Poznan University of Physical Education

TRENDS in SPORT SCIENCES

(formerly Studies in Physical Culture and Tourism)

quarterly • number 2 • volume 28 • year 2021

Editorial board address
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ISSN 2299-9590

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
ICI Journals Master List
AGRO database

Index Copernicus (2017): 88.38 points
KBN/MNiSW (2019): 20 points

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REVIEW ARTICLE

TRENDS in
Sport Sciences
2021; 28(**2**): 69-82
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.2-1

Influence of caffeine supplementation on bench press performance – review

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Abstract
Introduction. **Caffeine (CAF) is widely consumed psychoactive substance and one of the most used supplements. Due to the fact that strength and power training has become an essential component of conditioning programs in most of the competitive sports, the need for more specific analysis of CAF in terms of resistance training has been established. Furthermore, most of the research focused on the acute effects of CAF supplementation on muscle performance utilized the bench press (BP) exercise. Taking into consideration the popularity of the BP exercise, the main purpose of this review is to evaluate the current state of knowledge on the impact of CAF supplementation on the BP performance and to point out practical guidelines.** Material and Methods. **PubMed, Medline and GoogleScholar databases were searched from 2006 to 2020 for studies evaluating the effects of CAF on: (1) maximal muscle strength; (2) power output; and (3) strength-endurance performance as assessed in the BP exercise. Twenty-three articles met the inclusion criteria and were consequently included in the review.** Results. **In general, CAF in doses of 3 to 6 mg/kg has been found to be a safe ergogenic aid during the BP exercise in terms of improving maximal strength and power output, however the impact of CAF intake on strength-endurance is less clear. Additionally, doses of 9 mg/kg and 11 mg/kg might be ergogenic in the improvement of maximal strength and power output, however higher frequency of side effects observed has to be considered in supplementation strategy.** Conclusions. **The performed review showed that acute CAF intake can be an effective strategy to improve resistance training outcomes for maximal strength and power output tests during the BP exercise. However, extrapolation of these guidelines to long--term benefits of CAF influence on the BP exercise remains limited due to lack of evidence in this area.**

KEYWORDS: strength endurance, power output, maximal strength, ergogenic aid, upper-limbs.

Received: 6 February 2021
Accepted: 13 March 2021

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Introduction

Caffeine (CAF) is widely consumed psychoactive substance and one of the most used supplements by competitive athletes [53]. It has been shown not only to improve physical performance tasks, but also cognitive aspects, for instance, alertness, concentration, vigilance, and memory, notably in sleep-deprived subjects [42, 48]. CAF supplementation for improving sports performance has become particularly popular after the World Anti-Doping Agency (WADA) removed it from the list of prohibited substances in 2004 [15] and nowadays it is ubiquitous in all sport disciplines [53]. There are reports claiming that 75-90% of athletes consume CAF before or during training and competition [13]. However, CAF concentrations in samples from athletes representing strength-related disciplines were significantly higher in comparison to athletes from other sports [53] and increased significantly from 2004 to 2015 [1], which underline the need for more specific analysis of the impact of CAF as regards to resistance training.

Strength and power training has become an essential component of conditioning programs in most of the competitive sports. Thus, optimization of resistance training and the pattern of adaptive changes related to the development of muscular strength and power are the focus of interest of scientists and coaches [12], who are interested in the improvement of maximum strength, as well as the beneficial changes in power output and strength-endurance. Muscular strength is defined as "the capability to exert force under a particular set of biomechanical conditions" [10] and has been recognized as a vital factor impacting performance in various sports [65]. Muscular strength development is most often accomplished by means of resistance training [33] and commonly measured by the 1RM test [58]. The 1RM test is considered the gold standard for assessing muscle strength under non-laboratory conditions and should be conducted over a specific range of motion and with use of a proper technique [34, 60]. Similarly, to muscular strength, the muscular power is acknowledged to be a crucial component as regards to athletic performance in many sport disciplines and is likewise developed by means of resistance training [62]. Muscular power is defined by "the ability to exert a maximal force in as short a time as possible, as in accelerating, jumping and throwing implements". It is dependent on optimal values of the force generated by the muscles and the velocity of the movement, thus it is usually described by the relationship between the two aforementioned components [62].

Interestingly, there is a growing number of studies analyzing the effects of CAF supplementation on various aspects of resistance training. Furthermore, most of the research focused on the acute effect of CAF supplementation on muscle performance utilized the bench press (BP) exercise. The BP exercise is a commonly known resistance exercise, primarily used for the upper-body strength and power development among both recreational and professional athletes [36, 57, 68]. The BP exercise is performed as one of the specific disciplines in powerlifting [61]. It is also used by athletes in most strength-speed oriented sport disciplines [52]. The pectoralis major, anterior deltoid and triceps brachii are the main muscles involved in the BP exercise [31, 32], however it should be noted that various factors such as grip width [57], variation of the exercise [36, 59] or the type of the bar [31, 36] can affect exercise performance during the BP.

It is commonly known that supplementation, which could directly impact acute and chronic performance responses play an important role in improving the effectiveness of resistance training [9, 35, 67]. Interestingly, from investigating CAF's impact on aerobic exercise, recently the research interest has focused on anaerobic exercise performance outcomes, such as maximal strength, strength-endurance, and muscle power [26]. It should be emphasized that all of above-mentioned performance indicators of resistance training could be measured during the BP exercise, which is widely used in experimental protocols. Taking into consideration the popularity of the BP exercise [59] the main purpose of this review is to evaluate the current state of knowledge of CAF supplementation on the BP performance and to point out the practical guidelines of CAF supplementation when performing the BP exercise. The authors believe that the results will benefit athletes and practitioners in various sports in which muscle strength and/or power of upper limbs are important determinants of performance.

Mechanisms of action of caffeine during bench press performance

The mechanisms responsible for the ergogenic effect of CAF are related to the effect on various tissues, organs and systems of the human body. The potential effects of CAF at the cellular level can be explained by three possible mechanisms of action: a) the antagonism of adenosine receptors, especially in the central nervous system (CNS); b) the mobilization of intracellular calcium storage; c) the inhibition of phosphodiesterase. However, the influence of CAF on resistance performance is mostly associated with the impact of CAF on the CNS and antagonistic effects on adenosine receptors. Due to the fact that CAF is structurally similar to adenosine, its consumption blocks the binding of adenosine with A1 and A2A receptors and supports the release of neurotransmitters such as noradrenaline, dopamine, acetylcholine and serotonin [51], which affects the central nervous system and alters arousal and leads to improved performance. Moreover, through its action on adenosine receptors which are involved in nociception, CAF plays an important role in pain modulation [6]. It is important because resistance exercise may provide significant increases in pain perception [11]. Thus, it is possible that the improvement in performance during resistance exercise may be associated with better pain management. In addition, CAF may also increase the release of calcium from the sarcoplasmic reticulum as well as the recruitment of motor units, which may impact muscle contraction strength and help explain some of the ergogenic effects of CAF on resistance exercise performance [51]. Moreover, studies by Tallis et al. [50] and Mohr et al. [39] suggest that CAF may have a direct effect on skeletal muscle tissue, which could also explain its ergogenic effects. Lastly, factors such as motivation and belief due to CAF consumption may influence the response after CAF intake [48]. However, the placebo effect of CAF was examined only in a few studies analyzing the resistance exercises [19, 48], which found conflicting results. Nonetheless, currently psychological factors associated with CAF are often unaddressed in most experimental designs.

Caffeine dose and timing

Current studies confirmed the ergogenic effect of acute CAF intake in resistance training at doses of 3 to 6 mg/kg [29, 30]. However, the administration of a low CAF dose (~3 mg/kg bm) is mostly associated with action through the CNS and do not provide changes in exercise heart rate and the levels of catecholamines, lactate, free fatty acids, and glycerol [49]. Moreover, it has been shown that the plasma CAF levels needed to induce changes in the metabolic tissues are significantly higher than required to impact the adenosine receptors in the brain and peripheral nervous system [21]. Given the fact, that improving resistance performance may be related to several mechanisms of action, it might be concluded that there could not be major ergogenic effects with CAF doses of ~3 mg/kg bm or less where plasma levels are 15-20 μmol/L. Interestingly, for the resistance training the most typically used doses represents a range of 3 to 6 mg/kg, but two studies have shown a positive effect of higher doses varying from 9 to 11 mg/kg [41, 55]. It has been suggested that the CAF dose used could depend on the magnitude of load used, and higher CAF doses may be necessary when high loads are utilized, despite the appearance of side effects [41, 64]. Hence, the optimal dose may differ depending on the type and duration of the exercise, the type of contraction, and previous habituation to CAF [26, 30, 41, 47]. The recommended time of consumption is 30 to 90 minutes before exercise, while the form of supplementation (capsules, liquid, powder) of CAF is less important due to similarly quick absorption after acute intake [26].

Habitual intake, side effects and inter-individual differences in caffeine ergogenicity

It should be noted, that the daily level of CAF consumption and habituation to this supplement may modify the ergogenic effect of CAF on resistance performance. It could be important for the growing number of athletes, who typically consumed CAF on a regular basis [1]. According to Fredholm et al. [21], regular consumption of CAF is associated with an increase in adenosine receptors, which may have an impact on the effectiveness of CAF's blocking effect. Moreover, the production of cytochrome P450 enzymes responsible for CAF metabolism is also upregulated by regular CAF consumption, as a result increasing CAF metabolization speed in habitual users [43]. Repeated exposure to CAF also blunts some of the physiological responses observed by CAF-naïve individuals following acute CAF administration, such as increased adrenaline secretion [5]. In fact, several studies analyzing the effectiveness of CAF ingestion in resistance exercises conducted on habituated participants showed only partial improvement of performance [55] or did not observe a positive effect of CAF supplementation [56, 64]. However, several studies have shown that habitual consumption of CAF did not worsen the ergogenic benefits of acute supplementation [24, 27]. Pickering and Kiely [43] suggested that the maintenance of the ergogenic effect of CAF does still occur in habituated subjects but the used dose has to be higher than the typical daily level of CAF intake. However, due to several inconsistencies including various methods of classification, level of habitual intake and methods of its evaluation, which was recently discussed by Filip et al. [18], this issue is still unsolved and requires further research.

Although higher doses of CAF may seem beneficial for habituated users [43], it should be noted, that various side effects of CAF consumption have been shown to occur, including anxiety, nervousness, increased urine output, insomnia, tachycardia and heart palpitations [43, 64]. Generally CAF doses between 9 and 13 mg/kg seem to elicit severe side effects [64], as well they tend to be the most pronounced in individuals non-habituated to CAF [43]. Wilk et al. [64] have shown that high CAF doses (9 and 11 mg/kg) also cause negative side effects in habituated individuals, furthermore, these adverse effects can persist even 24 hours after ingestion impacting sleep and activities to be performed on the following day. It is important to note, that among habituated CAF users withdrawal is also often associated with negative effects, such as nausea, headaches, irritability and muscle pain [43]. Another factor to be considered as regards to CAF consumptions is the fact, that there are different individual responses following CAF ingestion, which may be influenced by variation in individual genotype (variation within CYP1A2 and ADORA2A genes), environmental factors or epigenetic mechanisms [43]. A single nucleotide polymorphisms within aforementioned genes has been shown to affect the speed of CAF metabolisation (CYP1A2) as well as habitual caffeine use and sleep disturbances (ADORA2A). Thus, substantial differences in performance improvement between individuals following CAF ingestion have been shown to occur, ranging from highly ergogenic to ergolytic [42, 43].

Gender is also a significant factor as regards to CAF ergogenicity [42, 56]. Although CAF has been shown to be ergogenic for both male and female subjects, due to the use of oral contraceptives as well as differences in menstrual cycle stage, CAF metabolization speeds may be altered among women [42]. It has been suggested that a longer time between CAF ingestion and exercise may be beneficial for females [42].

Effects of caffeine on maximal strength

With currently available scientific studies, it is difficult to confirm the positive effect of CAF on maximal strength during the BP exercise. For instance, several studies found no effect of CAF on the 1RM test during the BP exercise [4, 28, 64, 69], but contrary different investigations showed the positive effect of CAF supplementation on maximal strength [2, 7, 16, 23, 46]. The inconsistencies in results of the studies can be explained mainly by differences in characteristics of participants including a) training experience, b) strength level c) relation of used CAF dose to the level of habitual CAF intake. It is worth noticing, that studies, which involved participants who reported lower experience in resistance training [2, 23] showed a positive effect of CAF supplementation. Investigations including athletes with high training experience [4, 28, 69] did not confirmed the ergogenic effect of CAF. Additionally, in research which did not observe a significant increase in maximal strength [4, 28, 69], the initial 1RM in the BP exercise was higher than 100 kg, corresponding to at least 120% of the participants body mass. Pickering and Grgic [42] suggested that ergogenicity of CAF can be also connected to the sports level. For highly trained athletes there is less ‘potential for improvement’ after CAF ingestion because they are towards the upper end of their individual performance capabilities and are approaching absolute physical limits [8]. However, in these few studies, the positive trend after CAF intake was observed, which suggests the ergogenic effect but of a lower magnitude. Unfortunately, in most of the research analyzing the impact of CAF on maximal level of strength during the BP exercise inclusion criteria did not include the strength level of participants and did not estimate relationship between 1RM to body mass ratio, which makes it difficult to reach the final conclusion, if the ergogenic effect depends on the level of maximal strength. Thus, future studies need to analyze effectiveness of CAF ingestion on maximal strength in homogenous group of CAF intake.

The effectiveness of acute CAF intake on maximal strength could also be connected with used CAF dose and/or its relation to the level of daily CAF consumption. In fact, in the study by Wilk et al. [63], resistance-trained individuals (1RM in BP with a load of at least 120% of body mass; 118.3 ± 14.5 kg; mean ± standard deviation) improved the 1RM in BP exercise after intake 9 and 11 mg/kg of CAF, despite observed relative high frequency of side effects. Pallarés et al. [41] suggested that for higher loads, typically used CAF doses may not be sufficient in order to provide an ergogenic effect. Taking into consideration that most of previous studies used 6 mg/kg of CAF (Table 1), future studies need to analyze effectiveness of higher doses, especially in individuals habituated to CAF.

Unfortunately, only two studies investigating CAF impact on BP performance enrolled female subjects [23, 46] and interestingly showed a positive effect of CAF supplementation. However, those studies were conducted on participants with a relatively low level of 1RM, corresponding to approximately 50% [46] and 80% [23] of their body mass. Thus, further research is necessary in order to establish the ergogenic effect of CAF on maximal strength in female athletes, especially those on the elite level. Additionally, a limitation of this studies is that hormonal changes, as a result of the menstrual cycle were not controlled. To date, it remains unclear whether or not the ergogenic effect of CAF supplementation in terms of resistance training depends on the phase of menstrual cycle, thus this issue should be taken into consideration in future studies.

Effects of caffeine on power output

To date, several researches have analyzed the effects of CAF on power output during typically used dynamic BP exercises (Table 2). Interestingly, most of conducted studies showed the positive effect of CAF on power output and movement velocity during the BP exercise [20, 22, 37, 40, 41, 55]. However, in all of performed studies performance was assessed by using tools that measure bar velocity (such as linear position transducers). This might suggest that CAF has a more pronounced effect on muscle contraction velocity rather than on maximal force production during the BP exercise. Moreover, recently performed meta-analysis confirmed that CAF is highly ergogenic as regards to movement velocity during resistance exercise [45], which is also observed for the BP exercise (Table 2). It should be noted, that the effects of CAF might not be uniform

Table 1. Summary of studies exploring the impact of CAF supplementation on maximal strength

Author	Participants gender	Participants age (years)	Training experience	Daily CAF intake (mg/day)	Dose of CAF used (mg/kg)	CAF form	Timing of CAF ingestion before the experimental session (minutes)	Main findings
Arazi et al. [2]	men (15 participants)	21.16 ± 3.9	6-12 months 1RM = 56.30 ± 6.49 kg	no data	6	capsule	60	↑ 1RM; ↑ 3.42 ± 7.28 kg
Astorino et al. [4]	men (22 participants)	23.4 ± 3.6	6.0 ± 2.8 years 1RM = 114.9 ± 22.8 kg	110.5 ± 152.3	6	capsule	60	↔ 1RM
Beck et al. [7]	men (37 participants)	21 ± 2	1 year (at least) with 3-4 training sessions per week 1RM = 74.8 ± 12.5 kg	no data	~ 2.4 (201 mg total)	capsule	60	↑ 1RM; ↑ 2.1 kg
Diaz-Lara et al. [16]	men (14 participants)	29.2 ± 3.3	elite athletes; 5 years (at least) 1RM = 90.5 ± 7.7 kg	<60	3	capsule	60	↑ 1RM; ↑ 2.8 kg
Goldstein et al. [23]	women (15 participants)	24.6 ± 6.9	6 months (at least) 1RM = 52.1 ± 11.7 kg	0-416	6	powder	60	↑ 1RM; ↑ 0.8 ± 11.1 kg
Grgic and Mikulic [28]	men (17 participants)	26 ± 6	7 ± 3 years 1RM = 106.9 ± 11.9 kg	58 ± 92	6	liquid	60	↔ 1RM
Sabblah et al. [46]	men (10 participants) and women (8 participants)	24.4 ± 3.2 (men) 27.9 ± 6.13 (women)	moderately active (trained at least 3-5 h per week) 1RM (men) = = 101.5 ± 28.9 kg 1RM (women) = = 32.2 ± 9.0 kg	no data	5	liquid	60	↑ 1RM; ↑ 6.0 kg for men and 3.1 kg for women
Wilk et al. [63]	men (16 participants)	24.2 ± 4.2	4.1 ± 1.4 years 1RM = 118.3 ± 14.5 kg	411 ± 136	9 and 11	capsule	60	↑ 1RM; ↑ 4.0 ± 15.3 kg after 9 mg/kg of CAF and 5.9 ± 11.4 kg after 11 mg/kg of CAF
Williams et. al. [69]	men (9 participants)	26.2 ± 4.3	4.8 ± 2.4 years 1RM = 108.9 ± 6.5 kg	45 ± 20	~ 4 (300 mg total)	capsule	45	↔ 1RM

Note: CAF – caffeine, 1RM – one-repetition maximum

Table 2. Summary of studies exploring the impact of CAF supplementation on power output

Author	Participants gender	Participants age (years)	Training experience	Daily CAF intake (mg/day)	Dose of CAF used (mg/kg)	CAF form	Timing of CAF ingestion before the experimental session (minutes)	Testing protocol	Main findings
Del Coso et al. [14]	3 women and 9 men (12 participants)	30 ± 7	recreationally trained 1RM = 46.3 ± 13.9 kg	<60	1 and 3	energy drink	60	10 sets (1 repetition on a load from 10% to 100% 1RM with 10% increments); MP, PP	↑ PP and MP after 3 mg/kg of CAF
Filip--Stachnik et al. [20]	men (13 participants)	21.9 ± 1.2	recreationally trained 1RM = 79.2 ± 14.9	115.65 ± ± 42.46	6	capsule	60	5 sets (5 reps at 70% 1RM), 4 min of rest between sets, tempo X/0/X/0; MP, PP, MV, PV	↑ MP, MV ↔ PP, PV
Giráldez--Costas et al. [22]	3 women and 9 men (12 participants)	29 ± 8	experience in training + participation in a 4-week velocity-based training program of the BP exercise 1RM no data	<100 mg	3	capsule	60	4 sets (8 reps at 70% 1RM), 3 min of rest between sets, tempo 1/2/X/1; MV, PV, MP, PP	↑ MV, PV, MF, MP, PP
Lane and Byrd [37]	men (23 participants)	22.9 ± 3.6	recreationally trained 1RM = 89.1 ± 24.5 kg	no data	~ 3.5 (300 mg total)	no data	25	10 sets (3 reps at 80% 1RM), 1 min of rest between sets, tempo X/0/X/0; PP, MP, MNP	↑ PV in CAF trial
Lane et al. [38]	women (23 participants)	22.9 ± 3.6	recreationally trained 1RM = 35.2 ± 9.6 kg	no data	~ 1.7 (150 mg total)	no data	25	10 sets (3 reps at 80% 1RM), 1 min of rest between sets, tempo X/0/X/0; PP, MP, MNP	↔ PP, MP, MNP
Mora--Rodríguez et al. [40]	men (12 participants)	19.7 ± 2.8	7.2 ± 2.4 years 1RM = 1.15 ± 0.08 kg per kg of body mass	no data	3	capsule	60	2 sets (6 reps at 85% 1RM), 5 min of rest between sets, bar displacement (velocity) of 1.00 m/s; bar displacement velocity – MPV at 75% 1RM load and 1 m/s load, power output adaptations	↑ V at 75% 1RM load in AM_{CAF} and PM_{PLAC} groups ↑ MPV at 1 m/s load in PM_{PLAC} group

