load values in the two groups during three performed SSGs

		SSG1			SSG2			SSG3		
		M ± *SD*	*CI* (95%)	*p*	*M* ± *SD*	*CI* (95%)	*p*	*M* ± *SD*	*CI* (95%)	*p*
HR_{max} p = 0.050*	U-12	189.50 ± 1.91	186.45-192.55	0.206	193.75 ± 3.30	188.49-199.01	0.283	195.75 ± 3.30	190.49-201.01	0.073
	U-15	196.75 ± 11.14	187.43-296.07		200.00 ± 7.21	193.97-206.03		201.5 ± 5.31	197.05-205.95	
HR_{mean} p = 0.082	U-12	174.50 ± 3.31	169.22-179.77	0.099	176.75 ± 3.59	171.03-182.46	0.018*	181.50 ± 4.65	174.52 ± 188.91	0.028*
	U-15	186.75 ± 11.39	177.22-196.27		188.25 ± 10.51	179.46-197.03		190.75 ± 5.77	185.92-195.57	
$HR_{60\text{-}70}$ (%) p = 0.060	U-12	5.89 ± 5.00	–2.06-13.85	0.002**	0 ± 0	0 ± 0	0.515	4.04 ± 4.71	–3.46-11.54	0.091
	U-15	0 ± 0	0 ± 0		2.58 ± 4.78	–1.41-6.58		0 ± 0	0 ± 0	
$HR_{70\text{-}80}$ (%) p = 0.197	U-12	4.82 ± 2.31	1.14-8.50	0.162	12.68 ± 6.51	2.31-23.04	0.010**	4.80 ± 2.10	1.46-8.15	0.184
	U-15	3.65 ± 6.76	–2-9.31		1.94 ± 2.86	–0.44-4.34		2.45 ± 3.61	–0.56-5.47	
$HR_{80\text{-}90}$ (%) p =0.815	U-12	6.71 ± 1.63	4.11-9.32	0.109	11.45 ± 9.17	–3.59-25.6	0.535	6.16 ± 2.05	2.89-9.42	0.204
	U-15	4.64 ± 2.88	2.23-4.79		6.19 ± 4.66	2.29-10.09		3.70 ± 2.68	1.45-5.94	
$HR_{90\text{-}95}$ (%) p = 0.188	U-12	8.11 ± 3.66	2.27-13.95	0.109	3.75 ± 1.93	0.66-6.83	0.782	4.98 ± 3.43	–0.47-10.44	0.778
	U-15	3.22 ± 2.02	1.52-4.91		2.83 ± 1.13	1.87-3.78		4.63 ± 2.21	2.79-6.47	
$HR_{>95}$ (%) p = 0.162	U-12	74.45 ± 4.64	67.06-81.83	0.051*	72.56 ± 7.63	60.41-84.70	0.051*	80.00 ± 5.83	70.71-89.28	0.051*
	U-15	88.55 ± 9.84	80.32-96.78		86.44 ± 9.58	78.91-93.96		89.21 ± 5.43	84.69-93.73	

* statistical significance ($p < 0.05$); ** statistical significance ($p < 0.01$)

Table 3. External load values in the two groups during three performed SSGs

		SSG1			SSG2			SSG3		
		M ± *SD*	*CI* (95%)	*p*	*M* ± *SD*	*CI* (95%)	*p*	*M* ± *SD*	*CI* (95%)	*p*
Distance (m) p = 0.000**	U-12	162.31 ± 9.02	147.95-176.68	0.004**	195.00 ± 28.12	150.45-239.95	0.352	217.14 ± 27.41	173.57-260.71	0.018*
	U-15	197.75 ± 13.96	186.02-209.37		206.89 ± 11.87	196.97-216.81		261.43 ± 10.64	252.56-270.29	
Explosive distance (m) p = 0.029*	U-12	37.06 ± 2.76	32.65-41.47	0.018*	46.44 ± 5.07	38.32-54.47	0.533	53.07 ± 6.48	42.75-63.39	0.099
	U-15	48.91 ± 11.64	39.18-58.65		50.88 ± 11.76	41.04-60.71		63.62 ± 12.40	53.25-73.99	
Accelera-tions p = 0.018*	U-12	59.09 ± 4.65	59.09-73.91	0.558	58.67 ± 9.38	43.07-72.93	0.046*	59.86 ± 7.74	46.67-71.33	0.436
	U-15	66.57 ± 7.30	60.39-72.61		69.43 ± 5.07	64.76-73.24		61.75 ± 5.92	56.80-66.70	
Decelera-tions p = 0.040*	U-12	66.52 ± 4.21	59.81-73.19	0.558	58.25 ± 9.64	42.97-73.53	0.099	59.76 ± 7.74	46.74-71.26	0.455
	U-15	66.75 ± 6.81	61.01-72.49		69.17 ± 5.82	64.15-73.85		62.25 ± 5.77	57.42-67.08	
Max sprint p = 0.007**	U-12	15.23 ± 0.41	14.57-15.88	0.099	19.44 ± 0.65	18.44-20.47	0.204	19.82 ± 0.37	19.23-20.41	0.202
	U-15	18.23 ± 2.63	16.03-20.43		17.59 ± 2.14	15.81-19.38		21.01 ± 1.49	19.76-22.26	
Mean sprint p = 0.000**	U-12	5.06 ± 0.21	4.71-5.41	0.099	6.06 ± 0.68	4.97-7.15	0.352	6.46 ± 0.69	5.36-7.56	0.109
	U-15	5.56 ± 0.55	5.09-6.02		5.72 ± 0.18	5.57-5.87		7.07 ± 0.36	6.76-7.37	
Impacts p = 0.041*	U-12	101.75 ± 23.44	64.45-139.05	0.525	96.75 ± 8.65	82.98-110.52	0.206	120.25 ± 8.53	106.66-133.84	0.529
	U-15	111.77 ± 26.49	88.85-133.15		117.56 ± 27.81	94.26-140.74		138.5 ± 32.43	111.39-165.61	
Jumps p = 0.758	U-12	0.75 ± 0.95	–0.77-2.27	1.000	1.02 ± 1.15	–0.84-2.84	0.758	–	–	0.051*
	U-15	0.75 ± 0.88	0.01-1.49		0.75 ± 0.88	0.01-1.49		1.50 ± 1.19	0.50-2.50	
Player load$_{vol}$ p = 0.100	U-12	4.09 ± 0.23	3.70-4.47	0.042*	4.27 ± 0.29	3.80-4.74	0.109	4.68 ± 0.29	4.21-5.15	0.099
	U-15	4.52 ± 0.41	4.17-4.87		4.76 ± 0.46	4.31-5.08		5.14 ± 0.59	4.65-5.63	
Player load$_{int}$ p = 0.082	U-12	1.93 ± 0.09	1.78-2.07	0.024*	2.03 ± 0.11	1.84-2.22	0.206	2.24 ± 0.14	2.01-2.48	1.000
	U-15	2.13 ± 0.17	1.98-2.27		2.14 ± 0.23	1.94-2.34		2.38 ± 0.22	2.12-2.48	

* statistical significance ($p < 0.05$); ** statistical significance ($p < 0.01$)

periods (the implemented protocol) provided a favorable physiological adaptation with a decline in HR, and then an increase in SSG3, where the dimensions of the pitch size were greater (15 × 20 m) compared to SSG2 (10 × 15 m).

External load values of the soccer players are presented in Table 3.

It was noticed that the distance covered by the players always increased with the increase of pitch size. In SSG1, when analyzing the variables of distance covered, explosive distance, player load volume and player load intensity significant differences were observed between U-15 and U-12 soccer players. In contrast, in SSG2 significant differences between the age-groups were only observed in accelerations, while in SSG3 it was in distance covered and jumps.

In all the SSGs the U-15 players covered more distance and presented more accelerations, declarations and explosive distance compared to the U-12. In all these variables, as well as maximal velocity, average velocity and impacts, significant differences were observed when all the games were compared.

Average and maximal velocity also rose in line with the increase in pitch size, with the exception in the U-15 regarding the transition between SSG1 and SSG2 in the average velocity. As far as decelerations are concerned, no trend was evident throughout the SSGs, but the number of actions was always higher in U-15 when compared to U-12 soccer players. In accelerations no clear trend was also observable, with the number of actions being very balanced between the groups, except for SSG2, where significant differences were observed (69.0 ± 5.1 and 58.0 ± 9.3 for U-15 and U-12, respectively).

Discussion

To the best of our knowledge, this is the first study to monitor internal and external loads under different SSG conditions, specifically with young soccer players (U-15 and U-12) in a 1v1 context. The main findings of this study were that the performance of three SSGs of 2 minutes in duration and a 3-minute rest (different pitch sizes of 5 × 10 m, 10 × 15 m and 15 × 20 m, respectively) allow U-15 and U-12 soccer players to display a high level and increasing performance throughout all the SSGs. However, the internal and external loads in U-15 and U-12 soccer players presented differences in certain variables of internal and external loads, which needs to be considered in exercise prescription between different player soccer age-groups, and whenever possible, indicate an individualized evaluation of young soccer players.