Pallarés et al. [41]	men (13 participants)	21.9 ± 2.9	7.1 ± 3.5 years 1RM = 121.0 ± 22.7 kg	≤70	3, 6 and 9	capsule	60	4 sets (1 set – 3 trials 25% 1RM, 2 set – 2 trials 50% 1RM, 3 set – 1 trial 75% 1RM, 4 set – 1 trial 90% 1RM), 5 min of rest between sets, tempo 2/0/X/0; MPV, MPP	↑ MPV, MPP (25% and 50% 1RM) in all doses of CAF ↑ MPV, MPP (75% 1RM) after 9 mg/kg of CAF ↑ MPV (90% 1RM) after 9 mg/kg of CAF ↑MPP (90% 1RM) after 6 and 9 mg/kg of CAF
Wilk et al. [55]	men (12 participants)	25.3 ± 1.7	4.4 ± 1.6 years 1RM = 128.6 ± 36.0 kg	443 ± 142	3 and 6	capsule	60	5 sets (2 reps at 30% 1RM), 3 min of rest between sets, tempo X/0/X/0; PP, MP, PV, MV	↑ MP, MV after 3 and 6 mg/kg of CAF ↔ PP, PV for 3 and 6 mg/kg of CAF
Wilk et al. [56]	men (15 participants)	26.8 ± 6.2	4.2 ± 1.23 years 1RM = 122.3 ± 24.5 kg	426 ± 102	3, 6 and 9	capsule	60	3 sets (5 reps at 50% 1RM), tempo 2/0/X/0; PP, MP, PV, MV	↔ PP, MP, PV, MV after all CAF doses in each set
Wise et al. [70]	11 women and 12 men (23 participants)	21.2 + 3.7	6.4 ± 3.7 years	no data	328 mg (total)	Instant Via® coffee	30-90	3 sets (1 repetition at 30% 1RM); FOR, PP, PV, RFD	↑ PP, PV in both groups ↑ RFD in men ↔ FOR in both groups

Note: CAF – caffeine, PLAC – placebo, AM – trial at morning, PM – trial in the afternoon, FOR – peak force, MF – mean force, RFD – rate of force development, MNP – minimum power, MP – mean power, MPP – mean propulsive power, PP – peak power, MPV – mean propulsive velocity, MV – mean velocity, PV – peak velocity, V – velocity, 1RM – one-repetition maximum

Table 3. Summary of studies exploring the impact of CAF supplementation on strength-endurance performance

Author	Participants gender	Participants age (years)	Training experience	Daily CAF intake (mg/day)	Dose of CAF used (mg/kg)	CAF form	Timing of CAF ingestion before the experimental session (minutes)	Testing protocol	Main findings
Astorino et al. [3]	men (14 participants)	23.1 ± 1.1	7.5 ± 1.2 years 1RM = 105.2 ± 5.2 kg	218.2 ± ± 28.1	6	capsule	60	4 sets, 2 min of rest between sets, REP to failure at 70-80% 1RM, TWL (weight × REP)	↔ TWL (kg), REP to failure ↓ REP in each set
Astorino et al. [4]	men (22 participants)	23.4 ± 3.6	6.0 ± 2.8 years 1RM = 114.9 ± 22.8 kg	110.5 ± ± 152.3	6	capsule	60	1 set, REP to failure at 60% 1RM, TWL (weight × REP)	↔ REP at 60% 1RM
Beck et al. [7]	men (37 participants)	21 ± 2	1 year (at least) with 3-4 training sessions per week 1RM = 74.8 ± 12.5 kg	no data	~ 2,4 (201 mg total)	capsule	60	1 set, REP to failure at 80% 1RM TWL (weight × REP)	↔ TWL (kg), no data on REP
Diaz-Lara et al. [16]	men (14 participants)	29.2 ± 3.3	elite athletes; 5 years (at least) 1RM = 90.5 ± 7.7 kg	<60	3	capsule	60	1 set, REP to failure at 45,1 ± 12.9% 1RM, velocity, acceleration, muscle power	↑ REP to failure, MP
Duncan and Oxford [17]	men (13 participants)	22.7 ± 6.0	10.4 ± 2.3 years 1RM no data	169-250	5	liquid	60	1 set, REP to failure at 60% 1RM, TWL (weight × REP)	↑ REP to failure, TWL (kg)
Goldstein et al. [23]	women (15 participants)	24.6 ± 6.9	6 months (at least) 1RM = 52.1 ± 11.7 kg	0-416	6	powder	60	1 set, REP to failure at 60% 1RM	↔ REP at 60% 1RM
Green et al. [25]	men (13 participants) and women (4 participants)	21.0 ± ± 1.5 (men) 2.0 ± 1.5 (women)	≥8 weeks 10RM (men) = = 90.0 ± 41.0 kg 10RM (women) = = 35.0 ± 5.9 kg	no data	6	capsule	60	6 sets, 3 min of rest between sets, 3 warm-up sets (no more than 12 REP) and next 3 sets (successful REP to failure); 100% or near 100% of the estimated 10RM	↔ REP to failure
Grgic and Mikulic [28]	men (17 participants)	26 ± 6	7 ± 3 years 1RM = 106.9 ± 11.9 kg	58 ± 92	6	liquid	60	1 set, REP to failure with 60% 1RM	↔ REP to failure at 60% 1RM

Sabblah et al. [46]	men (10 participants) and women (8 participants)	24.4 ± 3.2 (men) 27.9 ± 6.13 (women)	moderately active (trained at least 3-5 h per week) 1RM (men) = = 101.5 ± 28.9 kg 1RM (women) = = 32.2 ± 9.0 kg	no data	5	liquid	60	1 set, REP to failure at 40% 1RM, TWL: 40% 1RM × REP	↑ TWL in men ↔ TWL in women
Wilk et al. [64]	men (16 participants)	24.2 ± 4.2	4.1 ± 1.4 years 1RM = 118.3 ± 14.5 kg	411 ± 136	9 and 11	capsule	60	1 set, REP to failure at 50% 1RM, REP, TUT_{CON}, PP, MP, PV, MV, tempo 2/0/X/0	↑ PV ↔ TUT_{CON}, PP, MP, MV
Wilk et al. [66]	men (20 participants)	25.7 ± 2.2	2.3 ± 0.63 years 1RM = 102.3 ± 8.5 kg	<200 mg/ week	5	capsule	60	1 set, REP to failure at 70% 1RM, PP, MP, PV, MV, VE_{MEAN}, TUT, REP, tempo X/0/X/0	↑ VE_{MEAN} in CAF group ↓ TUT in CAF group ↔ MP, PP, PV, MV, REP
Williams et al. [69]	men (9 participants)	26.2 ± 4.3	4.8 ± 2.4 years 1RM = 108.9 ± 6.5 kg	45 ± 20	~ 4 (300 mg total)	capsule	45	1 set, REP to failure at 80% 1RM, TWL (weight × REP)	↔ TWL (kg)

Note: CAF – caffeine, MP – mean power, PP – peak concentric power, MV – mean concentric velocity, PV – peak concentric velocity, VE_{MEAN} – mean eccentric velocity, TUT – time under tension, TUT_{CON} – time under tension during concentric contractions, 1RM – one-repetition maximum, REP – repetitions, TWL – total weight lifted across various external loads [41]. CAF dose of 3 mg/kg has been shown to be sufficient in order to increase the bar velocity at low to moderate external loads (25--50% 1RM), however at high external loads (90% 1RM) a higher dose of CAF (9 mg/kg) is necessary in order to achieve improvement in bar velocity [41].

Moreover, the different effect of CAF supplementation was observed depending on the time of day. In the study by Mora-Rodríguez et al. [40] trained men performed three exercise trials: a) a morning training session (10:00 am) after the ingestion of 3 $mg{\cdot}kg^{-1}$ of CAF; b) a morning training session after ingesting a placebo; and c) an afternoon session (6:00 pm) following the ingestion of a placebo. After the intake of CAF in the morning, bar velocity during the BP exercise significantly increased compared to placebo morning trial levels and reached approximately the level of afternoon trial. Results of this study suggest that CAF intake reverses the morning neuromuscular declines, improving performance to the levels of the afternoon trial, which should be taken into consideration while planning supplementation protocol.

However, it should be emphasized, as regards to resistance training, that an improvement of performance in fatigued state is of utmost importance. Unfortunately, most of the previous research analyzing the impact of CAF on the BP exercise used test procedures consisting only of a single set of an exercise. Evidence from studies, where the experimental protocol consisted of more than one set of the BP exercise [22, 37, 38] suggest that the positive effect of CAF supplementation may be accentuated during a whole resistance training session. However, this issue has to be more explored to be satisfactorily translated into meaningful conclusions for resistance training.

Effects of caffeine on strength-endurance performance

Previously conducted meta-analysis and review [44, 54] showed that CAF, when administered in a dose of 5-6 mg/kg can have an ergogenic effect on strength-endurance during resistance exercise. However, the results of the studies utilizing the BP exercise showed conflicting results. Most of the studies (Table 3) did not show the positive effect of CAF on strength-endurance during the BP exercise [3, 4, 7, 23, 25, 28, 63, 69]. On the contrary, in two investigations conducted by Diaz-Lara et al. [16] and Duncan and Oxford [17] CAF improved the number of repetitions performed to muscular failure. Additionally, in the study of Sabblah et al. [46] there was a tendency towards improvement in total weight lifted during a strength-endurance test performed to muscular failure at 40% of 1RM but only for males, suggesting a sex difference in responses to CAF ingestion.

It should be taken into consideration that differences between studies can be explained by different experimental protocols and methods used to analyze performance. In most of the studies, strength test was a part of protocol, consisting of a battery of performance tests and usually it was assessed in the latter/last part of the testing sequence. Thus, the fatigue state may have impacted obtained outcomes and different results might have been showed if strength-endurance had been measured separately or at the beginning of the testing protocol [28]. Additionally, most of the studies analyzed only the number of repetitions performed to the muscular failure. However, according to Wilk et al. [66] total time under tension (TUT) is a more accurate and credible indicator of work performed compared to the number of performed repetitions (REP). TUT provides accurate information about the duration of resistance effort for a set and for the entire training session and determines how long the resistance effort lasts regardless of the number of REP performed. Interestingly, in the study by Wilk et al. [66] CAF ingestion increased bar velocity in the eccentric phase of the movement, what resulted in shortening of the TUT needed for performing a specific number of repetitions, without decreasing power and velocity in the concentric phase of the movement. In other words, ingestion of CAF did not improve the number of REP performed to failure but reduced TUT. Thus, future studies have to include additional performance measurements, including TUT and bar velocity in order to better explore the impact of CAF on strength-endurance.

Conclusions

In general, CAF in doses of 3 to 6 mg/kg has been found to be a safe ergogenic aid during the BP exercise in terms of improving maximal strength and power output, but the impact of CAF intake on strength endurance is less clear. Additionally, doses of 9 mg/kg and 11 mg/kg might be ergogenic in order to improve maximal strength and power output, however higher frequency of side effects observed have to be considered in supplementation strategy. It is possible that habituation to CAF may modify the ergogenic benefits of CAF on BP performance but future studies need to analyze the effectiveness of CAF in groups with different level of daily consumption. Caution is advised when extrapolating these conclusions in context of improving performance during an entire training session as the vast majority of studies include single repetition or set of the BP exercise. Moreover, most of the research conducted in this area involved only male participants and future studies need to explore if such acute increases in BP performance after CAF ingestion also occurs among women. Finally, long-term studies are needed in order to explore whether or not these acute performance responses also impact long-term adaptations in the BP exercise.

Conflict of interests

The authors declare no conflict of interest.

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REVIEW ARTICLE

TRENDS in
Sport Sciences
2021; 28(**2**): 83-92
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.2-2

Acute impact of blood flow restriction during resistance exercise – review

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Abstract

Introduction. **Athletes, as well as recreationally trained individuals are increasingly looking for innovative techniques and methods of resistance training to provide an additional stimulus to break through plateaus, prevent monotony and achieve various training goals. Partial or total blood flow restriction (BFR) to the working muscles during resistance exercise has been used as a complementary training modality, aiming to further increase muscle mass and improve strength. BFR is usually used during low-load resistance exercise and has been shown to be effective in enhancing long-term hypertrophic and strength responses in both clinical and athletic populations. However, recently some attention has been focused on the acute effects of BFR on strength and power performance during high-load resistance exercise.** Aim of Study. **This article provides an overview of available scientific literature and describes how BFR affects the 1-repetition maximum (1RM), the number of repetitions performed, time under tension and kinematic variables such as power output and bar velocity.** Material and Methods. **Available scientific literature.** Results. **As a result, BFR could be an important tool in eliciting greater maximal load, power output and strength-endurance performance during resistance exercise.** Conclusions. **BFR as a training tool can be used as an additional factor to help athletes and coaches in programming varied resistance training protocols.**

KEYWORDS: occlusion, cuff, ischemia, bar velocity, 1RM test, repetition.

Received: 12 January 2021
Accepted: 4 February 2021

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Introduction

Blood flow restriction (BFR) has received much attention and has been shown to be beneficial for clinical cohorts, athletes and active individuals in improving their physical performance [35, 51]. Exercise with BFR is a strategy that involves application of an inflatable cuff, tourniquet [35] or elastic wrap [22] around a limb, proximally to the muscles being trained, in order to reduce the arterial blood flow and to shut the venous blood flow [51]. BFR is applicable to any form of physical activity; however, most research is focused on resistance training [5, 10, 24]. The BFR during resistance exercise at low external loads is generally used for rehabilitation purposes as well as a tool to prevent sarcopenia in the elderly [22]. The resistance exercise under BFR performed at higher loads is used in order to maximize training adaptation [35], typically to increase hypertrophy responses [9, 17, 54]. The mechanical tension generated by the cuff increases metabolic stress and is the main physiological mechanism influencing muscle adaptation after resistance training under BFR. The increase of metabolic stress during resistance exercise under BFR results in cell swelling [24], enhances intramuscular signaling [19, 28], increases recruitment of fast-twitch muscle fibers [27, 40] and enhances responses of the endocrine system [36, 39]. Furthermore, the hyperemia following occlusion may play a significant role in nitric oxide production [37], increased phosphocreatine resynthesis, altered oxy-deoxyhemoglobin kinetics [3] and increased oxygen uptake [1]. In addition to physiological factors, recently also mechanical factors (mechanical energy accumulated and released by the cuff) have been indicated to influence acute kinematic changes following resistance training under BFR [32]. During resistance exercise under BFR the strain of the material, of which the cuff is made, may produce additional elastic energy, which is released from the cuff during the concentric contraction [50], increasing the value of the maximum external load lifted, power output and the maximum number of repetitions performed [48]. Despite countless scientific studies that focus on resistance exercise under BFR, only a select few have analyzed the acute effect of BFR during isotonic resistance exercise. BFR used during resistance exercise can influence acute exercise volume and in turn, the resultant chronic changes in maximum strength, power output and endurance performance [11, 32, 48, 50]. Therefore, the main focus of this review is to analyze the current state of knowledge concerning the influence of BFR during resistance exercise on mechanical responses to resistance training (Table 1).

Table 1. Summary of studies exploring the acute impact of blood flow restriction on power output, maximal strength and endurance performance during resistance exercises

Reference	Occlusion pressure (% AOP/mm Hg)/ BFR protocol	Subjects/cuff width	Protocol	Main findings
Dankel et al. [8]	70% AOP/ BFR applied at the completion of the first set for the duration of the rest interval and the second set	7 resistance-trained men, 3 resistance-trained women/ cuff width 50 mm	unilateral dumbbell elbow flexion (70% 1RM) part 1: 1 set × maximal number of reps to exhaustion without BFR part 2: 1 set × maximal number of reps to exhaustion with BFR	↓ maximal REP for BFR condition compared to control
Gepfert et al. [11]	100% AOP 150% AOP intermittent BFR	10 male judo athletes/ cuff width 100 mm	back squat (70% 1RM) 3 sets × 3 reps with maximal velocity of movement in concentric phase	↑ PP, MP, PV, MV for 150% AOP compared to control ↑ PP, MP, PV, MV for 150% AOP compared to 100% AOP ↔ PP, MP, PV, MV for 100% AOP compared to control
Loenneke et al. [21]	~50-100 mm Hg pressure/ BFR applied immediately before exercise, removed immediately after post-exercise whole blood lactate measurement	10 recreationally active men, 10 recreationally active women/knee wraps 76 mm wide	bilateral leg extension (30% 1RM) 1 set × maximal number of reps to exhaustion	↓ maximal REP for BFR condition compared to control
Rawska et al. [32]	80% AOP continuous BFR	4 resistance-trained women/ cuff width 100 mm	bench press 5 sets × maximal number of reps to exhaustion for 2/0/X/0 and 6/0/X/0 movement tempo	↑ maximal REP for BFR compared to control for 2/0/X/0 tempo in set 1, 2, 5 ↑ maximal REP for BFR compared to control for 6/0/X/0 tempo in set 1 ↑ total REP for BFR compared to control for both tempos

Wernbom et al. [41]	200 mm Hg pressure/ intermittent BFR	13 recreationally active men, 3 recreationally active women/cuff width 135 mm	unilateral knee extension 4 sets × maximal number of reps to exhaustion at 20, 30, 40, 50% 1RM	↓ maximal REP for BFR compared to control at 20, 30, 40% 1RM ↔ maximal REP for BFR compared to control at 50% 1RM
Wernbom et al. [42]	100 mm Hg/ continuous BFR	8 resistance-trained men, 3 resistance-trained women/cuff width 135 mm	unilateral knee extension 3 sets × maximal number of reps to exhaustion at 30% 1RM	↓ maximal REP for BFR compared to control for each of 3 sets and for all 3 sets combined
Wilk et al. [44]	70% AOP/ intermittent and continuous BFR	11 resistance-trained men/cuff width 40 mm	bench press 8 sets × 2 reps (20 to 90% 1RM with 10% steps) with maximal velocity in concentric phase	↑ PV for intermittent and continuous BFR conditions at 20, 30, 40, 50% 1RM compared to control ↔ PV for intermittent and continuous BFR conditions at 60, 70, 80, 90% 1RM compared to control ↔ MV in all conditions
Wilk et al. [48]	100% AOP and 150% AOP/ intermittent BFR	12 resistance-trained men/cuff width 100 mm	bench press part 1: 1RM test, part 2: 3 sets (60% 1RM) × × maximal number of reps to exhaustion at maximal velocity of movement	part 1: ↑ 1RM for 150% AOP compared to control part 2: ↑ maximal REP, TUT for 150% AOP compared to control ↑ maximal REP, TUT for the 150% AOP compared to control 100% AOP
Wilk et al. [49]	90% AOP/ intermittent BFR	10 resistance-trained men/cuff width 100 mm	bench press 3 sets × 3 reps (70% 1RM) at maximal velocity of movement	↑ PP, MP, PV, MV for BFR condition compared to control
Wilk et al. [50]	90% AOP/ intermittent BFR	14 resistance-trained men/cuff width 40 mm (narrow cuff) and 100 mm (wide cuff)	bench press 1 set × 3 reps (70% 1RM) at maximal velocity of movement	↑ PP, MP, PV, MV for wide cuff BFR compared to narrow cuff BFR ↑ PP, MP, PV, MV for wide cuff BFR compared to control ↔ PP, MP, PV, MV for narrow cuff BFR compared to control

Note: AOP – arterial occlusion pressure; BFR – blood flow restriction; 1RM – 1 repetition maximum; PP – peak power output; MP – mean power output; PV – peak bar velocity; MV – mean bar velocity; TUT – time under tension; REP – number of performed repetitions; tempo of movement (2/0/X/0) – eccentric/isometric/concentric/isometric; ↑ denotes significant increases; ↔ denotes non-significant differences; ↓ denotes significant decreases

Factors affecting acute performance during BFR resistance exercise

Several factors regarding the acute impact of BFR resistance training on various adaptive changes have been distinguished; however, their exact impact still remains insufficiently examined and described. The current literature analyzes the influence of individual variables such as cuff width, cuff pressure, scheme of BFR use (continuous and intermittent) and type of movement, which can significantly affect the acute and long-term adaptive changes following resistance exercises under BFR conditions.