From the physiological point of view, in terms of the internal load during all the performed SSGs the U-15 players tended to have lower values for % HR zone (from 50 to 95%) when compared to the U-12, except for $HR_{95\text{-}max}$ and HR_{mean}. It should be noted that significant differences in HR throughout all the three SSGs were only recorded in HR_{max}. Nevertheless, values below the $HR_{90\text{-}95}$ were residual, in both age-groups and in all the performed SSGs, confirming that the physiological demand of SSGs in young soccer players is very relevant. This fact is very important for physiological adaptations in soccer training session routines, since attainment of VO_{2max}, despite being individual, is commonly associated to exercise durations of min. 2 minutes. Previously it was indicated that 98% of the total VO_{2max} is attained at four times the time constant of the primary phase of VO_2 kinetics [14], which in athletes is commonly below 30 seconds (evidence in high level athletes indicates it is below 20 seconds), so it is reasonable to speculate that in soccer, 2 minutes of exercise duration provide the possibility to attain VO_{2max}, and consequently, aerobic adaptations. These authors also confirmed that approximately 82% of VO_{2max} did not induce an appreciable rise in [La^-], a fact that in our perspective enables young soccer players to perform during 2 minutes in high level. It was also previously observed no effect of duration from 2 to 6 minutes for technical actions suggesting that these different durations can be used interchangeably in terms of technical proficiency [15].

Regarding this topic, it was indicated that the higher physiological strain typically observed in SSGs on larger pitches is likely to be due to the possibility to make longer offensive and defensive runs [25]. Also in a recent study it was observed in recreational soccer players that HR_{max} and HR_{mean} as well as time spent with HR above 90% of HR_{max} were higher during 5 vs 5 with 80 m^2 compared to 60 m^2 per player [22].

Interestingly, in our study it was observed that the $HR_{95\text{-}max}$ and HR_{mean} stabilized or even decreased between SSG1 and SSG2 (respectively 5 × 10 m and 10 × 15 m), then increasing in SSG3 (15 × 20 m). This reveals that the time duration of the different SSGs and the recovery time periods (all SSGs of 2 minutes with a 3-minute rest interval) allowed, in the first phase, a favorable physiological adaptation with a decline in HR, followed by an increase in SSG3, where the dimensions of the pitch were greater compared to SSG2.

This fact is particularly important, since coaches of young soccer players should ensure that players are given the appropriate stimuli for capacity development, particularly from the physiological point of view in the near pubertal and post pubertal career phases. Recently, this idea was corroborated with a more global perspective [29], indicating that the actual challenge for researchers is to align these new measures with the needs of coaches through a more integrated collaboration between coaches, practitioners and researchers, to produce practical and useful information that improves player's performance and coach activity.

Our results also suggest that, with respect to players' external loads, the distances covered by the players are proportional to the increase of the pitch size both in U-15 and U-12 soccer players. Despite this fact, in SSG2 no significant difference was observed between both soccer player age-groups. Nevertheless, in all the SSGs the U-15 players covered more distance compared to the U-12, the same was observed in explosive distance, whereas only in SSG1 significant differences were observed. This suggests that at smaller pitch dimensions, although the total distance is different between younger and older soccer players (in this specific case U-15 and U-12), the more vigorous actions in soccer differ depending on to the maturation phase of the players.

We should highlight here that in our perspective the individual characteristics of the players in this pre-pubertal (U-12) and post pubertal (U-15) phase contribute to the difference in the SSG dynamics, in parallel with factors such as the years of experience, the total weekly time of training practice as well as the duration and dimensions of the official weekly games, all of which should be considered with caution in the prescription of training tasks by soccer coaches.

Several studies, the majority with 3v3 or more players, have been conducted to examine a wide variety of different training variables for SSGs, such as player numbers [9] and pitch size [7]. These specific tasks are commonly used as a training drill by coaches to develop the physical fitness [26] or technical and tactical abilities of soccer players [21]. Fanchini et al. [15] tested the 3v3 format in three regimens and found that long sets (3 × 6 minutes / 2 minutes rest) contributed to a drop in HR responses compared to medium (3 × 4 minutes / 2 minutes rest) and short (3 × 2 minutes / 2 minutes rest) sets, although no significant differences were observed for perceived effort or technical actions. Köklü et al. [19], when comparing internal and external load variations in young players between training regimens, observed that shorter sets elicited a lower maximal HR, a shorter distance covered at low running speed and contributed to an increase in the distances covered at both medium and high running speeds.

Our results showed that the average and maximal velocity tend to rise independently of the regimens (work × rest = = 1 : 1.5, 2 minutes work and 3 minutes rest, respectively) in the three performed SSGs tasks, indicating that the main factor influencing the sprint is the pitch size, which lead the young soccer players (both U-15 and U-12) to always show more maximal velocity between SSG1 and SSG3 [except for the U-15 in the transition between SSG1 (5 × × 10 m) and SSG2 (10 × 15 m) in the average velocity, with a slightly decrease]. This fact seems to be associated with the limitation of SSGs in producing high-speed activities when played on smaller pitch areas (such as 5 × 10 m or 10 × 15 m compared to 15 × 20 m), where the players do not have enough space to reach their maximal sprinting speed for a relevant period of time.