Cuff width

There is no uniformly adopted and standard cuff width for BFR training. However, previous studies confirmed that cuff width is a significant factor that should be taken into account during resistance exercise under BFR [13, 21, 33]. There is a wide range of cuff widths (3-18.5 cm) presented in the BFR literature [31, 35, 51]. The cuff width and its impact on acute and chronic changes following BFR resistance exercise are directly related to the pressure value applied to the limb. The use of a wide (13.5-cm) cuff results in arterial blood flow restriction at a lower pressure compared to the narrow (5-cm) cuff [6, 21]. Furthermore, greater cardiovascular (heart rate and blood pressure) and perceptual (rate of perceived physical effort) responses are obtained when a wide cuff (13.5-cm) is used compared to a narrow (5-cm) cuff with equal pressure [33]. Similarly, Loenneke et al. [21] demonstrated that when constant pressure is applied, the use of a wider cuff results in different physiological adaptive responses compared to the use of a narrow cuff. Therefore, a wider cuff provides the same effect at a lower absolute pressure.

Wilk et al. [50] suggested that the effect of cuff width on the level of performance is related not only to physiological responses, but also affects the value of mechanical energy generated by the cuff. As suggested by Rawska et al. [32] and Wilk et al. [48], mechanical factors (mechanical energy accumulated and released by the cuff during the concentric phase of the movement) may impact acute performance changes under BFR condition; however, such a potential effect is proportional to cuff width [50]. A cuff is a passive element, but during movement, especially in the eccentric phase of the movement, the strain of the material, of which the cuff is made, may produce additional elastic energy. The mechanical energy accumulated in the cuff is probably proportional to its width [50]. A wider cuff has a larger surface area for mechanical work, thus the strain of a wider cuff may potentially produce more elastic energy when compared with a narrow cuff. A wide cuff may also act similarly to compressive gear used in powerlifting, supporting the athlete during the eccentric phase and giving a "rebound" effect during the concentric phase of the lift, which allows a greater load to be lifted [46]. However, the use of extremely wide cuffs may limit the range of movement during exercise [31, 50].

Cuff pressure

Cuff pressure has been recognized as a relevant factor that affects the effectiveness of resistance exercise under BFR [33, 48]. Arterial occlusion pressure (AOP) is the amount of pressure required to cease blood flow to a limb and is related to individual limb characteristics, shape and width of the cuff [31]. It can be accomplished by inflating the cuff being used during an exercise up to the point, where blood flow is completely cut off (100% AOP) and then a percentage of that AOP is used for BFR during exercise [31, 50]. Although in some studies pressures relative to brachial systolic blood pressure have been applied, because of a wide variety of cuffs setting pressure according to the individual value of AOP is recommended [31, 50]. Moreover, cuff pressure is related to individual characteristics such as the circumference of the occluded limb and composition of the body, as well as the width, shape and material, of which the cuff is made [13, 21, 30, 51].

According to Loenneke et al. [23], BFR may follow the hormesis theory, meaning that low or moderate pressures produce beneficial effects, while higher pressures (at or near arterial occlusion) may decrease the exercise benefits and increase health risks, thus moderate (about 50% AOP) pressure values are recommended. On the other hand, a wider range (40-80% AOP) of pressures to be applied has been suggested by Patterson et al. [31], while the use of high (80-90%) or extremely-high (100--150% AOP) pressure values has also been reported in the scientific literature [11, 32, 48, 49, 50]. However, it should be noted that only few studies investigated cuff pressure above 100% AOP [11, 48].

Type of exercise

The differences in BFR impact on the upper and lower body need to be taken into account. According to studies by Crenshaw et al. [6] and Loenneke et al. [24], the absolute value of pressure depends largely on the circumference of the limb, to which compression is applied. Thus, it should be noted that due to the larger circumference of the lower limb compared to the upper limb, for the lower body a higher absolute pressure and a wider cuff may be required to produce similar results as in the upper body [30]. Moreover, as suggested by Gepfert et al. [11], also the length of the occluded limb may impact performance changes under BFR conditions.

Scientific studies regarding the acute impact of BFR resistance training on various adaptive changes utilized both single-joint [20, 41] and multi-joint movement [11, 50] for the upper and lower body. During multi-joint movement such as the bench press or back squat not all of the main muscles involved are directly affected by occlusion [32], in contrast to single-joint movement; however, currently there is no available research directly comparing single and multi-joint exercises during BFR external compression. Furthermore, it has been suggested that the acute performance enhancement under BFR during a particular resistance exercise may differ from that in other types of exercises [50].

BFR exercise protocols

There are different types of BFR application protocols applied during resistance exercise. Continuous BFR refers to occlusion used during exercise and rest intervals between sets [31, 44]. Intermittent BFR is used only during the exercise and released upon completion of the set [11]. Furthermore, ischemic preconditioning is also differentiated as a method utilizing occlusion only before the exercise [12, 29, 44]. Thus, the duration of occlusion may vary substantially between used protocols [44].

Continuous BFR is typically used in most studies [22, 31, 42]. However, as demonstrated by Yasuda et al. [53], when cuff pressure is high (160 mmHg), similar muscle activation occurs with both continuous and intermittent cuff pressure. Furthermore, intermittent BFR may reduce swelling as well as physiological and metabolic stress compared to continuous BFR [31, 44]. Intermittent BFR seems more attractive in order to achieve improved performance and to minimize the negative effects of BFR [44], especially during multi-joint resistance exercises with full rest intervals (3-5 minutes) and short duration of the effort [11, 48].

Acute effects of BFR on strength-endurance performance

Strength-endurance is usually determined by parameters such as the number of repetitions and time under tension, which amounts to the total sum of the concentric, eccentric and isometric components of repetition [15, 34, 43, 45, 52]. It has been shown in several studies that BFR impacts the level of strength-endurance performance during resistance exercise. Wernbom et al. [42] demonstrated that BFR decreases the maximal number of repetitions performed during single-leg knee extension exercise at 30% of the one repetition maximum (1RM). A similar result was obtained by Loenneke et al. [20], who also showed a significant decrease in the number of performed repetitions during the knee extension exercise under BFR at 30% 1RM compared to the control. Aforementioned studies are partially consistent with a study by Wernbom et al. [41], who examined the impact of the BFR on the number of repetitions performed at various external loads (20, 30, 40 and 50% 1RM). Although, in that the participants performed a significantly lower number of repetitions under BFR at 20, 30, and 40% 1RM compared to the control, there were no significant differences at load of 50% 1RM. Therefore, the result of the study by Wernbom et al. [41] suggested that the acute effect of BFR on the number of performed repetitions can be related to the value of external load used. However, a study by Dankel et al. [8] showed that exercise under BFR at a higher load (70% of 1RM) resulted in a significant decrease in the number of repetitions performed, which is contrary to the result of the above-mentioned study by Wernbom et al. [41].

On the other hand, resistance exercise under BFR has also been reported to improve strength-endurance performance during resistance exercise [32, 48]. However, these results were obtained based on multi-joint, upper-body movements and much higher loads (60, 80% 1RM) compared to studies by Wernbom et al. [41, 42] and Loenneke et al. [20]. In turn, Rawska et al. [32] recorded an increase in the number of performed repetitions during 5 sets of the bench press exercise at 80% 1RM for the variant under BFR compared to the control. An increase in the number of performed repetitions during resistance exercise under BFR was also observed in a study by Wilk et al. [48]. The results of that study [48] showed an increase in the number of performed repetitions and time under tension during the bench press exercise at 60% 1RM with an extremely high cuff pressure amounting to 150% AOP compared to the control. The lower cuff pressure amounting to 100% AOP also showed an increase in the number of performed repetitions, but only in the first set of the bench press exercise. Moreover, Wilk et al. [48] reported significant increases in the number of repetitions performed and time under tension during BFR with 150% AOP cuff pressure compared to BFR with 100% AOP cuff pressure. Therefore, the value of cuff pressure is an important factor affecting the acute effect of BFR during resistance exercise.

However, the characteristics of the exercise may be an important factor influencing the increase in strength and endurance performance under BFR conditions during the bench press exercises [32, 48]. In the bench press exercise the main muscles involved are the pectoralis major, triceps brachii and anterior deltoid [14, 16]. However, as was pointed out by Rawska et al. [32], occlusion during the bench press is applied only on the triceps brachii. The main muscles involved are not directly affected by the occlusion, thus whether or not BFR is applied during a single or multi-joint exercise should also be taken into account. Moreover, studies regarding single-joint, lower-body movement under BFR conditions [20, 41, 42] showed a lower number of repetitions performed when both narrow (7.6 cm) and wide (13.5 cm) cuffs were used. These findings suggest that cuff width does not influence acute strength-endurance performance in single-joint movements at low external loads (30% 1RM), which may occur due to the prevalence of the physiological mechanism (increased metabolic stress) rather than mechanical factors as regards the obtained results.

Acute effects of BFR on power output and velocity of the movement

Power output is considered a crucial factor impacting performance in many athletic and sporting activities [18, 38]. The optimal level of the force generated by the muscles and velocity of the movement allows for maximal power output to be achieved [2, 47]. Resistance training is a fundamental tool used in improving power output and its variables have been extensively explored [2, 47]. Recently attention has also been focused on the acute impact of BFR on power output and velocity of the movement during multi-joint resistance exercises.

BFR applied during resistance exercise has been shown to increase power output and bar velocity [11, 44, 49, 50]. Such increases were observed during the back squat [11] and bench press exercise [44, 49, 50]. Wilk et al. [50] assessed the impact of intermittent BFR on power output and bar velocity changes during the bench press at 70% 1RM. For BFR both narrow (4 cm) and wide (10 cm) cuffs with pressure at 90% AOP were used. Significant increases in bar velocity and power output were recorded, but only when the wide cuff was used. However, such an improvement was not observed during resistance exercise under the narrow cuff, suggesting that cuff width significantly affects acute exercise responses during BFR resistance training [50], which is also compatible with the previous studies [13, 21, 33]. Results of the study by Wilk et al. [50] were confirmed by Wilk et al. [49], who also reported significant increases in power output and bar velocity during the bench press exercise at 70% 1RM for the BFR condition compared to the control. Moreover, the study by Wilk et al. [49] demonstrated that acute increases in power output and bar velocity under BFR occur during several sets of bench press exercise.

Although the above-mentioned studies by Wilk et al. [49, 50] showed an acute increase in power performance for BFR conditions, it applies only to the constant value of the external load. The acute impact of BFR on movement velocity during the bench press using variable loads was assessed in another study by Wilk et al. [44]. Wilk et al. [44] showed that peak bar velocity significantly increased during the intermittent and continuous BFR bench press exercise, but only at lower external loads (20-50% 1RM). No such improvement was observed at higher external loads (above 60% 1RM). Furthermore, intermittent or continuous BFR did not change the mean bar velocity at all used loads. It might be concluded that power performance enhancement under BFR is associated with the external load used. Furthermore, it has been suggested that in order to achieve an increase in bar velocity during exercise under BFR at higher external loads, a higher occlusion pressure and wider cuffs are necessary [44].

The acute impact of BFR on power output and bar velocity has been examined not only when applying various external loads, but also different types of movement (upper body/lower body). A study by Gepfert et al. [11] focused on the acute BFR impact on power output and bar velocity in lower-body, multi-joint movement. Similarly to the study by Wilk et al. [48], during the experimental protocol intermittent BFR with an extremely high cuff pressure (100 and 150% AOP) was used. Gepfert et al. [11] showed that only extremely high-pressure external compression (150% AOP) significantly increased the peak and mean values of power output and bar velocity during the back squat exercise at 70% 1RM. However, no such improvement of performance was observed at lower cuff pressure (100% AOP), which is contradictory to the findings reported by Wilk et al. [50]. In that study Wilk et al. [50] showed a significant increase in power output and bar velocity during the bench press exercise with cuff pressure amounting to 90% AOP. It seems that compression pressure during the back squat needs to be higher than the compression pressure during the bench press in order to provide a similar enhancement in power output and bar velocity, which is possibly due to the larger circumference and length of the lower limb in comparison to the upper limb [11]. Therefore, the level of cuff pressure may be a critical factor in BFR multi-joint resistance exercises in terms of power output and bar velocity enhancement. A higher cuff pressure may allow to store and recoil larger amounts of elastic energy [48], which may be the main factor affecting the increase in performance [11].

Furthermore, as previously suggested by Rawska et al. [32], the performance increase under the BFR condition occurred regardless of the fact that the main muscles involved in the movement are not directly affected by occlusion. While Rawska et al. [32] refered to the bench press exercise, a similar phenomenon occurs during the back squat exercise investigated in a study by Gepfert et al. [11]. During the back squat cuffs are located at the most proximal region of each leg [11]; however, a major contributor, particularly during the concentric part of the squat, is the gluteus maximus, which exhibits greater EMG activity compared to the vastus lateralis, vastus medialis and biceps femoris [4]. Thus, exercise characteristics may also partially contribute to the improved power output performance during the back squat exercise under BFR.

As presented in the aforementioned studies regarding the acute effects of BFR on power output and velocity of the movement, BFR resistance training focused on power development should consider the use of a wide cuff and high or extremely high cuff pressure. Resistance training under BFR may serve as a novel tool in power development, particularly for high-level athletes [11, 44, 49, 50].

Acute effects of BFR on maximal strength

Maximal strength has been acknowledged as a major factor influencing sports performance [38] and is usually measured by the maximal load lifted for 1RM [7]. BFR impact on maximal strength currently remains insufficiently examined. Although some research indicated that BFR may improve 1RM performance, the authors examined chronic adaptations following 6- and 7-week resistance training programs [25, 26]. Only one study by Wilk et al. [48] examined the acute impact of BFR on the result of the 1RM test. In that study Wilk et al. [48] showed significant increases in the result of the 1RM test during the bench press exercise under BFR at the pressure of 150% AOP; however, such increases were not observed at 100% AOP. It should be noted that both conditions (100 and 150% AOP) caused full arterial occlusion and a similar level of metabolic stress and fatigue, which was relatively low given the short duration of the effort [48]. Thus, the effectiveness of BFR was possibly less related to the metabolic factors and more to the mechanical factors, such as the mechanical energy accumulated in the cuff proportional to its width [48]. Therefore, similarly to the result related to power performance it seems that in order to increase the maximal load lifted under BFR extremely high pressure values need to be applied. However, to the best of the authors' knowledge there is no other study analyzing the acute impact of BFR on 1RM performance, which limits the possibility for comparison to other results.

Furthermore, a similar increase in the maximal load lifted is also observed during the bench press exercise when the bench press shirt is used [46]. Similarly to the cuff, the bench press shirt is a passive element, but during movement (especially in the eccentric contraction) the strain of the material, of which the shirt is made, may provide additional elastic energy [46]. Moreover, the effectiveness of the bench press shirt is related to the level of compression [46], which may confirm that the effectiveness of BFR in increasing 1RM performance during the bench press exercise is related to mechanical factors [48].

Conclusions

The results of the studies focused on the acute effect of BFR during isotonic resistance exercise are indicative of its utility as a tool to increase athletic performance; however, long term adaptations are rather unclear [11]. It should be taken into account that BFR resistance exercise is not devoid of drawbacks and potential side effects. It should be introduced gradually, carefully and with proper periodization as a supplemental training method [44]. Furthermore, it should be mentioned that certain individuals do not benefit from exercise under BFR (non-responders) and individual characteristics of an athlete may also influence resistance training under BFR [51], establishing a need for personalized training programs [50]. BFR resistance exercise effectiveness seems to be dependent on mechanical factors such as mechanical energy accumulated and generated by the cuff, which may explain increased acute exercise responses under BFR, particularly when multi-joint exercises and high or extremely high cuff pressures are used. It is also important to note that the magnitude of impact of respective factors on performance enhancement during resistance exercise under BFR still requires further research.

Conflict of interests

The authors declare no conflict of interest.

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REVIEW ARTICLE

TRENDS in
Sport Sciences
2021; 28(**2**): 93-107
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.2-3

Evaluation of cerebral cortex activation during balance tasks using fNIRS: a systematic review

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Abstract
Introduction. **Functional near-infrared spectroscopy (fNIRS) is used as a neuroimaging tool for the study of different areas of the brain involved in motor control through the measurement of changes in brain hemodynamics. Its wireless usage and portability has made it suitable for investigating the cortical control of postural balance under static and dynamic testing conditions.** Aim of Study. **The aim of this systematic review is to evaluate studies on cortical activation while performing static and dynamic balance tasks using fNIRS as a tool and emphasizing the location of brain areas activated.** Material and Methods. **The search was performed following the PRISMA guidelines. Relevant keywords were used for the search through Google Scholar, PubMed, Science Direct, Taylor and Francis, and Scopus. The methodological quality of included studies was assessed using the Downs and Black checklist. Ten studies met the inclusion criteria.** Results. **The included studies were found to be of good methodological quality. The results in this review showed that the dorsolateral prefrontal cortex, sensory motor area and superior temporal gyrus are activated predominantly during static and dynamic balance tasks.** Conclusions. **The recent findings reflect a whole new scope of analysis involving multitasking during complex motor activities. The fNIRS technique is an adjunct to assess static and dynamic postural imbalances in persons with balance related issues with availability of a greater number of channels and more regions of interest to be covered at one given instance.**

KEYWORDS: balance, static balance, dynamic balance, cortical activation, neuroimaging, wireless fNIRS.

Received: 21 December 2020
Accepted: 3 February 2021

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Introduction

Balance is defined as the ability to maintain the body's centre of gravity over its base of support with minimal sway and maximal steadiness [11, 30], and it is a key component of motor skills ranging from maintaining posture to executing complex motor skills. When equilibrium is maintained during stationary activity it is termed as static balance, while maintaining equilibrium during motion is termed as dynamic balance [35]. It requires integrating sensory information from the visual, vestibular and somatosensory system [8] and it is a vital component of the human body to function optimally and stay injury free [12]. This component is a determinant of appropriate biomechanics [20], which is helpful in freedom of movements and maintenance of quality of life [22, 23]. Balance abilities can be tested with a functional approach to check for existing balance problems and to assess the risk of falling as well. The importance of various centers such as the primary motor cortex, premotor cortex, supplementary motor area, prefrontal cortex (PFC) and their role in postural control is of great importance as any alteration in the functioning of these structures leads to altered biomechanics of an individual [22, 23, 34].
Functional near-infrared spectroscopy (fNIRS) is used as a neuroimaging tool for the study of different areas of the brain involved in motor control through the measurement of changes in brain hemodynamics [5].

Neuroimaging studies have focused on investigation of brain activation during maintenance of standing posture control [21, 26, 31]. fNIRS is one of the functional neuroimaging techniques, which detects differences in the absorption spectra of oxygenated hemoglobin (Oxy Hb) versus deoxygenated hemoglobin (Deoxy Hb) in the near-infrared spectrum range of 700-900 nanometers. Advantages of fNIRS compared to other neuroimaging techniques such as functional magnetic resonance imaging (fMRI), positron emission technique (PET) or electroencephalogram (EEG) include its non-invasiveness, good spatial (≈1.0-3.0 cm) and temporal resolution (normally up to 10 Hz), robustness against artifacts and lately its wireless usage and portability. This has made it suitable for investigating the cortical control of postural balance under static and dynamic testing conditions [9].

Among various techniques, e.g. fMRI, PET, and EEG, have certain limitations for the analysis of movement control strategies, exercise-cognition experiments have not been extensively done [9, 29]. fMRI is immobile, susceptible to movement artifacts and has a relatively low temporal resolution [19]. PET is expensive and since it uses radioactive tracer substances it is not suitable for experiments involving repetitive testing [28]. Similarly, EEG is susceptible to movement artifacts and it is a time-consuming process [3]. Previous studies did use PET [2, 26] and EEG [1, 4, 33], but they focused on restricted static balance control paradigms and this limits the number of balance challenge tasks that can be evaluated. This stationary characteristic of these neuroimaging technologies prevented us from assessing full mobility and restricted our understanding of neural mechanisms essential for balance control under various scenarios.

A previous systematic review [34] on cortical imaging of human balance control studies included fNIRS, EEG and fMRI. Pertaining to fNIRS they reported 21 studies, out of which only 2 studies were based on wireless fNIRS technology. As technological advancements have taken place it has enabled researchers to study static as well as dynamic balance and their associated cortical activation patterns with the use of wireless fNIRS. Thus, this systematic review was designed to evaluate studies on cortical activation while performing static and dynamic balance tasks using fNIRS as a tool and to focus on different locations of brain areas activated in static and dynamic tasks.

Material and Methods

Search strategy

This systematic review used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Figure 1) approaches [17]. The keywords included fNIRS, balance, human balance, static balance control, dynamic balance control, brain activation during balance, postural balance and equilibrium. These search keywords were linked with “AND” to ensure that at least one term of each field could be found in the results. The terms in each of the search fields were linked with “OR”. The articles published between the year 2000-2020 were included.

Search process

The primary information sources included in this review are: Google Scholar, PubMed, Science Direct, Taylor and Francis, and Scopus. The database search included search terms found in the article title, abstracts and keywords. The results from each database were added to the Zotero software and checked for any duplicate results.

Inclusion and exclusion criteria

Search inclusion and exclusion were based on the use of fNIRS neuroimaging modality. Literature included in this review aimed to investigate human balance control using fNIRS. Studies were included if their task incorporated balance challenges (e.g. perturbations, eyes closed, dual-task, balance testing equipment, etc.). Only articles in the English language were considered.

We excluded literature from this review when either the neuroimaging technique was other than fNIRS and balance testing involved walking balance or any other method which did not match the goals of the study. We also excluded studies involving any neurodegenerative conditions, in which balance was assessed. Studies which used isolated joint movement and coordinated body movement (arms and legs) were excluded.

Data extraction

Three authors (SS; AS; PKS) were involved in the selection of articles independently. All the duplicate articles were removed. All the titles and abstracts were evaluated to exclude unrelated articles. Full texts of all the related articles were examined according to inclusion and exclusion criteria. Information regarding the age of the participants, population characteristics, and areas involved during different balance tasks, region of interest in fNIRS, number of channels used in fNIRS, variables studied (Oxy, Deoxy, differential, total hemoglobin, etc.) task/test involved, data representation, filters used for data refining, company of fNIRS were assessed in the studies.

Methodological quality assessment

Each included study was assessed for quality using the Downs and Black checklist [6]. This checklist includes

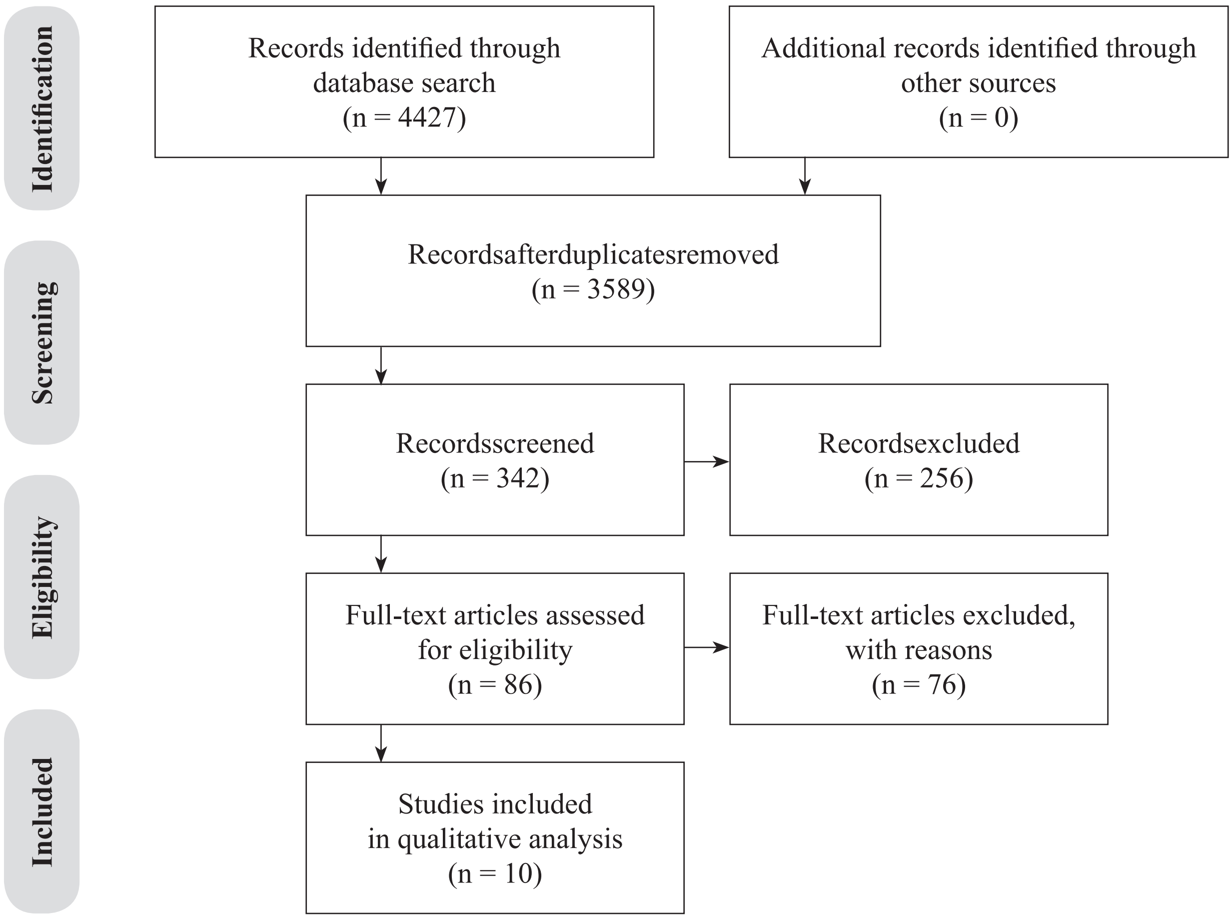

Figure 1. PRISMA flow chart of search strategy and retrieval of articles

27 criteria, covering areas of reporting quality, external and internal validity, and power. The quality of each study was independently assessed by the three authors, with discrepancies resolved through discussion and agreement.

Results

The database search and additional sources yielded 4427 records (Figure 1). After the removal of duplicates and records with missing/unavailable abstracts, 3589 records remained. After screening of relevant articles 342 remained, after which the relevancy of the topic, availability of full article, as well as full text eligibility were checked. The number of articles included in the final synthesis was 10 (n = 10). Reasons for exclusion during the full-text eligibility assessment were the following: a large number of studies were outside the scope of our aim of use of the fNIRS neuroimaging technique and balance tasks. The qualitative analysis (Table 1) was carried out as per the Downs and Black, 1998 [6]. All extracted relevant information of the articles selected for final synthesis is shown in Tables 2, 3 and 4. The inclusion criteria were taken into account.

Quality assessment

According to the quality assessment scale by Downs and Black, 1998 [6], the corresponding quality levels as stated are scores of excellent (26-28), good (20-25), fair (15-19) and poor quality (≤14). We found that out of the 10 included studies, all were of good quality according to the criteria in the scale. Four studies had a score of 20 and five studies had a score of 21, while one study had a score of 22 details, which is represented in Table 1.

Characteristics of subjects

All the included participants in the studies were healthy adults. Out of the 10 studies analysed, eight studies included only young adults, one study [32] had younger and older adult subjects and one study [18] had middle-aged and old-aged subjects. The mean age (in years) for

Table 1. Downs and Black checklist for quality assessment of included fNIRS studies

		Mihara et al., 2008 [21]	Karim et al., 2012 [14]	Karim et al., 2013 [13]	Moro et al., 2014 [24]	Ferrari et al., 2014 [7]	Hiyamizu et al., 2014 [10]	Takakura et al., 2015 [31]	Herold et al., 2017 [8]	Lin et al., 2017 [18]	Teo et al., 2018 [32]
REPORTING											
Q1.	Hypothesis / aim / objective clearly described	1	1	1	1	1	1	1	1	1	1
Q2.	Main outcomes in Introduction or Methods	1	1	1	1	1	1	1	1	1	1
Q3.	Patient characteristics clearly described	1	1	1	1	1	1	1	1	1	1
Q4.	Interventions of interest clearly described	1	1	1	1	1	1	1	1	1	1
Q5.	Principal confounders clearly described	1	1	1	1	1	1	1	1	1	1
Q6.	Main findings clearly described	1	1	1	1	1	1	1	1	1	1
Q7.	Estimates for random variability provided for main outcomes	0	0	1	1	1	1	1	1	1	1
Q8.	All adverse events of intervention reported	1	1	1	1	1	1	1	1	1	1
Q9.	Characteristics of patients lost to follow-up described	1	1	1	1	1	1	1	1	1	1
Q10.	Probability values reported for main outcomes	1	1	1	1	1	1	1	1	1	1
EXTERNAL VALIDITY											
Q11.	Subjects asked to participate were representative of source population	UTD	UTD	UTD	UTD	UTD	0	UTD	UTD	UTD	UTD
Q12.	Subjects prepared to participate were representative of source population	1	1	1	1	1	1	1	1	1	1
Q13.	Location and delivery of study treatment was representative of source population	1	1	1	1	1	1	1	1	1	1
INTERANAL VALIDITY – BIAS AND CONFOUNDING											
Q14.	Study participants blinded to treatment	UTD	UTD	UTD	UTD	UTD	0	UTD	0	UTD	UTD
Q15.	Blinded outcome assessment	UTD	UTD	UTD	UTD	UTD	0	UTD	UTD	UTD	UTD
Q16.	Any data dredging clearly described	1	0	0	0	0	1	1	1	1	1
Q17.	Analyses adjust for differing lengths of follow-up	1	1	1	1	1	1	1	1	1	1
Q18.	Appropriate statistical tests performed	1	1	1	1	1	1	1	1	1	1
Q19.	Compliance with interventions was reliable	1	1	1	1	1	1	1	1	1	1
Q20.	Outcome measures were reliable and valid	1	1	1	1	1	1	1	1	1	1
Q21.	All participants recruited from the same source population	1	1	1	1	1	1	1	1	1	1

Q22.	All participants recruited over the same time period	1	1	1	1	1	1	1	1	1	1
Q23.	Participants randomized to treatment(s)	UTD	UTD	UTD	UTD	UTD	1	UTD	UTD	UTD	UTD
Q24.	Allocation of treatment concealed from investigators and participants	UTD	UTD	UTD	UTD	UTD	0	UTD	UTD	UTD	UTD
Q25.	Adequate adjustment for confounding	1	1	1	1	1	0	1	1	1	1
Q26.	Losses to follow-up taken into account	1	1	1	1	1	1	1	1	1	1
POWER											
Q27.	Sufficient power to detect treatment effect at significance level of 0.05	0	1	1	0	0	0	1	0	0	1
TOTAL		20	20	21	20	20	21	21	21	21	22
		GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD

Note: 0 = NO; 1 = YES; UTD = unable to determine. Downs and Black score ranges were given corresponding quality levels [6]: excellent (26-28); good (20-25); fair (15-19); and poor (≤14)

Table 2. Illustration of included fNIRS studies

Sr. No.	Author	Aim	Population	Procedure	Regions of interest	Variables focused
1.	Mihara et al., 2008 [21]	To evaluate perturbation based changes in the prefrontal cortex.	15 healthy subjects (9 males, 6 females)	Two conditions: warned and unwarned were tested; an auditory warning signal was provided 2 sec before perturbation in the former condition, while it was not provided in the latter condition. Before each measurement was started, the current condition was informed to the subjects. In each condition, 20-30 perturbations were provided at intervals randomized between 5 and 20 sec (mean, 10 sec). Perturbation was provided as a horizontal translation of a custom-made moving platform. The subjects were instructed to stand at the center of the platform with their feet shoulder-width apart.	bilateral frontal and parietal cortices	Oxy Hb Deoxy Hb
2.	Karim et al., 2012 [14]	To record blood flow changes in the frontal, motor, sensory, and temporal cortices during active balancing associated with playing a video game simulating downhill skiing (Nintendo WiiTM; Wii-FitTM).	9 healthy subjects (5 males, 4 females)	The test method included repeated trials of a commercial video game simulating downhill slalom skiing (Nintendo Wii™; Wii-Fit™ video game). Each subject preformed 6 trials at the beginner level and 8 trials at the advanced level. Participants stood on an instrumented balance board for 30 sec (standing rest), after which the game was started. A 30-sec standing rest period was added after the subject reached the bottom of the virtual ski slope. The balance task (skiing down the hill) was self-paced depending on the skill and speed of the subject.	bilateral prefrontal cortex, frontal cortex, and superior temporal gyrus	Oxy Hb Deoxy Hb
3.	Karim et al., 2013 [13]	To investigate how the brain processes information from multiple sensory modalities during dynamic posturography.	15 healthy subjects (9 males, 6 females)	The method included posturography while undergoing fNIRS brain imaging. Four standard conditions from the sensory organization test (SOT) were performed and each consisted of an initial baseline condition (45 sec), a test condition (45 sec), and a repeat of the baseline condition (60 sec). Each condition challenged one sensory condition when going from baseline to test condition while the other was kept constant. For e.g. if the baseline was vestibular proprioception then vestibular was tested.	bilateral frontal, temporal and parietal brain regions	Oxy Hb Deoxy Hb
4.	Moro et al., 2014 [24]	To assess prefrontal cortex oxygenation response during an incremental and a control swing balance task (ISBT and CSBT, respectively) in a semi-immersive virtual reality (VR) environment driven by a depth-sensing camera.	16 healthy male subjects	Subjects were asked to stand barefoot while watching a 3D virtual representation of themselves projected onto a screen. They had to maintain their balance on a virtual blue swing board susceptible to external destabilizing perturbations during a 3-min ISBT (performed at four levels of difficulty) or during a 3-min CSBT (performed constantly at the lowest level of difficulty of the ISBT). The protocol included the ISBT and the CSBT; each task lasted 7 min. During the first 2 min (baseline), each subject was asked to stand still observing his image and the blue virtual swing board represented on the projection screen by the 3D model followed by an auditory signal indicated the start of a 3-min ISBT or CSBT. The ISBT was divided in four steps (S1; S2; S3; S4) of increasing difficulty (i.e., 1-4 m/s), each 45 sec in duration, and each level of difficulty contained 7 random perturbations (forward backward direction).	prefrontal cortex (Brodmann areas 10, 11 and 46)	Oxy Hb Deoxy Hb

				The CSBT was divided in four steps (S1; S2; S3; S4) of constant difficulty, each 45 sec in duration, executed at the lowest level of difficulty of the ISBT (i.e., 1 m/s). Each step contained 7 random perturbations (forward–backward direction). After the end of the last step of ISBT/CSBT, each subject had to observe his image on the projection screen without moving his body for 2 min (recovery time). The interval between the two tasks was 3 min, and the task order was counterbalanced across subjects.		
5.	Ferrari et al., 2014 [7]	To assess by fNIRS the prefrontal cortex oxygenation response to a tilt board balance task, performed either at constant (control tilt board balance task – CTBBT) or incremental (incremental tilt board balance task – ITBBT) level of difficulty executed in a semi-immersive virtual reality environment driven by a depth-sensing camera.	22 healthy male subjects	The task involved medial–lateral postural sways on a virtual tilt board (VTB) balancing over a pivot. The protocol included ITBBT and CTBBT; each lasted 9 min. Twenty two subjects were divided into two groups performing ITBBT and CTBBT, respectively. During the first 2-min (baseline), the subject was asked to stand still observing his image (represented on the screen by the 3D model). The 5-min ITBBT or CTBBT was started by a beep.	bilateral prefrontal cortex	Oxy Hb Deoxy Hb
6.	Hiyamizu et al., 2014 [10]	To compare effects of observing the performance of others and self-performance on standing balance learning in healthy young subjects and to examine cortical activation during performance using functional near-infrared spectroscopy (fNIRS).	39 healthy young subjects (24 females, 15 males); groups consisting of an equal number of 13 subjects (8 females and 5 males per group): Control, Other Observation (OO), and Self-Observation (SO) group	All subjects were instructed to keep the platform horizontal for 30 sec after a preparation period of sitting on a high chair for 30 sec. A rest period with sitting for 30 sec after the task was given. All subjects performed 5 practice trials following a pre-test and then performed a post-test. Additionally, they performed a retention test at 24 h after the post-test. All subjects were instructed to look at a target placed 2 m in front of the subject at eye level during task performance, and they were permitted to use their upper extremities to maintain balance.	supplementary motor area (SMA), premotor cortex (PMC), and dorsolateral prefrontal cortex (DLPFC)	Oxy Hb Deoxy Hb Total Hb

7.	Takakura et al., 2015 [31]	To investigate cortical cognitive processes during instances of sensory conflict in postural balance activities.	11 healthy male subjects	Each subject performed the EquiTest® SOT (NeuroCom International, Inc., USA), which is an objective assessment of the main sensory systems involved in balance and stability. Each subject completed 5 trials under each condition. Each trial lasted 20 sec and each trial interval was set for more than 60 sec. During the trial, each subject stood on a fixed platform with his eyes open and with the three sensory systems operational (i.e., under the same conditions as SOT 1). After completing 3 trials under the six SOT conditions, the subjects rested for a few minutes. This task involved 30 trials overall and typically lasted about 60 min. The six sensory conditions were analyzed to find the involvement of vision, vestibular and somatosensory inputs in the balance function.	right frontal operculum/inferior frontal gyrus (f-Op), right parietal operculum (p-Op), frontal eye field (FEF), right supramarginal gyrus, right angular gyrus, right superior temporal gyrus (STG), lateral part of sensorimotor cortex in the right hemisphere, medial part of the sensorimotor cortex, superior parietal lobule, and the supplementary motor area	Oxy Hb
8.	Herold zet al., 2017 [8]	To evaluate the effect of balancing on a balance board on cortical activity in sensorimotor areas as assessed by fNIRS and to identify possible relations between sway parameters and hemodynamic responses in sensorimotor brain areas.	10 healthy young adult subjects	fNIRS and balance board (TOGU Board Tri axial inertial measurement unit) was used in the testing method. Every participant performed three blocks, in which a block consisted of three phases: at first participants had to stand still on the floor for 30 sec (baseline) and then another 30 sec for the standing condition. Afterwards, they stepped on the balance board and maintained balance in feet side by side position for 30 sec (balance condition). After each balancing period they had to step down and were allowed to rest standing on the floor for 30 sec.	supplementary motor area (SMA), precentral gyrus, postcentral gyrus	Oxy Hb Deoxy Hb
9.	Lin et al., 2017 [18]	To investigate hemodynamic changes in frontal-lateral, temporal-parietal, and occipital regions of interest (ROIs) during four sensory integration conditions that manipulate visual and somatosensory feedback.	15 middle-aged subjects (5 males, 10 females) and 15 older adults subjects (8 males, 7 females)	All participants performed 4 trials of standing on a NeuroCom posturography platform (Natus®, USA). The sensory modifications involved changing either visual input [eyes open in light (EO) and dark (EOD)] or somatosensory input [fixed or sway-referenced (SR) platform]. The EOD condition was accomplished by having the participants keep their eyes open while wearing darkened goggles. Each trial consisted of a change from greater sensory input to reduced sensory input. Each subblock lasted 40 sec. All participants performed the four trials one time, in a random order.	five ROIs; occipital, right frontal lateral, right temporal parietal, left frontal lateral, left temporal parietal	Oxy Hb Deoxy Hb