Likewise, as previously indicated, the distance and explosive distance rose from SSG2 to SSG3 in both age-groups of soccer players, but the accelerations and decelerations from SSG2 to SSG3 decreased in the U-15 soccer players, but not in their U-12 colleagues, where the number of actions remained stable. Considering that in U-15 between SSG1 and SSG2 both accelerations and decelerations rose, but this trend was not evident in U-12 (a decrease from SSG1 and SSG2) the increase in distance from SSG2 to SSG3 in both groups may have been related metabolically to the aerobic pathway, since it is clear that glycolytic reserves are limited, and the increase in accelerations and decelerations between SSG1 and SSG2 only in U-15 is probably related to the muscular development in the U-15 maturation phase compared to the U-12. The significant difference observed in accelerations between U-15 and U-12 in SSG2 supports this evidence and lead us to consider that changes in external load in soccer are more relevant and associated to the tasks compared to the monitoring of HR. When differences between SSGs were analyzed in terms of external load, no differences were observed only in jumps and player load (both volume and intensity). Contrary to internal load, in which a significant difference between SSGs was found in HR_{max}, the significant differences throughout all SSGs in distance covered, accelerations, declarations, explosive distance, maximal velocity, average velocity and impacts, revealed that the dynamic related to external load during the three performed SSGs is greater compared to internal load.

Moreover, Rábano-Muñoz et al. [23] recently studied the SSGs with different soccer player age-groups (senior, U-19 and U-17), concluding that this forms of games in the training routine could be an adequate stimulus for aerobic training of these age-groups because the reported values were close to the 80-85% of HR_{max}. Previous evidence also indicates that young soccer players experience negative outcomes relating to physical performance [2] and hormonal profile [20] during periods of higher density training [28], which require careful balancing of workloads in the younger individual. SSGs can facilitate this balance by providing a multidimensional approach to addressing the diverse demands of soccer play [27].

This study had some limitations. The sample was not large, thus the inferences should be taken cautiously. Moreover, in the future it will be useful to analyze alongside with internal and external load also the tactical behavior of players combining such variables with technical performance in order to understand the outcomes. Nevertheless, the results of this study are pertinent for improving training practices that integrate SSGs in U-15 and U-12 soccer players, aiming at the young soccer player development. Further studies may include maturation assessment of players, as well as the maximal velocity of each player to determine the percentage exhibited in each SSG format. It could also be interesting to determine repeated sprint ability of the players aiming at a comparison with the physical performance displayed in each SSG format.

Conclusions

The findings of this study suggest that SSGs in U-15 and U-12 soccer players are useful daily training tools for physiological and motor enhancement. SSGs performed in the beginning of the soccer training session, after the warm-up, of 2 minutes in duration with a 3-minute rest interval in three consecutive different pitch dimensions

(5 × 10 m, 10 × 15 m and 15 × 20 m), allow young soccer players to perform at a high level and, consequently, to prepare for transfer to the competition level.

The physiological and motor display seems associated with the increase in the pith size, but tasks below 15 meters should be carefully analyzed, because the lack of space influences sprint capacity. Training prescription in soccer between different age-groups should be carefully analyzed and whenever possible, evaluated from an individual perspective, since performance levels differ between U-15 and U-12 soccer players.

External load measures should be considered in training monitoring in youth soccer, since HR alone does not provide reliable information regarding players' adaptations to the tasks. SSGs are useful in young soccer players but should be implemented in the training sessions with caution, since the physiological and motor enhancement may cause excessive physical and cognitive stress, which in turn can result in burnout and/or injury in young soccer players.

Acknowledgements

The authors are grateful to the team and the soccer players involved in this study, which was supported by the Foundation for Science and Technology, I.P., Grant/Award Number UIDB/04748/2020.

Conflict of Interests

The authors declare no conflict of interest.

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SHORT REPORT

TRENDS in
Sport Sciences
2021; 28(**1**): 55-60
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.1-7

Is crowd support a significant factor in home advantage on the highest level of competition in football?

MACIEJ JAGUSZEWSKI

Abstract
Introduction. **Home advantage is an important factor in determining the result of a football game. Crowd support is considered to be a major factor influencing home advantage, but it has not been verified individually on the professional level. Due to the COVID-19 pandemic, football matches started to be held without the participation of an audience, which gave an opportunity to examine crowd effects. In this article the impact of crowd effects was examined on the highest level of competition, in four best European leagues.** Aim of Study. **The aim of the study was to check if crowd support is an important factor in home advantage in four best European football leagues and to examine tendencies in home advantage in those leagues from 2015 to 2020.** Material and Methods. **Football match results from 2015 to 2020 in the Spanish, English, German and Italian leagues were collected and used in the analysis. Two coefficients: Home Advantage Rate and Difference between percentage of home team wins and losses were used. Statistical calculations were carried out using the STATISTICA software package.** Results. **It was noticed that in Spain and in Germany home teams performed worse in matches without an audience than in those with crowd support. However, in England and in Italy the results of home teams with and without crowd presence were similar. Moreover, home advantage has been decreasing in recent years in the best European leagues.** Conclusions. **There is a statistically significant impact of crowd support on home advantage on the highest level of competition in football.**

KEYWORDS: football, home advantage, crowd effects.

Received: 4 January 2021
Accepted: 12 January 2021

Corresponding author: maciej.jaguszewski@gmail.com

Adam Mickiewicz University, Faculty of Mathematics and Computer Science, Poznań, Poland

Introduction

Home advantage has been established as an important factor in determining the result of a football game at least since the start of organized football at the end of the 19th century. It is observed around the world, but varies depending on the country and level of competition. Although home advantage is a factor determining results not only in football, but also in other team sports, in European football (soccer) it tends to have a greater impact and for this reason the scope of this article is limited to this particular sport.

The first report of home advantage in football was written by Morris [3] in 1981. Then there were articles released by Dowie [2] and by Pollard [5], who later updated his researches [6, 11]. Many researchers followed the subject later [10] as home advantage is an extensive topic and can be examined in many different ways – depending on the level of competition in leagues, location and time, in which a given competition took place.

According to a study by Pollard [4], explanations for home advantage in football include crowd effects, travel effects, familiarity, referee bias, psychological factors, to name just a few. Crowd support is the most obvious factor related to home advantage [4, 12]; while many researchers examined its relationship with crowd size [6, 10, 11], this aspect is still unclear. Moreover, crowd support can influence home advantage directly through its effect on the players as a psychological factor, while it may also impact the referee's decisions.

Although researchers acknowledged crowd effects as an obvious factor having impact on home advantage, there were limited opportunities to examine this factor individually in professional leagues, especially on the highest level of competition, as almost all games were played with the participation of the audience of fans. Due to the COVID-19 pandemic, most professional leagues stopped playing and then finished the 2019/2020 season with matches played without an audience, which provided a rare opportunity to examine how home advantage has changed without the crowd support and if it is clearly a significant factor in home advantage on the highest level of competition in football.

The impact of home advantage has been declining over years. One of the reason for this decrease is the fact that players are becoming less familiarised with the home ground, as we are in the era of free agency, as a result professional players can change teams easier and do it more often. Increased professionalism and market culture in football are also reasons for reducing the impact of home advantage. There are also other explanations of this decline, such as advances in technology and medicine, which make players better prepared for away matches. The downward trend for the impact of home advantage was also verified in this particular paper.

Europe is considered the best continent in football (soccer), as this is the most popular sport in many countries there. It is also seen in the FIFA ranking, where among the 20 best countries, 14 are European. As a result, the best European leagues are considered the best in the world and should be considered as the highest level of competition in football.

In this article four best European leagues (according to the UEFA ranking) were investigated. Those four European leagues have been the top 4 in the ranking for more than a decade and have built their reputation as the best European leagues for many years. Furthermore, according to the UEFA rules four best European leagues have the highest number of their teams in the Champions League and the Europa League every year, which further confirms their prestigious status.

Aim of Study

The purpose of the study was to check if crowd support is an important factor in home advantage in four best European football leagues and to examine tendencies in home advantage in those leagues from 2015 to 2020. This information was used to verify a well-established hypothesis concerning the crowd support's impact on home advantage in football matches on the highest level of competition. Moreover, it was checked whether even without the crowd effects, home advantage could still be observed in the best European leagues.

Material and Methods

Results from football matches played from the 2015/2016 to the 2019/2020 seasons both with and without crowd support (in the 2019/2020 season) in four best European leagues: the English Premier League, the Spanish La Liga, the German Bundesliga and the Italian Serie A were included in the analysis in this particular paper.

Data was presented as qualitative data (number of wins, draws, losses) and in tables (also percentage-wise depending on the season, country and presence of crowd). Two coefficients were used – the Home Advantage Rate (HAR), which is counted as the proportion (percentage) of points scored by the home teams to all points by the home and away teams, and the Difference between the percentages of home team Wins and Losses (DWL).

The threshold value for HAR is 50%, while for DWL it is 0 percentage points (p.p.), which means that there is no difference in the results between home and away matches. Bigger values of both coefficients indicate better results in matches played at home, while smaller values means better results for the teams which played away matches.

A structural test was also used to check if the difference between the results of games played with and without the crowd presence is statistically significant. This statistical analysis was conducted using Dell Inc. (2016) Dell Statistica (data analysis software system), version 13. software.dell.com. The level of significance for the statistical test was set at $p \leq 0.05$.