10.	Teo et al., 2018 [32]	To investigate the effects of aging on the dorsolateral prefrontal cortex when sensory cues are removed or presented inaccurately (i.e. increased sensory complexity) during the sensory orientation test (SOT).	20 young subjects (aged 18-25 years, 10 males, 10 females) and 18 older (aged 66-73 years, 10 males, 8 females) sedentary, otherwise healthy adult subjects	The NeuroCom Balance Master system (NeuroCom International Inc, USA) was used for SOT, which comprised six different sensory conditions in quiet stance, and measured the center of pressure (COP) path. The test started with condition 1 (eyes open in a static stance), and consecutively moved through each condition which progressively became more challenging by either distracting or removing visual and/or proprioceptive feedback. The visual surround and force platform were sway-referenced, which referred to the tilting of the support surface and/or visual surround in response to movement of the participant's COP. Three 20-sec trials were conducted for each sensory condition with an inter trial rest period of 60 sec. During each rest period, all participants were allowed to adjust their foot position if needed and were asked to remain standing still upright for at least 30 sec with their eyes opened and focused onto a fixation cross at eye-level in front.	bilateral dorsolateral prefrontal cortex (DLPFC)	Oxy Hb Deoxy Hb

Table 3. Cortical activation location of included fNIRS studies

Sr. No.	Author	Type of balance task	Cortical activation areas
1.	Mihara et al., 2008 [21]	static	Enhanced activation in the sensory motor area and right posterior parietal cortex was observed. Significant task-related increase of Oxy Hb signals after postural perturbation. No significant signal changes in Deoxy Hb were reported. In the frontal cortices, the left and right middle frontal gyri, the left and right superior frontal gyri, the left supplementary motor area, and the left precentral gyrus showed significant task-related increase of Oxy Hb signals after postural perturbation. In the parietal cortices, the left postcentral gyrus, the left and right superior parietal lobules also showed a significant task-related increase of Oxy Hb signals.
2.	Karim et al., 2012 [14]	dynamic	Activation of right superior temporal gyrus was modulated by the difficulty of the task and supramarginal gyrus in both left and right hemispheres.
3.	Karim et al., 2013 [13]	static	Increased activation was reported in the temporo-parietal regions in the area around the superior temporal gyrus, when subjects relied primarily on vestibular information. In the condition when only proprioception was degraded, less activation in the left superior temporal gyrus was observed. When only vision was degraded, a decrease in oxy-hemoglobin in the right prefrontal cortex and left temporoparietal area was observed as well as small activations in the right temporoparietal area. The superior temporal gyrus on either side was found to be activated.
4.	Moro et al., 2014 [24]	dynamic	Oxygenation increased over the prefrontal cortex of both hemispheres in healthy subjects performing an ISBT in a semi-immersive VR environment. The observed prefrontal cortex (PFC) activation was modulated by levels of difficulty of the task signifying that PFC is bilaterally involved in attention-demanding balance tasks. The increase in difficulty during the first three levels led to an increase in Oxy Hb values and a less consistent Deoxy Hb decreased over 8 measurement points of PFC.
5.	Ferrari et al., 2014 [7]	dynamic	The prefrontal cortex (PFC) oxygenation increased in case of subjects performing an ITBBT in a semi-immersive virtual reality environment. The activation increased as the level of difficulty of task suggesting that PFC is bilaterally involved in attention-demanding balance tasks.
6.	Hiyamizu et al., 2014 [10]	static	There was no significant difference in any cortical area in the control and observation groups. Predominantly, in the observation group, SMA and Right DLPFC hemodynamic values remained unchanged post-test. In the self-observation group, post-test values in left DLPFC were significantly decreased compared with the pre-test.
7.	Takakura et al., 2015 [31]	static	Oxy Hb concentrations in the frontal operculum/inferior frontal gyrus (f-Op), right parietal operculum (p-Op), and superior temporal gyrus (STG) around the Sylvian fissure were increased under SOT 2, 3, 5, and 6, and specifically in under SOT 5 and 6. These Oxy Hb and Total Hb responses were gradually decreased after the end of the task. Substantial hemodynamic responses were not observed in any of the region of interest under SOT 1.
8.	Herold et al., 2017 [8]	dynamic	The Oxy Hb values increased considerably from standing to balancing in supplementary motor area (SMA). The analysis of Deoxy Hb values revealed no significant differences between the conditions.
9.	Lin et al., 2017 [18]	static	The temporal-parietal ROI were activated more when somatosensory and visual information was absent in both groups, which indicated the use of vestibular input for maintaining balance. While both older adults and middle-aged adults had greater activity in most brain ROIs during changes in the sensory conditions, older adults had greater increases in occipital ROI and frontal lateral ROIs.
10.	Teo et al., 2018 [32]	static	Bilateral DLPFC activation during postural control increased. The results confirmed that with comparison to younger adults, older adults had greater bilateral DLPFC activation particularly during more complex balance tasks, while younger adults showed greater lateralization to right DLPFC with increased sensory demands.

Note: Oxy Hb – oxygenated hemoglobin; Deoxy Hb – deoxygenated hemoglobin; Total Hb – total hemoglobin

Table 4. fNIRS system characteristics and signal processing methods of included fNIRS studies

Sr. No.	Study	No. of channels used	Filters used	Sampling frequency	Representation of data	Company
1.	Mihara et al., 2008 [21]	50	high pass filter (0.05 Hz)	4 Hz	time line analysis graph	OMM 3000; Shimadzu Corp., Kyoto, Japan
2.	Karim et al., 2012 [14]	32	not mentioned	4 Hz	time line analysis graph brain map	CW6 real time system; TechEn Inc., Milford, Massachusetts, USA
3.	Karim et al., 2013 [13]	32	not mentioned	4 Hz	time line analysis graph	CW6 real time system; TechEn Inc., Milford, Massachusetts, USA
4.	Moro et al., 2014 [24]	8	low pass filter (0.1 Hz)	1 Hz	bar graph box plots graph	NIRO-200, Hamamatsu Photonics, Japan
5.	Ferrari et al., 2014 [7]	8	low pass filter (0.1 Hz)	1 Hz	time line analysis graph	NIRO-200, Hamamatsu Photonics, Japan
6.	Hiyamizu et al., 2014 [10]	51	not mentioned	5 Hz	bar graph	FOIRE-3000; Shimadzu Corp., Kyoto, Japan
7.	Takakura et al., 2015 [31]	50	band-pass Fourier filter (0.01-0.1 Hz)	not mentioned	time line analysis graph bar graph connectivity maps cortical representations maps	OMM 3000; Shimadzu Corp., Kyoto, Japan
8.	Herold et al., 2017 [8]	24	low pass filter (0.5 Hz) and high pass filter (0.01 Hz)	10 Hz	scatter plot graph	Continuous fNIRS Wave System, ETG 4000 optical system, Hitachi Medical Corp., Tokyo, Japan
9.	Lin et al., 2017 [18]	30	not mentioned	4 Hz	bar graph cortical representation maps	CW6 real time system; TechEn Inc., Milford, Massachusetts, USA
10.	Teo et al., 2018 [32]	8	high-pass-0.01 Hz and low-pass-0.50 Hz	10 Hz	bar graph scatter plot graph	OxyMon Mk III, Artinis Medical Systems, The Netherlands

young adults was found to be 25.83±4.60; for middle aged 46±11 and for old aged 71±2.82.

Discussion

The aim of this systematic review was to classify and focus on studies using fNIRS as a tool to investigate the location of activation in the cerebral cortex during the performance of different balance tasks.

Ten studies which met the inclusion criteria were reviewed and further illustrated in the next section and Tables 2, 3 and 4. The balance tasks used in these studies ranged from basic tasks, such as sensory organization test, perturbations and posturography, to more advanced tasks, such as incremental swing balance tasks and downhill skiing on a video game.

Overview of test methods used

fNIRS can be utilized to evaluate changes in cortical activation in a variety of balance tasks. In the studies which met the inclusion criteria for the systematic review (Table 2); four studies used sensory organization balance/posturography test methods to assess balance. Two studies used advance technological instruments, such as the TOGU Board Tri axial inertial measurement unit and tilt board with Noraxon pressure sensors, while one study used a video game (Nintendo WiiTM) in order to challenge the balance of the subjects.

The TOGU Board uses four air-filled balls below the wooden board, which enables people of any fitness level and age to step into sensory motor function training and increase their capabilities. The tilt board with Noraxon pressure sensors enables to record the pressure beneath the foot with an even distribution. The Nintendo WiiTM provides an interactive user interface for testing static and dynamic conditions with the use of pre-installed games.

Overview of fNIRS variables

In the studies included for the systematic review (Table 3), eight studies used both oxy- and deoxyhemoglobin to describe changes in cortical activation, whereas one study used only oxyhemoglobin [31] and one study [10] used oxy, deoxy and total hemoglobin to describe cortical activation. The studies included in this review tend to be focused on one common finding that the oxyhemoglobin (O_2Hb) is mainly linked to the oxygen inflow of the tissue, while deoxyhemoglobin (HHb) is linked to the amount of oxygen absorbed by the tissue. An increase in the O_2Hb is correlated to a decrease in HHb. During activation of the tissue (e.g. excitation of brain areas or straining of muscles), oxygen is consumed within the tissue and hemodynamically the tissue responds by increasing the flow of blood toward that tissue. Combining both O_2Hb and HHb yields the total hemoglobin concentration changes, which are linked to changes in total blood volume in the tissue underneath the sensor [9].

Usage of channels for assessing cortical activation changes in the studies included for the systematic review were as follows;three studies [7, 24, 32] used 8 channels, two studies [13, 14] used 32 channels, two studies used 50 channels [21, 31], one study [10] used 51 channels, one study [18] used 30 channels and one study [8] used 24 channels.

Signal acquisition in fNIRS requires a set frequency and filtering techniques to remove artifacts. Physiological noises such as heartbeat, respiration, blood pressure fluctuations, extra-cortical noises from the superficial layers, and motion artifacts affect the obtained cortical activity data [34]. It is essential to remove these noises prior to analyzing the brain functions.

Overview of signal processing of fNIRS data

In preprocessing of the fNIRS data, the physiological noises are removed using band pass filtering [15, 27] with cut-off frequencies of approximately 0.01-0.9 Hz that corrects the artifacts in the frequency range between a low pass and high pass filter [16, 25, 27]. The review included:four studies [13, 14, 18, 21] using 4 Hz, two studies [8, 32] using 2 Hz, two studies [7, 24] using 1 Hz and one study [10] using 5 Hz as their sampling frequency. The filters used were band pass filters in three studies [8, 21, 31]; low pass filters in two studies [7, 24], while one study [21] reported the use of high pass filters for refining the data. As per the technological availability the pre-processing and removal of movement artifacts was done in the included studies.

Overview of cortical activation

This study reviewed 10 articles using fNIRS neuroimaging modality to investigate the cortical activation involved in human balance control. This review reported that different tasks elicited different areas of brain activation. The dorsolateral prefrontal cortex was activated during postural control tasks, which were attention demanding [7, 10, 18, 24, 32]. There was activation of the sensory motor area (SMA) observed in four studies, which met the inclusion criteria. In their study Hiyamizu et al., 2014 [10], when studying changes during balance learning reported that there was an increase in Oxy Hb in SMA post training of a previously learned task of balance. Herold et al., 2017 [8] stated that Oxy Hb increased in SMA more during a balance task as compared to standing, emphasizing the use of higher cortical processes. The investigated studies show that SMA activation is dependent on the level of difficulty imposed during the balance task.

Mihara et al., 2008 [21] studied changes in SMA during two conditions of perturbation; warned and unwarned, in which they reported a significant activation in the case of warned perturbation because of preparation to an impending activity, which was not found in the case of an unwarned situation. They also reported that the posterior parietal cortex got activated due to warned and unwarned perturbations as a preparation to the forthcoming perturbation involving visuospatial attention.

Takakura et al., 2015 [31] reported a significant increase in Oxy Hb and Total Hb of SMA in stages 5 and 6 of the sensory organization test (total 6 stages), as these stages compromise more sensory inputs. However, no significant difference was reported from the baseline in the values of the initial stages. It was also found that the posterior parietal cortex was activated during a task involving obstruction of vestibular and visual information. The results prove that the supplementary motor area is involved in the execution of volitional action and establishment of new motor programs to maintain postural balance. The posterior parietal cortex and the premotor cortex are involved in the updating and computation of spatial reference frames during instances of a sensory conflict between vestibular and visual information.

Karim et al., 2013 [13] reported that the superior temporal gyrus (STG) became activated during the sensory organization test when subjects relied primarily on vestibular information. In a situation when only proprioception was degraded, less activation in the left superior temporal gyrus was observed. Compared to when only vision was degraded, a decrease was observed in oxyhemoglobin in the right prefrontal cortex and left temporo-parietal area, as well as small activations in the right temporo-parietal area. The superior temporal gyrus on either side was found to be activated. In another study [14], which involved a downhill slalom skiing video game task it was found that the activation of the right superior temporal gyrus was observed as an adjustment to the increased difficulty of the video game task involving inclination and also thesupramarginal gyrus in both the left and right hemispheres.

These findings provide insight into how the visual, somatosensory, auditory and vestibular systems are in conjunction to each other for maintaining an individual's balance. Moreover, the included literature confirmed the use of fNIRS as a neuro-imaging technique to analyze brain activation during static and dynamic balance tasks as an advantage over fMRI, EEG and PET scan where the movement must be restricted.

There are few limitations of fNIRS including inability to assess deeper structures of the brain [9]. Studies included [7, 24, 32] had the limitation with regard to the availability of usage of channels. Another limitation was the area to be tested at one given instance, such as reported by [13, 14], who were not able to examine the occipital lobe due to technical limitations.

Practical relevance

The relatively recent breakthroughs in wireless neuroimaging have empowered researchers to examine brain function during normal human movement. It is obvious that the use of neuroimaging systems to the domain of human balance control is still developing. Significant opportunities remain in the detection of neural mechanisms underlying the control of human balance and the use of these structures should be completely portable and should be able to assess functional limitations as incurring in our daily lives.

Future directions

Larger areas and a greater number of channels must be used in future studies in order to show a clear picture of cortical activation during balanced tasks. Both static and dynamic tasks need to be used in a particular study and must be compared for cortical activation. The effect of confounding variables such as age, gender, physical activity levels and regular sporting activity might be addressed further.

Conclusions

The results of this review showed that the bilateral dorsolateral prefrontal cortex, sensory motor area predominantly get activated during both static and dynamic balance tasks. Specifically in the case of dynamic balance tasks the right superior temporal gyrus becomes activated, whereas during static balance tasks cortical areas of the frontal operculum, right patietal operculum, temporo-parietal cortex and bilateral superior temporal gyurus get activated. With developments in fNIRS a whole new dimension of brain activity and cognition has opened up because of the unique advantages of this technology, which facilitates quantification of brain activity during the execution of various movements and tasks. This technique serves as an adjunct to assess static and dynamic postural imbalances in persons with balance related issues with a greater number of channels and more regions of interest to be covered at one given instance.

Conflict of interests

The authors declare no conflict of interest.

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ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2021; 28(**2**): 109-115
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.2-4

How did athletes train and avoid injuries during the COVID-19 quarantine period?

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Abstract
Introduction. **During the isolation period of COVID-19, athletes may not train, which leads to an increased risk of injury, which can be slight or more severe depending on their fitness level.** Aim of Study. **The current study aimed to investigate training exercises and injury prevention programs during the COVID-19 quarantine period among athletes.** Material and Methods. **A self-administered web-based survey was developed. The survey aimed to obtain information concerning exercises and injury prevention protocols implemented by athletes during the COVID-19 quarantine period. The survey's other goal was to investigate the type of exercises such as running, strength, stretching, plyometrics, balance, or injury prevention programs and the average training time. Data was collected in the period between April to June 2020.** Results. **A total of 606 respondents completed the survey, with a response rate of 80% from 132 countries worldwide. Most respondents were male (n = 353, 58.3%), and aged between 30 to 39 years (n = 175, 28.9%). Sixty-one percent of the total sample reported that they had been training during the quarantine period. They consisted of amateur-level (n = 180, 29.7%) and semi-professional athletes (n = 159, 26.2%). Squat, push up, single-leg squat, and side lunges were the top five implemented exercises with an average training time of 30 to 60 minutes. Most injury prevention protocols (18.8%) were reported as non-specified programs, followed by the Knee Injury Prevention Program (KIPP) (12.5%) and the iSPRINT Injury Prevention Program (10.6%).** Conclusions. **Most athletes continued their training and exercise during the COVID quarantine period to maintain their physical fitness level and reduce injury levels once they resume their regular training.**

KEYWORDS: COVID-19, isolation, athletes, injury prevention.

Received: 30 December 2020
Accepted: 20 March 2021

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Introduction

The coronavirus disease 2019 (COVID-19) pandemic started spreading in Wuhan, China, in December 2019. It was identified as the cause of respiratory failure, including also such symptoms as fever, fatigue, diarrhoea, cough, and muscle soreness [8]. It is also believed that COVID-19 may result in multiple organ failure, RNAaemia, as well as cardiac, liver and renal damage [24]. These manifestations are thought to be mediated by a specific cytokine profile response associated with COVID-19 disease [24]. Athletes infected with the COVID-19 virus may display varying levels of symptoms ranging from no symptoms at all to severe symptoms requiring hospitalization [25]. Of all complications, myocarditis seems to be the most feared sequelae of viral infections, resulting in further damage to the heart following COVID-19. Therefore, prevention of COVID-19 spread among athletes is essential to avoid the cardiorespiratory complications and their negative impact on training [23]. It can be achieved by practising preventive strategies such as good hand hygiene, wearing a face mask in public, and self-isolation while planning for a safe return to participation insports events [23].

Close contact sports with several players may pose a high risk of infection. Potential infection sources in sports competitions are related with the physical contact between athletes and their teammates, the competing team, the environment, or equipment. Transmission of the virus between team members and spectators may occur by inhaling the droplets or aerosols of infected persons while sneezing or coughing or when coming in close contact. Additionally, studies have indicated that the virus may remain viable for hours and days on surfaces [26]. Several major sporting events have been either canceled or postponed as a precautionary measure, such as the Tokyo Olympic and Paralympic 2020 games, which were postponed to 2021 [23].

The training volume and aim of professional athletes vary from those of amateur athletes. In contrast to amateur athletes, professional athletes train to participate in tournaments and events based on monetary prizes and rewards and are highly competitive [10]. Additionally, professional athletes are more satisfied socioeconomically, psychologically, and spiritually when compared to their semiprofessional and amateur colleagues [20]. Anthropometric characteristics can also differ. Jones et al. [13] found that professional rugby union players were heavier, taller and leaner. It may be due to the variation in the training volume, physical requirements and the augmented strength and conditioning that professional players receive.

Lockdown due to COVID-19 may have negatively affected all athletes' categories. Reduced physical activity of athletes due to the lack of training and the imposed quarantine may lead to consequential effects. It may cause psychological, physical, and functional deterioration [1, 21, 26]. Moreover, Castrogiovanni et al. [4] found that prolonged inactivity can decrease the lubrication and nutrition of joint cartilage leading to degeneration and imbalance in the joint structures, cartilage, ligaments, and synovium [4]. In a joint statement by the National Collegiate Athletic Association (NCAA) and the National Strength and Conditioning Association (NSCA), 60% of non-contact injuries in athletes occur following periods of inactivity due to a sudden increase of activity load [5]. To mitigate the risks of developing injuries, researchers recommend implementing a conditioning training program and maintaining a balanced diet that meets reduced physical activity requirements [1, 5, 23].

General muscle strengthening exercises and sport-specific exercise help decrease the risk of getting injured [4], while maintaining optimal body weight, decreasing pain and fatigue, and increasing muscle strength and joint flexibility [6]. Regular exercises to maintain physical fitness can also be performed to maintain body strength and balance [14]. Research shows that resistance training can effectively increase muscle strength, whereas sustaining participation in a resistance training program during the preseason may reduce the risk of injuries [1, 9]. Other effective strategies include nutrition monitoring, mental fatigue reduction, alternative training protocols, and adequate recovery [14].

Aim of Study

Maintaining regular exercise during the lockdown period has many benefits. Based on the differences in the training volume and objectives between athletes and the deconditioning effects of the COVID-19 pandemic on the athletes, the current research aims to explore current training exercises and injury prevention programs implemented by athletes during the COVID-19 isolation interval.