Results

It was observed that in Spain the home teams performed worse in matches played without crowd support, as they won only 40.9% of those games compared to over 47% in four out of the five seasons from 2015/2016 to 2019/2020. In the 2018/2019 season, in which home teams won 44.2% games, there were more draws (28.9% of games), which led to a similar HAR to that for the other seasons – in every season in the matches with the audience presence the HAR value was higher than 59%, in contrast to 55% in the 2019/2020 season in the matches without fans present. The same conclusions were reached for DWL – it was higher in the seasons with the crowd effects, as the average value was almost 19 p.p. and it dropped to 9.1 p.p. in the matches without crowd support (Table 1).

In England the home teams had similar results in the matches both with and without the audience, as 46.7% matches were won by the home teams without crowd

Table 1. Results in four best European leagues from 2015/2016 season to 2019/2020 season depending on country, season and crowd presence
[a] games in 2019/2020 season without crowd presence; [b] all games from 2015 to 2020 (with and without crowd presence)

Country of league	Season	Games	Wins [%] (N)	Draws [%] (N)	Losses [%] (N)	HAR [%]	DWL [p.p.]
Spain (La Liga)	2015/2016	380	48.2 (183)	24.2 (92)	27.6 (105)	61.2	20.6
	2016/2017	380	47.6 (181)	23.4 (89)	28.9 (110)	60.1	18.7
	2017/2018	380	47.1 (179)	22.6 (86)	30.3 (115)	59.1	16.8
	2018/2019	380	44.2 (168)	28.9 (110)	26.8 (102)	59.6	17.4
	2019/2020	270	47.8 (129)	27.8 (75)	24.4 (66)	62.9	23.4
	2015-2020	1790	46.9 (840)	25.3 (452)	27.8 (498)	60.4	18.9
	2019/2020[a]	110	40.9 (45)	27.3 (30)	31.8 (35)	55.0	9.1
England (Premier League)	2015/2016	380	41.3 (157)	28.2 (107)	30.5 (116)	56.0	10.8
	2016/2017	380	49.2 (187)	22.1 (84)	28.7 (109)	61.1	20.5
	2017/2018	380	45.5 (173)	26.1 (99)	28.4 (108)	59.4	17.1
	2018/2019	380	47.6 (181)	18.7 (71)	33.7 (128)	57.4	13.9
	2019/2020	288	44.8 (129)	25.0 (72)	30.2 (87)	58.0	14.6
	2015-2020	1808	45.7 (827)	23.9 (433)	30.3 (548)	58.4	15.4
	2019/2020[a]	92	46.7 (43)	21.7 (20)	31.5 (29)	58.2	15.2
Germany (Bundesliga)	2015/2016	306	44.1 (135)	23.2 (71)	32.7 (100)	56.2	11.4
	2016/2017	306	49.0 (150)	24.2 (74)	26.8 (82)	62.1	22.2
	2017/2018	306	45.4 (139)	27.1 (83)	27.5 (84)	59.9	17.9
	2018/2019	306	45.1 (138)	23.9 (73)	31.0 (95)	57.6	14.1
	2019/2020	224	43.8 (98)	21.4 (48)	34.8 (78)	54.8	9.0
	2015-2020	1448	45.6 (660)	24.1 (349)	30.3 (439)	58.3	15.3
	2019/2020[a]	82	30.5 (25)	24.4 (20)	45.1 (37)	42.0	–14.6
Italy (Serie A)	2015/2016	380	46.1 (175)	25.0 (95)	28.9 (110)	59.3	17.2
	2016/2017	380	48.4 (184)	21.1 (80)	30.5 (116)	59.6	17.9
	2017/2018	380	43.2 (164)	21.8 (83)	35.0 (133)	54.4	8.2
	2018/2019	380	43.7 (166)	28.4 (108)	27.9 (106)	58.7	15.8
	2019/2020	256	40.2 (103)	22.7 (58)	37.1 (95)	51.7	3.1
	2015-2020	1776	44.6 (792)	23.9 (424)	31.5 (560)	57.1	13.1
	2019/2020[a]	124	44.4 (55)	21.8 (27)	33.9 (42)	55.7	10.5
All four leagues	2015/2016	1446	45.0 (650)	25.2 (365)	29.8 (431)	58.3	15.2
	2016/2017	1446	48.5 (702)	22.6 (327)	28.8 (417)	60.7	19.7
	2017/2018	1446	45.3 (655)	24.3 (351)	30.4 (440)	58.1	14.9
	2018/2019	1446	45.2 (653)	25.0 (362)	29.8 (431)	58.4	15.4
	2019/2020	1038	44.2 (459)	24.4 (253)	31.4 (326)	57.0	12.8
	2015-2020	6822	45.7 (3119)	24.3 (1658)	30.0 (2045)	58.6	15.7
	2019/2020[a]	408	41.2 (168)	23.8 (97)	35.0 (143)	53.3	6.2
	2015-2020[b]	7230	45.5 (3287)	23.3 (1755)	30.3 (2188)	58.3	15.2

support and this was 1 p.p. higher than the average wins percentage presented in those played with the crowd presence from 2015 to 2020. It was also shown by similar values of HAR and DWL – in both coefficients the value for the matches without the audience was only 0.2 p.p. lower than that for the five seasons played with fans present (Table 1).