Material and Methods

Study design and survey development

A self-administered questionnaire was developed, consisting of socio-demographic questions and three questions related to sports-specific practices to avoid injuries during the isolation period of the COVID-19 disease. Respondents were prompted to respond to every question provided in the survey before the next questions were presented. A respondent was required to answer a maximum of ten questions categorized into three sections: (1) the study invitation and participation agreement, (2) demographic questions, and (3) sports-specific questions. The study invitation and agreement represented the informed consent to participate in the study. Questions 1 to 6 in the demographics section were related to gender, age, country, type of sports practice, and its level. For questions 1 to 3 in the sports-specific section, participants were asked if they were currently training and practising injury prevention exercise during the COVID-19 period. Those who answered "yes" were asked to select options from various exercises such as running exercises, strength exercises, stretching exercises, plyometrics exercises, balance exercises, and injury prevention programs. They were also asked about the average training time (minutes per day). The participants who answered "no" were directed to submit the form. This project was reviewed and approved by the Biomedical Ethics Committee at Umm Al Qura University. Approval

No. HAPO-02-K-012-2020-10-461. Consent was obtained from each participant in the study before data collection began.

Participants and survey dissemination

The eligibility criterion for participants was their status as athletes. We followed the definition of athletes, described by the European Society of Cardiology as "individuals of young and adult age, engaged in exercise training regularly and participate in official sports competition, either amateur or professional" [18]. To have a convenient sample of athletes, the survey invitation was distributed through LinkedIn (LinkedIn Corporation, Sunnyvale, California, United States) identifying potential athlete participants. The invitation provided a brief background on the survey and encouraged athletes with or without injury prevention experience to participate. Interested respondents clicked on an electronic link that led them to the survey description, and they were able to provide their informed consent and access the survey. Surveys were completed anonymously via Google Forms (Alphabet Inc., Mountain View, California, United States). The survey was open for respondents to complete from April through June 2020.

Sample size and statistical analysis

Seven hundred and fifty participants were invited, considering a 4% margin of error at a 95% confidence level; responses were analyzed using the Statistical Package for the Social Sciences (SPSS) version 24.0 (IBM Corp., Armonk, New York, United States). Descriptive statistics were computed to describe sample characteristics and survey data. A chi-square test for association was conducted between gender, training during the isolation period, while Phi (φ) was used to assess the association's strength between the variables. The Cochran–Armitage test of the trend was applied to determine whether a linear trend existed between the respondent's athletic-level, age groups, and training during the isolation period. Kendall's tau-b correlation was used to determine the relationship between the respondents' athletic-level and daily workout time. The alpha level for all analyses was set at 0.05.

Results

A total of 606 respondents from 132 countries completed the survey with a response rate of 80%, as depicted in Figure 1.

Male respondents (n = 353, 58%) and those aged between 30 to 39 years (n = 175, 29%) represented most of the total sample. Participation from the European region was the highest among all regions (n = 226, 37%). Amateur-level athletes represented 30% of the total athletes in the sample (n = 180). Of the total sample, 61% reported that they had been training during the isolation period. The most-reported average training time was 30 to 60 minutes per day. The respondents' demographic characteristics are described in Table 1.

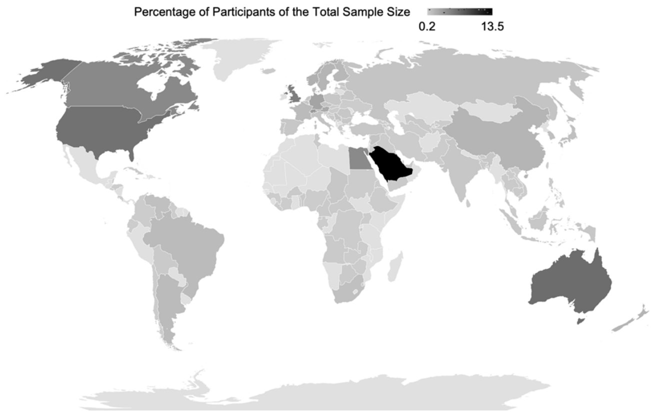

Figure 1. Sample distribution across countries

Table 1. Respondents' information

Gender	N	%
male	353	58.3
female	253	41.7
Age group (years)	**N**	**%**
15-19	139	22.9
20-29	167	27.6
30-39	175	28.9
>40	125	20.6
Region	**N**	**%**
Africa	65	10.7
Asia and the Western Pacific Region	208	34.3
European Region	226	37.3
North America and Caribbean Region	78	12.9
South America Region	29	4.8
Level	**N**	**%**
professional	130	21.5
semi-Professional	159	26.2
amateur	180	29.7
recreational	137	22.6

Duration of training (min/day)	N	%
0	237	39.1%
10-30	54	8.9%
30-60	91	15.0%
60-90	71	11.7%
90-120	60	9.9%
120-150	49	8.1%
150-180	43	7.1%
270-300	1	0.2%

Association between gender and training during the isolation period

There was no statistically significant association between gender and training during the isolation period, $\chi^2(1) = 0.174$, $p = 0.676$, $\varphi = 0.017$. A large proportion of the male (36%) and female (25%) athletes were training during the isolation period (Figure 2).

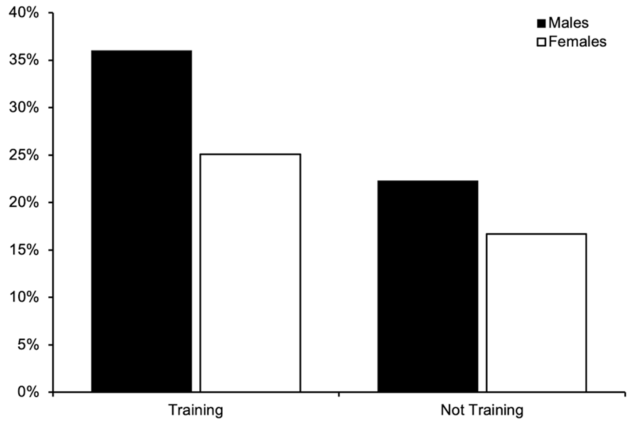

Figure 2. Percentages of participants' training during isolation based on sex

Association between age groups, athletic level, and training during the isolation period

The Cochran–Armitage test of trend showed a statistically significant linear trend, with higher athletic levels associated with a greater proportion of reported training during isolation (p = 0.005). The respondents' athletic levels were recreational (n = 137), amateur (n = 180), semi-professional (n = 159), and professional (n = 130) with the proportion of respondents reporting training during isolation amounting to 54%, 56.7%, 66.7%, and 67.7%, respectively (Table 1).

There was a statistically significant linear trend with the younger age groups associated with a higher proportion of reported training during isolation (p = 0.008). The respondents' age groups were 15-19 years (n = 139), 20--29 years (n = 167), 30-39 years (n = 175), and >40 years (n = 125) with the proportion of respondents within each age group reporting training during isolation at 66.2%, 65.3%, 55.1%, and 53.6%, respectively (Table 2).

Table 2. The participants' age groups and proportion of reported training during isolation

Age group (years)	N	Proportion of reported training
15-19	139	66.2%
20-29	167	65.3%
30-39	175	55.1%
>40	125	53.6%

Association between athletic level and daily workout time

A Kendall's tau-b correlation revealed a trivial, negative, and non-significant association between athletic-level and daily workout time, $\tau b = -0.036$, $p = 0.394$.

Injury Prevention Programs (IPPs)

For those who reported that they had been training during the isolation period, there was a significant variability in the reported IPPs and exercise regimens. Figure 3 shows the variability of the self-reported IPPs, with the majority of IPPs (19%) non-specified, followed by knee injury prevention programs (13%) and the iSPRINT injury prevention program (11%).

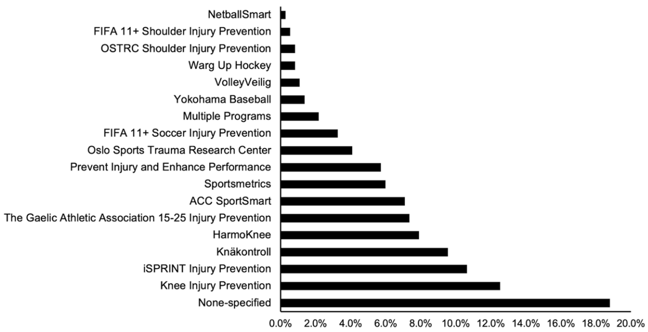

Figure 3. Injury Prevention Programs followed by the participants

Exercises performed by the participants

The exercises performed by the participants via the IPPs were aggregated. The results showed that the most performed exercises with frequencies ranging from 76 to 100% across the participant groups included squat, push up, single-leg squat, and side lunges, which were the top five implemented exercises with an average training time of 30 to 60 minutes. The most practised exercises also included the Nordic hamstring, kneeling lunge, Copenhagen adduction, pelvic lift and deep sumo squat. Dspin, side-lying adduction, pelvic mobility, squat with rotation and jumping with shoulder contact, jumping lunge and hamstring stretch, and other exercises were reported second with frequencies between 51 to 75%. Data also showed that ankle mobility, hip thrusts and single-leg jump were performed by 26 to 50% of the participants. However, most exercises such as walking lunge with a high knee lift, kneeling hip stretch, duckwalk, stand up were performed by less than 25% of the participants.

Discussion

The purpose of this study was to explore the current training exercises and injury prevention programs applied by athletes during the COVID-19 pandemic. Numerous national and international sporting events have been cancelled or suspended in efforts to keep all individuals socially distanced, which negatively affected athletes who were unable to continue regular training [1]. Home workouts and self-applied training programs were the only options to stay active and practice sport-related activities [1, 23].

This study indicated that about 30% of professional athletes were not training during the isolation period. It is expected that athletes will be returning with a spectrum of conditioning levels due to the lifestyle modifications associated with the COVID-19 pandemic. Evidence has shown that cessation of training leads to muscular morphological and functional alterations in athletes leading to a decline in their physical fitness and performance [3, 14]. In addition to physical health issues, high levels of anxiety over the COVID-19 can harm athletes' mental health and readiness [1, 7]. Consequently, it puts them at risk of developing non-contact injuries once they resume regular exercise at a pre-COVID-19 level [5, 11]. Therefore, it is imperative to reach out to athletes, sports organizations, and those involved in sports programs to address the proper resumption of sports activities and training [14, 21].

Lack of knowledge on the appropriate manner of return to sport among athletes, coaches, trainers and physical therapists may jeopardize athletes' health and safety [16, 27]. The current study showed that exercises such as squat, push-up, side plank, forward lunge, Nordic hamstring, and Copenhagen adduction exercises, etc. were the most commonly applied exercises by athletes to avoid injuries. Also, most athletes trained for 30 to 60 minutes per day, which is considered less than the average training duration [19]. Jagim et al. [12] also found that only 46% of 71 athletes in the United States were still training for 5-6 days per week. It is also evident that the participants' exercises in the current study are based on body weight, which is similar to the findings of Pillay et al. [19]. Such valuable information can assist the athletes, coaches, trainers, physical therapists, or any other related professionals in designing injury prevention programs during lockdown periods. Given that a decreased physical activity has been documented [22], such exercises can also help design intervention strategies to reverse the negative effects of inactivity across a wide range of the population, including athletes, children, and patients.

Our study results showed that most athletes were continuing their training and exercise regimens during the COVID-19 isolation period using workout equipment at home despite restrictions enforced on training facilities and workout routines. It appears that most of the athlete respondents are overcoming the challenges, continuing with alternative training, and adapt to maintain their physical fitness level and to reduce the possibility of post-lockdown injury. However, while some athletes were able to cope during the pandemic, other athletes were not. In a cross-section study by Pillay et al. [19] on 692 South African elite and semi-elite athletes, 31% of the respondents expected to return to sport after 1 to 3 months. Regarding their training behavior, most athletes trained alone (61%) at a moderate intensity (58%) for 30-60 minutes daily (61%). Lockdown also affected their lifestyle, as 76% reported eating excessive carbohydrates, 52% felt depressed, and 55% required motivation to keep active. Spanish handball players were surveyed by Mon-López et al. [17], who also found reduced training intensity and deteriorated sleep quality as well as increased sleep hours during the lockdown period. Thus, the COVID-19 pandemic impacted the physical activity status of athletes and their nutritional and psychological well-being. In terms of the financial aspect, elite sportswomen reported impacted financial status due to reduced sponsorship or match fees. Interestingly, in their opinion, men's sport was a higher priority, leading to reduced access to sports facilities. Overall, the systematic review by Stockwell [22] revealed decreased physical activity and increased sedentary behaviour of adults, children, patients and athletes reported by the sixty-six studies included in the review.

This study also showed that more significant proportions of training reported during isolation were accompanied by higher athletic performance levels. This may be explained by the variation in sport commitment among athletes. Higher athletic levels were associated with a higher proportion of respondents who reported training during isolation. Differences in strength, power, personality, and mindsets were found among athletes with varying participation levels [2, 15]. The younger age groups were associated with a higher proportion of respondents who reported training during isolation and variability in the IPPs and exercise regimens that those respondents reported. The trivial and non-significant relationship between athletic level and daily workout time might be related to the lack of variability in the workout time reported by participants in each athletic level. In a similar study to the one conducted by Pillay et al. [19], Jagim et al. [12] reported a significant reduction in the self-reported training goal of athletes in the United States for strength training (–1.65 ± 4.32 h/wk), conditioning (–1.47 ± 3.93 h/wk), and sport-specific activities (–6.44 ± 6.28 h/wk) post-shutdown. The authors reported an apparent reduction in the frequency of training across various self-reported training goals.

Conclusions

This study involved athletes from different countries across the world. This study's highlight was that many athletes were keen on continuing their training and exercising during the COVID-19 isolation period to maintain their physical fitness level and prevent injury levels once they are back on the field to play matches and competitions. Squats, lunges, Nordic hamstring, and Copenhagen adduction exercises were amongst the most applied exercises. These findings suggest that young age groups and high athletic levels represent a higher proportion of respondents in the study who reported training during the isolation period.

Conflict of Interests

The authors declare no conflict of interest.

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ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2021; 28(**2**): 117-125
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.2-5

Association between team sports and anxiety with reaction time of individuals with visual impairment versus individuals with normal vision

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Abstract
Reaction time plays a major role in the functioning of every human being. The purpose of this study was to investigate the correlation between sports and anxiety in visually impaired individuals compared with people with normal vision. In this study 79 subjects who participated were divided into four groups. Two instruments were used. The first was a self-report questionnaire, the Symptom Rating Scale for Depression and Anxiety, which aimed to investigate anxiety. The Optojump Next was the other instrument which measured reaction time in real conditions. The results showed that sports influence reaction time positively, whereas a visual impairment influences reaction time negatively. Finally, it was shown that there was a correlation between anxiety and reaction time. Research findings show that sports improve reaction time. Improving reaction time is useful for people with special needs, including visually impaired people, as it can enhance their autonomy and functionality.

KEYWORDS: goalball, soccer, visually impaired athletes, non-blind athletes, auditory stimuli.

Received: 3 July 2020
Accepted: 18 March 2021

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Introduction

People receive a multitude of stimuli from their environment and are expected to react to them [34]. Reaction time is the time between the appearance of a stimulus and a person's onset of action [27]. Cognitive, perceptual and kinetic functions need to be involved in reaction time [27]. More specifically, a person has to process the stimulus, decide what the appropriate action is, and respond appropriately [27, 31]. There are three types of reaction time: simple reaction time, choice reaction time and recognition reaction time [19, 27, 32]. Simple reaction time is a response to a stimulus [27, 32]. Choice reaction time is a reaction corresponding to a given stimulus [27, 32], whereas in recognition reaction the person has to react to some stimuli and not to others [19]. The stimuli, to which a person reacts, can be visual, auditory or haptic [15, 24]. Visual stimuli incur a reaction to light, auditory stimuli to sound and haptic stimuli to touch. Reaction time to visual stimuli is about 180-200 ms, whereas to auditory stimuli it is about 140-160 ms [21]. Reaction to an auditory stimulus is faster than reaction to a visual stimulus, as the auditory stimulus needs half the time to reach the brain [19]. Reaction time plays an important role also in sports. People that do not practice sports have a worse reaction time than people who do [17, 31]. Exercise may influence and improve reaction time, which can be reduced by 0.12 seconds when the person changes their technique [17]. There are many factors that influence reaction time. Specifically, age is one of these factors [33]. At the age of 9 and 10 there is the greatest development of reaction time [17], whereas after 65 years of age there is a large increase in reaction time [19].

Anxiety is also related to reaction time. General anxiety affects body reactions. When a teenager has symptoms of generalized anxiety he/she may develop generalized anxiety also as an adult [22]. An intense activation in the brain is often correlated with anxiety [13, 14]. People with high anxiety levels may show better performance in an easy activity [7]. When a person suffers from anxiety their reaction time in the case of a normal stimulus may be slower than to a negative stimulus [5]. Before a game the level of anxiety is often smaller than after the game [7]. The reaction time of an athlete is often faster due to brain activation [7]. The more anxiety a person feels, the slower the reaction time is; there is a statistically important negative correlation between the two. The experience of anxiety may cause a lessening of brain activation and there is a correlation between anxiety and loss of control [26]. Athletes who may show less anxiety and better reaction time before the game, might also show higher performance in agility [7].

Audition plays an important role for people generally, and especially for people with visual impairments, influencing their integration in the society [3]. Touch and audition may create internal representations of a part of what one could see [20]. Due to the lack of vision, a blind person learns to make better use of the other two basic senses: touch and audition, which may partially replace vision [12, 20]. Touch and audition in blind people may activate the visual cortex [35]. Blind people participate in various sports, such as football, goalball and running. The motor skills of blind people depend on the other two senses: audition and touch. For example, instructions from their coaches are mainly auditory [2]. When the stimulus cannot be understood by an athlete due to blindness, it must be replaced by another stimulus that can be understood [38]. Regarding blindness and reaction time, some researchers mention that there are no statistically significant differences between people who have lost their vision at birth and people with typical vision in simple reaction time to auditory stimuli [8, 9]. However, the small differences that exist showed that blind people who lost their vision at birth are faster [8, 9]. Reaction time in the case of auditory and haptic stimuli may be faster in blind people who have lost their vision at birth, especially in orienting exercises in space [9]. It is worth mentioning that blind people who have lost their vision at birth often show better performance in exercises that demand audio recognition when compared to people with typical vision [9, 12]. Blind people often show better performance at perceptual processes, such as reaction time to auditory stimuli, from people with normal vision [30]. When an auditory-tactical stimulus occurs near the person with visual impairment, the person often reacts faster [10]. There are no studies in literature that show the influence of physical exercise in blind people [2]. It is also mentioned that simple reaction time to auditory stimuli in subjects with partial blindness is often slower than in subjects with normal vision [16]. In turn, reaction time for totally blind people is often faster than for people who are partially blind [16].

Lack of vision may also lead to the development of anxiety. Everyday life of people with lack of vision, and especially of older people, often causes more anxiety than that of people with normal vision [4, 18, 25, 36]. An appropriate treatment, for example some activities, can prevent anxiety [37]. The changes that take place in the bodies of teenagers with normal vision due to their adolescence can cause anxiety that does not occur in visually impaired teenagers [4].

Aim of Study

Taking into consideration the information that has already been mentioned an interesting question would be how sports and anxiety correlate with reaction time of people with visual impairment in comparison with people with typical vision. The present research aims to answer the above main question. The research is designed to investigate also the correlation between age and drills, differences between the dominant and non-dominant hand, differences in reaction time among the four groups, and finally differences between the above-mentioned sports.