In Germany the home teams had surprisingly bad results in the matches played without fans, as they won only 30.5% matches, significantly fewer than they lost (45.1%), which resulted in the only negative value of DWL in Table 1. This was also shown by the lowest value of HAR (42%), which confirmed that the away teams performed better than the home teams in those 82 games played with the crowd absence. Meanwhile, in the seasons with the crowd presence the home teams performed better than the away teams, winning at least 43.8% of the matches and with the DWL higher or equal to 9 p.p. (Table 1).

It was noticed that in Italy the home teams performed similarly in the matches with and without the presence of an audience. In the games without fans present the home teams won 44.4% matches, which is 0.2 p.p. smaller than the results from 2015 to 2020, in which there was a crowd effect. Furthermore, HAR (55.7%) and DWL (10.5 p.p.) in the matches without fans present did not differ much (being by 1.4 p.p. and 2.6 p.p. lower) from the results in the matches with crowd support between 2015 and 2020 (Table 1).

A greater variability was also observed in Italy and Germany in the HAR depending on the season compared to in Spain and England. Moreover, it was noticed that in England and Italy the results in the matches played without fans were similar to those played with the crowd presence, in contrast to Spain and Germany, where the home teams performed worse with the audience absence, as shown by the value of their smallest coefficients in the 2019/2020 season in the matches without fans (Table 1, Figure 1).

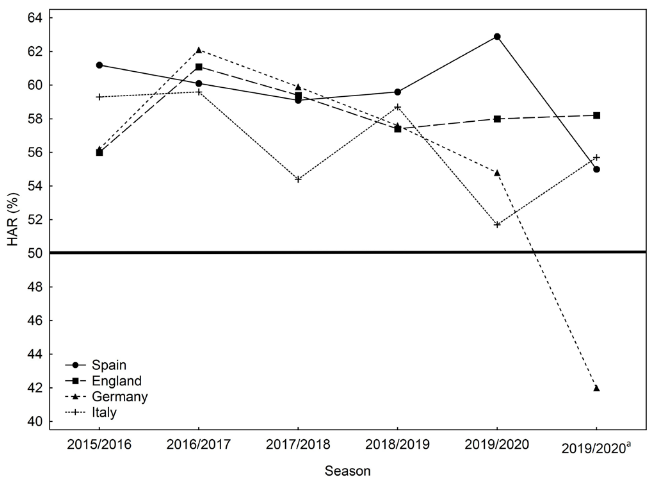

Figure 1. Home Advantage Rate in each of four best European leagues in between 2015/2016 to 2019/2020 seasons

[a] games in 2019/2020 season without crowd presence

Results of HAR in all the four leagues in every season included in the analysis were presented in Figure 1. The home advantage trends are shown in five most recent seasons depending on the country and the absence of the audience impact on HAR in each of the top 4 European leagues.

Looking at all the four leagues, in the matches without the crowd support, a decrease was recorded in the home teams' winning percentage (41.2% compared to over 44% in the other seasons), HAR (53.3% compared to min. 57% in the seasons with the audience presence) and DWL (6.2 p.p. compared to over 12 p.p. in every other season) (Table 1). That tendency was confirmed by the statistically significant result ($p = 0.0349$) of the structural test, which compared all the matches with and without fans present, considered in this article.

Discussion

Although the HAR value changes from season to season, with some unexpected one-year spikes, a downward trend was observed for this coefficient, which means that the home advantage is declining. This coefficient was examined in many studies [7, 8, 9] in different time periods in the European leagues, including this paper.

A drop of HAR was observed especially in Spain, where between 1929 and 1983 HAR was almost continuously above 70% (reaching as much as 75% several times in the 1970s), but then decreased significantly to as little as slightly over 60% in the early 2000s. Also in Italy a decrease of HAR was observed over the years, from over 70% after the Second World War to just slightly above 60% in the early 2000s [9].

Moreover, HAR was examined in six straight seasons from 1997/1998 to 2002/2003 in every European league [7]. According to the UEFA ranking from the 2002/2003 season the four best leagues were exactly the same as they are now (Spanish, Italian, English and German). In each of those leagues the average HAR from those 6 seasons was over 60%. The lowest value was recorded in the English league (61.19%) and the highest – in the Spanish league (63.90%).