Methods

Participants

This study was conducted with the participation of people visually impaired and people with normal vision. We used a convenience sample in our research, as we visited places where people with severe visual impairment or totally blind live. More specifically, the total population sample for this study was 79 people who were divided into four groups. The people were aged from 18 to 59 years old. There were 65 males and 14 females in total. In the first group there were 20 visually impaired people (mean 30 years old) who were also athletes (8 athletes practicing goalball, 12 athletes playing soccer, 18 right handed, 2 left handed) (AVI). In the second group there were 19 non-athletes totally blind (NATB) (18 right handed, 2 left handed, mean

27 years old). The third group comprised 20 people with normal vision (mean 28 years old) who were also athletes (9 athletes playing soccer, 11 athletes playing handball, 17 right handed, 3 left handed) (ANV). Each group consisted of both men and women. Handball was selected as it has many similarities with goalball. For example, in both sports athletes shoot the ball with their hands in order to score a goal. The fourth group included 20 non-athletes with normal vision (NANV) (17 right handed, 2 left handed, mean 30 years old). Goalball and soccer were selected as these sports are the most popular in Greece for blind people. The level of the athletes was the same and all of them played in a regional team. The level of the visual impairment of the people was already rated and each person gave us the final assessment. The group of athletes had severe visual impairment, whereas the group of non-athletes were totally blind. All the data were collected by the researcher.

Instruments

Two instruments were used for the research. The first was a self-report questionnaire. The questionnaire was the Symptom Rating Scale for Depression and Anxiety, which was translated and validated in Greek [11], (α = 0.816) This questionnaire concerns depression, anxiety, melancholy, asthenia and mania; however, for this research we used only the sections related to depression and anxiety. The other instrument was the Optojump Next (Optojump Next, Microgate, Bolzano, Italy) which measures reaction time in real conditions (α = 0.715). This instrument has photocells which measure reaction time, from the moment when the audio stimulus is heard until the time the subject raises their leg from the ground. For reaction time in real conditions two exercises were included: shoot of the ball and contact with the ball. We selected these two skills in order to measure the body reaction time. In the exercise when the subject has to shoot the ball, the instrument measures the time between the appearance of an audio stimulus until the time the leg is raised from the ground to shoot the ball. The ball was 20 cm away from the subject. The exercise must be performed when the subject hears the audio stimulus. Two skills were involved with both right and left feet. There were 5 trials, but prior to the test there were some preliminary trials in order to familiarize the subject with the instrument.

Procedure

We sent an informed consent form to the Center for Education and Rehabilitation for the Blind (CERB) in Thessaloniki in order to contact visually impaired individuals and ask them if they wanted to participate in the research. The study was conducted in a quiet room so the people who were visually impaired could hear the audio stimuli. The questions were read out loud by the researcher and the participant had to answer orally. After they had answered the questionnaire, the same day we met at their training court and the researcher measured the participant's reaction time in real conditions. Reaction time in real conditions is the simple reaction time, the response to one stimulus [29]. The reaction time in real conditions was measured at the places that the athletes practiced their sports (soccer arena, goalball court). For the people who were non-athletes the reaction time was measured in a sport complex. Reaction time in real conditions was the interval between the appearance of the audio stimulus and the moment when the leg was risen from the ground to shoot and meet the ball. Finally, the researcher collected some demographic traits for every subject such as sex, age.

Statistical analysis

Quantitative data analysis was performed. For the analysis of the results, descriptive statistics was used first for the demographic characteristics, in order to calculate means and standard deviations. In order to investigate any correlations between the variables Pearson's correlation test was used. To explore differences among the means for various sports, the Independent t-test was applied, whereas to investigate differences between the four groups regarding their reaction time and psychopathology characteristics, variance analysis with an intersubjective factor was used, while for paired comparison testing the Bonferroni test was applied. These methods were selected, as the objective of the study was to identify differences between the groups and correlations between age and the variables. SPSS was used in order to analyze our data.

Results

The correlation of age compared to the reaction time of athletes and non-athletes with visual impairment and normal vision

A statistically positive correlation was found between the age of individuals with reaction time in the drill of making contact with the ball with the right foot after a bilateral test was performed, with $r = 0.35$, $p = 0.03$. There was no statistical significance between the other variables and age.

Comparison of the two sports regarding reaction time within the group of athletes with visual impairment

In order to explore differences between the sports in the reaction time of individuals with visual impairment, the Independent t-test was used. A statistically significant difference was found between the two sports in the reaction time of shooting with the right foot in the first group (AVI) after a bilateral test was performed t(18) = = 3.65, p = 0.00. More specifically, a longer reaction time in shooting with the right foot was demonstrated by soccer athletes (M = 0.53, SD = 0.12) in comparison with goalball athletes (M = 0.40, SD = 0.03). A statistically significant difference was found between the two sports in the reaction time of making contact with the ball with the right foot in the two sports after a bilateral test was performed t(18) = 2.62, p = 0.02. Soccer athletes (M = 0.52, SD = 0.12) demonstrated also in this case a longer reaction time than goalball athletes (M = 0.42, SD = 0.05). A statistically significant difference was found between the two sports in the reaction time of making contact with the ball with the left foot, after a bilateral test was performed t(18) = 2.81, p = 0.01. The soccer athletes with visual impairment (M = 0.54, SD = 0.12) demonstrated again a longer reaction time compared to the goalball athletes (M = 0.43, SD = 0.06) (Table 1).

Table 1. Differences in reaction time among athletes with a visual impairment depending on the type of sport

	Type of sport	Mean	Std. Dev.	t	p
Shot with right foot	soccer	0.52	0.12	3.65	0.00
	goalball	0.40	0.03		
Shot with left foot	soccer	0.50	0.14	2.09	0.05
	goalball	0.41	0.04		
Reception with right foot	soccer	0.52	0.12	2.62	0.02
	goalball	0.42	0.05		
Reception with left foot	soccer	0.54	0.12	2.81	0.01
	goalball	0.43	0.06		

Comparison of the two sports regarding the reaction time within the group of athletes with normal vision

To investigate the differences between the sports in the reaction time of athletes with normal vision, the Independent t-test was used. Regarding the third group (ANV), statistically significant differences were found again between soccer and handball in the reaction time of shooting with the right foot, after a bilateral test had been performed t(18) = 2.74, p = 0.01. The reaction time in soccer (M = 0.40, SD = 0.04) was longer than the reaction time in handball (M = 0.35, SD = 0.03). Statistically significant differences were found between soccer and handball in the reaction time of shooting with the left foot, after a bilateral test was performed t(18) = 2.46, p = 0.02. The reaction time in soccer (M = 0.40, SD = 0.04) was longer than the reaction time in handball (M = 0.35, SD = 0.04). No statistically significant differences were found between soccer and handball in the reaction time of making contact with the ball with the right and the left foot, respectively (Table 2).

Table 2. Differences in reaction time among athletes without visual impairment depending on the type of sport

	Type of sport	Mean	Std. Dev.	t	p
Shot with right foot	soccer	0.40	0.04	2.74	0.01
	handball	0.35	0.03		
Shot with left foot	soccer	0.40	0.04	2.46	0.02
	handball	0.35	0.04		
Reception with right foot	soccer	0.41	0.03	1.8	0.9
	handball	0.38	0.05		
Reception with left foot	soccer	0.42	0.04	1.31	0.21
	handball	0.40	0.05		

Anxiety in correlation to the reaction times in the 4 groups of individuals

In terms of the correlation of anxiety with field reaction time, Pearson's correlations were used. A statistically positive correlation was demonstrated between the reaction time of shooting with the left foot and anxiety, after a bilateral test was performed with r = 0.22, p = 0.05. The bilateral test showed a statistically positive correlation between the reaction time of making contact with the ball with the right foot and anxiety, with r = 0.22, p = 0.05. No statistically significant difference was found between the reaction time of making contact with the ball with the left foot and anxiety. There was no statistically significant difference between each group and anxiety.

The relationship of anxiety with reaction time for the group of athletes with visual impairment

Regarding the investigation of anxiety in relation to the field time, Pearson's correlations were used. No statistically significant correlation was found between the reaction time of making contact with the ball with the right and the left foot and anxiety.

Correlation of anxiety with reaction time for the groups of athletes with normal vision

The correlation of anxiety with field reaction time for athletes with normal vision was investigated using Pearson's correlations. A weak statistically significant correlation was found between the reaction time of shooting with the right foot and anxiety, with r = 0.42, p = 0.06. A bilateral test showed a statistically positive correlation between the reaction time of shooting with the left foot and anxiety, with r = 0.47, p = 0.05. There was a weak positive correlation between the reaction time of making contact with the ball with the right foot and anxiety, as shown by the bilateral test with r = 0.43, p = 0.06. A weak statistically positive correlation was found between the reaction time of making contact with the ball with the left foot in relation to anxiety after a bilateral test was performed with r = 0.44, p = 0.05.

Comparison of the reaction time in each group

In order to investigate the differences between the groups in the reaction time and the personality traits and psychopathology characteristics, variance analysis was performed with an intersubjective factor, the population, at four levels, i.e. the four groups of the sample population. The analysis was carried out separately for each group of the population.

Field reaction time in shooting with the right foot – group comparison

It should be reported that there are statistically significant differences between the four groups of the sample in the reaction time of shooting with the right foot, with F(3.75) = 6.96 and p = 0.00. The Bonferroni paired comparison testing showed that the first group of the sample (AVI) in the field drill with the right foot did not demonstrate any statistically significant differences compared to the second group (NATB). Nevertheless, statistically significant differences were found (p = 0.03) between AVI (M = 0.44) compared to ANV (M = 0.37). There was no statistically significant difference between the first group (AVI) compared to NANV. Statistically significant differences were demonstrated between the second group (NATB) (M = 0.49) compared to the third group (ANV) (M = 0.37) (p = 0.00).

Field reaction time in shooting with the left foot – group comparison

It should be reported that statistically significant differences were found between the groups in the reaction time of shooting with the left foot, with F(3.75) = 9.86 and p = 0.00. The Bonferroni paired comparison testing showed that the first group of the sample (AVI) in the field drill with the left foot did not demonstrate any statistically significant differences compared to the second group (NATB). Statistically significant differences were demonstrated between the group of AVI (M = 0.44) compared to ANV (M = 0.37) (p = 0.02). There were no statistically significant differences between the first group (AVI) compared to NANV. Statistically significant differences are demonstrated again between the second group (NATB) (M = 0.51) compared to the third group (ANV) (M = = 0.37) at p = 0.00. There were statistically significant differences between the second group (NATB) (M = = 0.51) compared to the fourth group (NANV) (M = = 0.42) at p = 0.00. The comparison between ANV in relation to NANV showed no statistically significant differences (Figure 1).

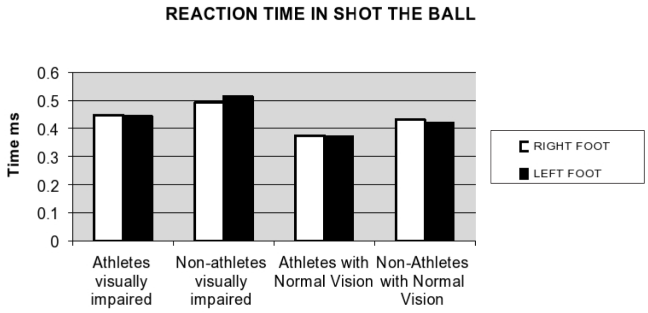

Figure 1. Differences in reaction time among the four groups in shot the ball with right and left foot

Field reaction time in making contact with the ball with the right foot – group comparison

It should be reported that statistically significant differences were found between the groups in the reaction time of making contact with the ball with the right foot, with F(3.75) = 11.43 and p = 0.00 (Figure 2). The Bonferroni paired comparison testing showed that the group (NATB) (M = 0.56) compared to (AVI) (M = = 0.46) demonstrated statistically significant differences (p = 0.00). The comparison between the group of AVI with the group of ANV did not show any statistically significant differences. Furthermore, no statistically significant differences were found between the first group (AVI) with the group of NANV. Statistically significant differences were demonstrated between the second group (NATB) (M = 0.56) compared to the third group (ANV) (M = 0.39) (p = 0.00). Statistically significant differences were demonstrated between the second group (NATB) (M = 0.56), compared to the fourth group (NANV) (M= 0.46) (p = 0.00).

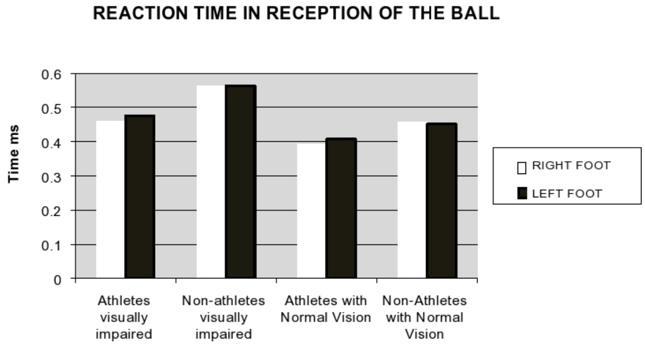

Figure 2. Differences in reaction time among the four groups in reception of the ball with right and left foot

Field reaction time in making contact with the ball with the left foot – group comparison

It should be reported that statistically significant differences were found between the groups in the reaction time of making contact with the ball with the left foot (F(3.75) = = 10.94; p = 0.00). The Bonferroni paired comparison testing showed that between the group of NATB (M = 0.56) and the group of AVI (M = 0.47) statistically significant differences were demonstrated (p = 0.00). In contrast, no statistically significant differences were found between the group of AVI compared to the group of ANV or the group of NANV. Statistically significant differences were shown between the second group (NATB) (M = 0.56) and the third group (ANV) (M = 0.41) (p = 0.00). There were statistically significant differences between the second group (NATB) (M = 0.56) and the fourth group (NANV) (M = 0.45), (p = 0.00). The comparison between the group of ANV in relation to NANV did not show any statistically significant differences.

Discussion

It is reported in the relevant literature that age plays a major role in the reaction time of adults; more specifically, as a person grows older his/her reaction time increases, whereas the younger a person, the shorter his/her reaction time [17, 19]. The fact that age shows a correlation with the reaction time of an individual in real-life conditions was only confirmed in the case of field reaction time in the drill of making contact with the ball with the right foot in the population sample with normal vision. In the other drills of reaction time there was no correlation with the age of the individuals. This may be due to the fact that, since the drill of making contact with the ball was more demanding, and when combined with the change from the drill of shooting the work of the participants became more difficult and thus, at this point, correlations were demonstrated with the age of the participants. Another possibility is that the size of the population sample of individuals participating in the study has an impact. In the study two sports were used in each group that consisted of athletes. Differences were identified between the two sports; while it may have been expected that soccer players are faster, since the drills were taken from this specific sport and they were more familiar with them, the opposite was observed. The relevant literature referring to differences in the reaction time between sports is rather scarce. In more detail, individuals with visual impairment who played goalball showed a faster reaction time than soccer athletes in the drill of shooting with the right foot, in the drill of making contact with the ball with the right and the left foot, respectively. Handball players with normal vision showed a faster reaction time than soccer athletes with normal vision. More specifically, the group with normal vision showed a faster reaction time in handball, in the drill of shooting with the right and the left foot. This was possibly due to the fact that in the first group (AVI) the mean age of the soccer players was relatively higher than the mean age of athletes who played goalball. Nonetheless, in the population with normal vision the group of handball players was of an older age, and also had a faster reaction time in relation to the group of soccer athletes. This is possibly due to the sport, which is different from soccer; therefore further research is required in order to investigate the reaction time in soccer compared to handball and other sports.

Next anxiety was investigated in relation to the reaction time of individuals. Anxiety shows a direct correlation with hypervigilance [26]. When a person is characterized by anxiety, the reaction time to a natural stimulus is longer than the reaction time to a negative stimulus [5]. Regarding anxiety before a match, the longer the anxiety, the longer the reaction time, showing a statistically significant correlation [7]. Athletes who showed less pre-match anxiety and faster reaction time were those who showed longer motor performance [7]. The argument that there is a positive correlation of anxiety with reaction time was partly confirmed by the research findings. More precisely, in the four groups overall a positive correlation was identified between anxiety and the reaction time of shooting with the left foot, making contact with the ball with the right foot, and the reaction time for the right and the left hand. In the group of athletes with normal vision a positive correlation was detected between anxiety and the reaction time of shooting with the right and the left foot. When it comes to the investigation of differences between the four groups of individuals, and whether blindness affects the reaction time, the findings showed that there was a statistically significant difference between ANV and AVI in the field reaction time of shooting with the right and the left foot. The ANV group had a faster reaction time. To the best of my knowledge, no relevant literature has been found regarding the above finding, thus this specific result may not be fully substantiated. In literature it is reported that individuals who are born blind sometimes perform better in activities that require sound recognition than individuals with normal vision, as the former become familiar with the sounds more quickly [9, 12]. Individuals with blindness demonstrate better perceptual processes such as reaction time to auditory stimuli, when compared to individuals with normal vision [30]. When an audio-tactile stimulus is near a visually-impaired person, that person responds faster to such sounds [10]. It is also reported that the standard reaction time to auditory stimuli in partially blinded subjects is longer than in subjects with normal vision [16]. Nevertheless, there are several studies that do not identify any differences in terms of standard reaction time between visually impaired individuals and individuals with normal vision [8, 9]. The findings of this study contradict most literature sources. The above finding can possibly be justified first by the fact that the sample population with visual impairment that was used in this study did not consist exclusively of blind individuals, but also of individuals with severe visual impairment. Another argument to substantiate the finding that ANV demonstrated faster reaction time than AVI is the fact that the sample population used in the study was specific and limited. Statistically significant differences were identified between NATB and NANV. This finding was identified in the field drills of shooting with the left foot and making contact with the ball with the right and the left foot. In these cases NANV were faster. In terms of the effect of sports on the reaction time of individuals, the findings showed statistically significant differences between NAVI and AVI. The AVI participants were faster in the field drill of making contact with the ball with the right and the left foot. Statistically significant differences were also identified between NATB compared to NANV. In turn, ANV were faster in all the field drills than NATB, except for the comparison of AVI with NANV, where the visually impaired dominated, while the individuals with normal vision were faster.

According to literature, practice improves reaction time in athletes [19, 31]. Through athletic drills and thanks to sports reaction time can be improved by 0.12 seconds [17], which is the reason why athletes appear to be faster. The literature agrees with the findings, since it is reported that sports play an important role in the everyday life of any person, and the same applies to his/her mental functions. Individuals who are involved in sports demonstrate statistically faster reaction time compared to those who are not involved in sports [1, 17, 23, 31]. There is a statistically significant difference in the reaction time after auditory stimuli between athletes and non-athletes who play soccer [28]. There is a statistically significant difference in terms of auditory stimuli between professional athletes, amateur athletes and non-athletes regarding their physical reaction time [6].

This study had also some limitations. For instance, a convenience sample was used, as we visited a specific place where people with severe visual impairment or blind people live. We also measured their achievement in specific sports, such as goalball and soccer. Moreover, our study was a cross-sectional study. Future researchers can measure athletes' achievement in more cases in a year.

Conclusions

In terms of the practical implication of research findings it should be noted that the level of blindness influences reaction time in sports, since it enhances the reaction time and can improve it. In the field of sports reaction time plays a prominent role, since it is one of the factors that affect the final performance of a person. Anxiety is also a trait that people cope with in their everyday life, including sports. It should be reported that individuals with no impairment as well as individuals with special needs (e.g. blind, deaf) can become more functional, independent and calm in their everyday life, provided that they have developed their reaction time.

Conflict of Interests

The authors declare no conflict of interest.

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ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2021; 28(**2**): 127-135
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.2-6

Could socks play an active role in ankle sprain prevention? A preliminary investigation

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Abstract
Introduction. **Ankle sprain represents about 10% to 30% of all recorded musculoskeletal injuries, and is one of the most prevalent injuries in sports. Thus, any type of intervention based on prevention is extremely important to reduce its incidence.** Aim of Study. **To compare the immediate effect of three different types of socks, namely standard, compression, and Prevent Sprain Technology (PST) socks, on the dynamic unipodal balance and ankle joint position sense in healthy participants.** Material and Methods. **Forty-two healthy adults, aged 20.34 ± 1.69 years old, volunteered to participate in the study. Participants were randomly assessed using three different sock models. The main measured outcomes selected for this study were the dynamic balance using the Biodex Balance System®, and the active ankle joint repositioning movement through the Biodex System Pro 4®. We used the Friedman test to compare the variables under study among the three conditions, with Dunn's post-hoc analysis and a significance level of 0.05.** Results. **In the Biodex Balance System® the participants had a lower Global Instability Index value with the PST socks compared to compression socks (p = 0.031), and standard socks (p = 0.005), but only lower anteroposterior (p = 0.042) and mediolateral (p = 0.026) instability indices when compared to standard socks. Regarding the ankle joint position sense, subjects with PST socks revealed lower absolute errors compared to standard socks (p = 0.007), smaller minimum errors compared to compression socks (p = 0.049), and smaller maximum errors compared to compression socks (p = 0.049) and standard socks (p = 0.008). Analysis of relative errors revealed a significant miss regarding the target joint position at higher inversion angles only with standard socks (which is potentially more dangerous) when compared to PST socks (p = 0.031), which error tends to be at lower inversion angles (which is potentially less dangerous).** Conclusions. **The PST socks seem to have a global positive influence on the mechanisms underlying the dynamic unipodal balance and active joint position sense, which could be an important tool for ankle sprain prevention.**

KEYWORDS: Prevent Sprain Technology socks, compression socks, proprioception, joint position sense, unipodal dynamic balance.