HAR was also examined between 2006 and 2012 worldwide [8]. In each of the four best European leagues the values of HAR were smaller than the aforementioned from 1997 to 2003. The highest HAR value from those four leagues during the 6-season period was held by the Italian league (62.25%), while the lowest – by the German league (58.35%), which was the only result below 61% in the four best European leagues.

Comparing this above-mentioned results with those examined in this article (5 seasons between 2015/2016 and 2019/2020 in matches with fans present) another decrease of HAR was observed as the highest value was recorded in the Spanish league (60.4%) and the lowest – in the Italian league (57.1%). That means the downward trend for the home advantage was also seen in recent years (Table 1).

Furthermore, HAR in each analysed league in those average results from 2015 to 2020 in matches with the crowd presence was higher than that in games without the crowd effects in the 2019/2020 season. Although the difference in England was really small (0.2 p.p.), in the other countries it was more significant (1.4 p.p. in Italy, 5.4 p.p. in Spain and 16.3 p.p. in Germany), which shows the crowd support's impact on the home advantage (Table 1).

According to a study by Bray [1], home advantage exists if the difference between the home team's wins percentage and the home team's losses percentage (in this article presented as DWL) is higher than 5 p.p. It was not observed only in two cases (in Germany in the 2019/2020 season in matches without fans and in the 2019/2020 season in those with the crowd support in Italy) and there were only three more cases in those leagues, in which DWL was smaller than 10 p.p. (Table 1).

Looking at the results from all the four leagues, in the matches with the crowd presence the lowest DWL value was 12.8 p.p., in the 2019/2020 season before the pandemic and in the years 2015-2020 the average DWL was over 15 p.p. Then a drop by over 50% in the matches without fans was noticed, as the value of DWL in this case was 6.2 p.p., meaning that in the matches without the crowd presence the home advantage still existed, but it was significantly smaller than in the matches with fans in the audience (Table 1).

That also was observed considering HAR (which is dependent on DWL), as it also decreased in games without fans from 57.0% (the lowest value of a single season with the crowd effects in HAR from 2015 to 2020) to 53.4% (HAR from the matches without fans in the 2019/2020 season). Taking in consideration 50% as the threshold value, this decrease could be seen as a little over 50% drop in home advantage (Table 1).

Considering a reduction bigger than 50% without the crowd effects, it could have been assumed that the crowd support has the biggest impact among all the factors of home advantage. This hypothesis was not yet examined, as we would need check the impact of other factors on the results of football matches. For example, to verify the effect of familiarity, matches with the crowd effects similar to those played at home, but played in neutral venues, should also be examined. While it will be difficult to obtain a big sample size and do it especially for the highest level of competition, if possible it would be of great interest.

The sample size of matches without the crowd presence is a slight limitation in this study, as not every possible match-up between every pair of teams was played and also every match-up appeared at maximum once. It would have been preferable to have a bigger sample size, with the full season (every possible match-up played twice) played without the crowd presence. Understandably it was an unprecedented circumstance to have matches without fans present on the highest level of competition, so nothing can be done in this case. Nevertheless, in the opinion of the author the sample size of over 400 matches is sufficient to consider the results significant. It is possible that the full 2020/2021 season will be played without the crowd effects, then the results of the home teams in this full season would be an interesting topic to examine in further studies.

This paper is based on the four best European leagues, which might not be fully representative for all types of football leagues considering specific conditions in other countries and different levels of competition. Still the main topic of this study was to check if the crowd effect is a significant factor in home advantage on the highest level of competition.

Conclusions

In conclusion, this study shows that there is a statistically significant impact of crowd support on home advantage on the highest level of competition in European football (soccer). Although home advantage still exists without this factor, it is significantly smaller. Moreover, home advantage shows a tendency to decrease over the recent years and it raises a question whether in the next 30 years or so it would still be a significant factor in determining match results in football.

Conflict of Interests

The authors declare no conflict of interest.

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Table 1. Descriptive statistics and comparative analysis of maximal oxygen uptake (VO_2max in ml/kg·min^{-1}) between genotypes of the I/D *UCP2* gene polymorphism

UCP2	DD					ID					II				
Sex	*N*	$\bar{x}$	*SD*	*Min*	*Max*	*N*	$\bar{x}$	*SD*	*Min*	*Max*	*N*	$\bar{x}$	*SD*	*Min*	*Max*
F	42	45.65	*6.14*	32.30	59.00	36	45.66	*7.18*	30.60	59.80	7	45.07	*7.60*	35.00	54.80
M	72	54.01[a]	*6.20*	40.30	79.00	70	55.60	*7.32*	42.30	76.80	12	59.07[a]	*9.04*	49.70	74.90

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