Received: 11 May 2020
Accepted: 16 February 2021

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Introduction

Ankle sprain is the most prevalent sports injury [10] and is estimated to represent 10% to 30% of all musculoskeletal injuries [9]. Its mechanism of injury involves a sudden movement of the ankle beyond its normal range of motion, commonly associated with ankle inversion movement, affecting several joint structures [9]. The importance of ankle injury is evident due to its socio-economic impact. Indeed, it is estimated that in the United States alone there are more than 2 million ankle sprains per year, resulting in an annual expenditure of $3.65 billion [20]. At the same time European countries,

such as e.g. the Netherlands, face the same challenge, where ankle sprains are associated with costs of around €43 million per year [26], reinforcing the importance of developing prevention strategies.
It is important to recognize the risk factors associated with this injury to implement preventive measures. In addition to intrinsic risk factors, such as postural control deficits [18], a decreased dorsiflexion range of motion [11], and a reduced joint position sense in active and passive inversion movements [15], some authors suggest extrinsic risk factors, such as the non-implementation of a proprioceptive exercise program [27] and not using external supports (orthoses and functional taping) [6]. However, orthoses and functional taping are not always used as preventive methods, because athletes often report them as uncomfortable and refer changes in the technical landing gesture [13]. Thus, even athletes who present some risk of injury do not use any external preventive method. Instead, they use standard or compressive socks as an interface between the foot and footwear. Although during the rehabilitation period they accept orthoses or bandages, athletes often return to wearing only standard socks during practice. Thus, external methods that more closely resemble the characteristics of a sock may be more easily accepted by athletes [13]. However, the effect of socks on postural and ankle stability is not well understood yet. Indeed, there are few studies in this field. In a recent research, a novel ankle-realigning sock immediately improved dynamic postural stability in a subjective ankle instability scale in individuals with chronic ankle instability [16]. Moreover, You et al. [30] found that a circumferential ankle pressure applied above the talocrural joint (to allow unrestricted ankle movement) seems to provide an additional tactile stimulation around the ankle, which reveals improved proprioceptive acuity, active stiffness in the ankle and thus, also postural stability. Nonetheless, Jaakkola et al. [12] found no differences between groups which performed 8 weeks of exercise of static and balance and postural control, leg strength and agility training, using three different types of socks, recommending further investigation examining the effects of wearing socks on motor behavior. In fact, proprioceptive information is essential for the preparation, maintenance, and restoration of stability of both the entire body (postural stability) and the segments (joint stability) [22]. This information coming specifically from receptors in the skin and the skeletal muscle system from the ankle-foot complex allows adjustments to be made in ankle position and proximal joints to successfully perform the complex motor tasks required in sports [23].

Aim of Study

The aim of this study was to compare the immediate effect of three different types of socks available in the market, namely standard, compressive, and Prevent Sprain Technology (PST) socks on the unipodal dynamic balance and the active joint position sense of the ankle in healthy participants.

Material and Methods

Participants

This is a cross-sectional study with a convenience sample. Forty-two healthy higher education students of both sexes, aged between 18 and 25 years, were included in this research. To be included in this study volunteers had to participate in mild or moderate levels of physical activity as assessed through the International Physical Activity Questionnaire (IPAQ), have fewer than four “Yes” responses in the Ankle Instability Instrument to ensure that participants had no functional ankle instability [6], and have an absence of mechanical ankle instability, tested through the anterior drawer test by an expert physiotherapist. All participants with musculoskeletal, neurological, or visual dysfunctions were excluded. At the same time, participants using common medication that directly interfered with postural control or joint position sense were also excluded. Furthermore, any participant considered an outlier regarding the range of motion was excluded, since this characteristic could affect the tasks assessed in the study. The current investigation was approved by the local Ethics Committee (EC-3392) and all the participants provided their informed written consent based on the Declaration of Helsinki.

Instruments

Dynamic balance was assessed using the Biodex Balance System® (model 950-441, United States, Biodex Medical Systems, Inc.). The Biodex Balance System used to assess postural stability consists of a movable balance platform that provides up to 20° of surface tilt over a 360° range of motion. The movable balance platform includes coordinate lines to standardize foot position on the platform and a sensing mat to record the position. The balance assessment and/or training platform measure the degree of inclination on each axis: the sagittal plane (anterior/posterior) Y-axis and the frontal plane (medial/lateral) X-axis, providing an average oscillation score in degrees. This instrument makes it possible to modify the degree of freedom of movement of the surface through twelve levels of instability, programmed according to the degree of difficulty to be used, and to evaluate two types of support, i.e. bipodal and unipodal. It provides valid, reliable, and objective measurements, in which three indices are described: global, anterior/posterior, and medial/lateral instability. Platform reliability was obtained by a calculation having the intraclass correlation coefficient reach (ICC): 0.881, which is in agreement with the Hinman study with a 95% confidence interval and an intraclass correlation coefficient of (ICC): 0.81 [12].

The joint position sense was assessed by the Biodex System Pro 4 ® (United States, Biodex Medical Systems, Inc., Shirley, NY). This instrument facilitates evaluation of the joint position sense and provides valid, reliable, reproducible and objective measurements. The reliability of the joint position sense in the isokinetic dynamometer was obtained by calculating the intraclass correlation coefficient as (ICC): 0.95, similar to the study of Drouin et al. [7], which assessed the same variable with a 95% onfidence interval, and an intraclass correlation coefficient of (ICC): 0.99.

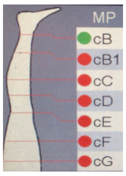
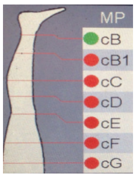
So as to assess the ankle dorsiflexion range of motion, bubble inclinometer (Baseline®, Fabrication Enterprises Inc., White Plains, NY) was used, and means of three measurements were obtained in a weight-bearing lunge [17].

In order to verify if the participants had any functional ankle instability, we used the Ankle Instability Instrument (AII), which is a reliable and valid tool [6]. The AII is organized into three components: severity of initial ankle sprain; history of ankle instability; and instability during daily life activities, and presents a total of nine closed (dichotomous) questions. The AII is confirmed by four affirmative answers, including the first question. This instrument presents ICC values ranging from 0.99 to 1.00 and a Kuder–Richardson coefficient of 0.79, suggesting a good internal consistency [24].

Sock features

Three types of socks were used in this study, all of them being commercially available in January of 2019. Table 1 provides information on the composition of

Table 1. Textile characteristics of socks under study [mean (standard deviation)]

Characteristics				
Textile fibers (composition expressed in the information leaflet for each model)	polyamide	72%	95%	90%
	cotton	26%	–	–
	elastane	2%	5%	10%
Structural properties	anti-slip material	No	No	Yes
	ankle restraint	No	No	Yes
Compression (mmHg)[a] 	cB	15.70 (1.93)	13.48 (0.19)	23.34 (0.21)
	cB1	9.96 (2.25)	13.24 (0.30)	16.38 (0.67)
	cC	18.56 (1.66)	12.72 (0.13)	16.02 (1.00)
	cD	27.76 (2.45)	14.38 (0.18)	14.34 (1.00)
Elasticity (cm)[b] 	cB	24.24 (0.15)	20.62 (0.13)	19.58 (0,08)
	cB1	25.68 (0.13)	20.18 (0.18)	23.10 (0.10)
	cC	26.26 (0.17)	21.16 (0.13)	25.08 (0.08)
	cD	19.18 (0.11)	23.14 (0.09)	25.56 (0.05)
	Total length[c]	106.24 (0.15)	70.14 (0.09)	81.14 (0.09)

Note: PST – Prevent Sprain Technology; cB – ankle region 1 cm above the malleolus; cB1 – region below the gastrocnemius muscle belly; cC – gastrocnemius muscle belly; cD – region 1 cm inferior to the popliteal fold

[a] MST MK V – device used for the assessment of compression – Swisslastic Ag, St. Gallen, Switzerland); [b] Electric Stretch Tester – device used for the assessment of elasticity – CETME, Italy); [c] overall length of stocking from toe to collar

each socks and the compression and elasticity per sock segment. Five measurements were made for each sock segment, and then the mean and standard deviation of these measurements were calculated. All measurements were made under the same temperature (24°C) and humidity conditions (60%).

Procedures

The study began with a detailed explanation of the procedures, as well as the delivery of informed consent and the International Physical Activity Questionnaire (IPAQ). During the procedures the researchers were always responsible for the same tasks in order to minimize the inter-observer error. A calm environment with controlled temperature was maintained in order to standardize the collection conditions. All assessments of balance and active joint position sense were preceded by a trial with the participant's personal socks to enhance familiarization with the procedures, as well as diminish the learning effect. Before starting the data collection, a bubble inclinometer, placed at 15 cm of the anterior tuberosity of the tibia, was used to evaluate the ankle dorsal flexion range of motion in the participant's dominant limb. With hands resting on a table and the dominant limb in front of the non-dominant, the participant was asked to reach the maximum dorsiflexion range of motion, moving the knee of the dominant limb in the anterior and inferior direction without allowing the heel of that foot to leave the floor. Data on the dorsal flexion range of motion under load was collected since the decrease of ankle dorsal flexion is considered a risk factor for ankle sprain [11]; this made it possible to conclude that the participants had no amplitude deficits, based on reference values, which could influence data collection [16].

Each participant was asked to perform three trials using each sock and the average value was used for the analysis. The order of the tests as well as the type of socks was randomly selected. The data was recorded in the Biodex Balance System using an instability level of 4 (level 1 is the most unstable and level 12 is the most stable); this level was selected to induce a significant instability, but at the same time it was attainable for all the participants. This analysis was based on preparatory procedures, such as positioning of the dominant foot (chosen to kick a ball) on the platform, with the foot in the same position during the three trials with the different socks to ensure that the center of pressure (CoP) remained centered with the visual reference on a display at 50 inches away from the participant at the eye level. This visual reference was only available prior to collection with the different socks and was not available during the trials. In each trial the participant was asked to remain as stable as possible for three sets of 20 seconds on a unipodal support, the support lower limb with 5° of knee flexion, the contralateral lower limb with 45° of knee flexion (measured with a Baseline® Universal Goniometer), hands on the waist, and eyes straight ahead. The recovery time between sets was 40 seconds, in which the participant remained seated on a bench, but

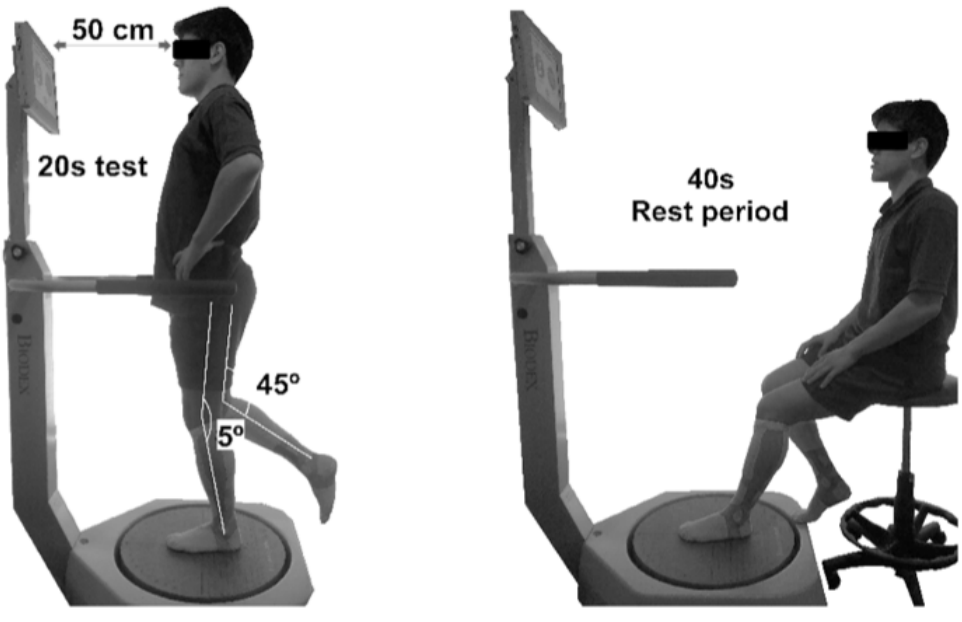


Figure 1. Experimental setup. Participant positioning on the Biodex Balance System – Dynamic Balance Assessment Procedure

with the dominant foot always in the initially defined position. Invalid testing was considered whenever the participant removed their hands from the waist or supported the non-dominant foot on the platform during the trial (Figure 1).

In the evaluation of the Active Joint Position Sense, the participant remained with the test member at 45º of knee flexion, keeping the tibia parallel to the floor and supported on the proximal third. The hip joint remained at 45º of flexion and the trunk supported on the backrest with 30º of inclination in relation to the ground. The ankle remained at 0º (plantar/dorsal flexion) and the test amplitude was defined between 15º of eversion and 30º of inversion. The participant remained blindfolded. The trials consisted of three sets of active joint repositioning, interspersed with 30 seconds of rest. Each set involved an active inversion movement (starting at the 15° eversion – start position) until the dynamometer was locked (at the 15° inversion – target position) and the participant had 5 seconds to memorize this position. Then, the researcher passively positioned the dynamometer again at 15º of eversion and asked the participant to actively assume the target position. When the participant expected to have reached the target position, they pressed a knob/switch that had been previously handed to them (Figure 2).

The order of evaluations was random for both the instrument used (Biodex Balance System or Isokinetic Dynamometer) and socks worn (standard, compression, or PST).

Statistics

The descriptive and inferential statistical analysis of the data was performed using the IBM software Statistical Package for the Social Sciences® (SPSS), version 24.0, which has a 95% confidence level (significance level of 0.05).

Regarding descriptive statistics, the mean value was used as a measure of central tendency and the standard deviation was used as a measure of dispersion. Nonparametric inferential tests were also used, since most variables did not follow normality, which was tested using the Shapiro–Wilk test. To compare the variables under study among the three conditions we used the Friedman test with Dunn's post-hoc analysis.

Results

No participants were excluded, thus the final sample consisted of 42 participants (30 male and 12 female).

Table 2. Sample characterization

	Mean	Standard deviation
Age (years)	20.34	±1.69
Height (cm)	173	±10
Mass (kg)	70.74	±15.49
Ankle dorsal flexion (degrees)	39.92	±4.64
IPAQ (MET – min/week)	4102.36	±3214.01

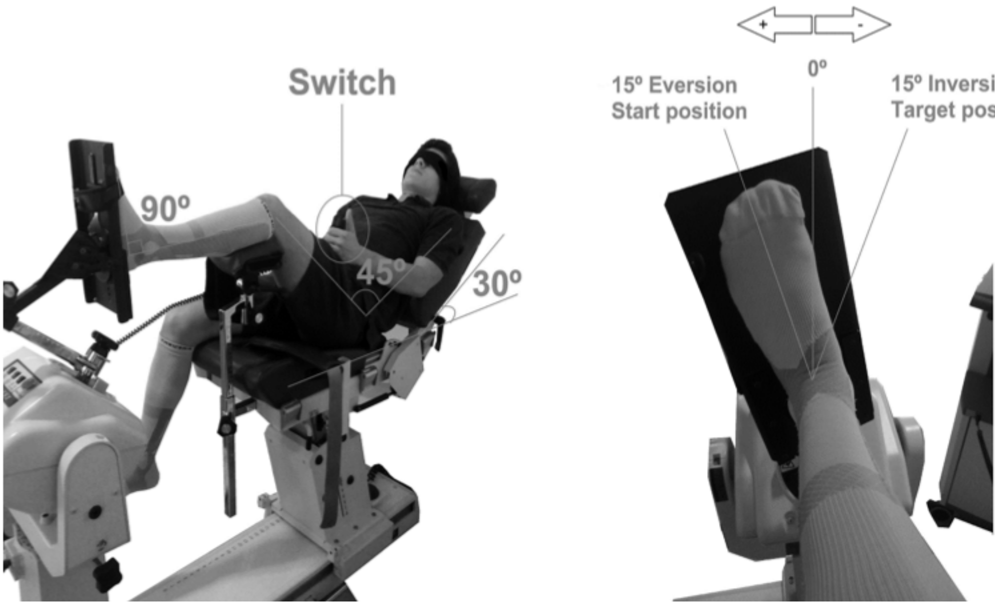


Figure 2. Experimental setup. Participant positioning on the isokinetic dynamometer for assessment of Active Joint Position Sensation Procedure

Table 3. Differences in instability indices and in the ankle joint position sense between different socks [median (interquartile range)]

		Standard (St) Median (IQR)	Compression (Cp) Median (IQR)	Prevent Sprain Technology (PST) Median (IQR)	Friedman test	p-value	Dunn's post-hoc
Instability indices variation (degrees)	global instability indices	2.000 (1.35)	2.100 (0.82)	1.900 (1.03)	11.937	p = 0.003	St > Cp (p = 1.000) **PST < Cp** (p = 0.031)* **PST < St** (p = 0.005)*
	anteroposterior instability indices	1.500 (1.23)	1.500 (0.80)	1.350 (1.03)	6.443	p = 0.040	St = Cp (p = 1.000) PST < Cp (p = 0.305) **PST < St** (p = 0.042)*
	mediolateral instability indices	1.050 (0.90)	1.000 (0.83)	0.850 (0.53)	8.680	p = 0.013	St > Cp (p = 1.000) PST < Cp (p = 0.100) **PST < St** (p = 0.026)*
Ankle joint position sense (degrees)	absolute errors	3.600 (1.80)	3.500 (3.20)	2.700 (1.83)	10.287	p = 0.006	St > Cp (p = 1.000) PST < Cp (p = 0.057) **PST < St** (p = 0.007)*
	minimum errors	1.650 (1.73)	1.350 (2.10)	0.700 (1.30)	7.176	p = 0.028	St > Cp (p = 1.000) **PST < Cp** (p = 0.049)* PST < St (p = 0.087)
	maximum errors	5.950 (4.08)	5.850 (4.50)	4.250 (2.63)	10.267	p = 0.006	St > Cp (p = 1.000) **PST < Cp** (p = 0.049)* **PST < St** (p = 0.008)*
	relative errors	–0.450 (5,83)	0.150 (5.68)	1.200 (3.60)	6.695	p = 0.035	St < Cp (p = 0.380) PST > Cp (p = 0.900) **PST > St** (p = 0.031)*

Note: St – Standard sock; Cp – Compression sock; PST – Prevent Sprain Technology sock
* significant differences between groups

Thirty-nine participants had the dominant right lower limb. Table 2 shows the sample characteristics, namely participants' age, anthropometric data, IPAQ classification and dorsal flexion range of motion.

Table 3 shows the instability indices measured on the Biodex Balance System and the ankle joint position sense with each of tahe sock models: standard, compression, and Prevent Sprain Technology (PST).

The participants had a significantly lower global instability index when they used the PST compared to the compression socks (p = 0.031) and the standard stocks (p = 0.005). They also had significantly lower anteroposterior and mediolateral instability indices compared to the standard stocks (p = 0.042 and p = 0.026, respectively).

The participants also had significantly lower absolute error level with the PST socks compared to the standard socks (p = 0.007). At the same time, when analyzing only the best (minimum error) and worst (maximum error) trials with each sock it was found that the PST allowed smaller minimum errors compared to compression socks (p = 0.049), as well as smaller maximum errors compared to compression (p = 0.049) and standard socks (p = 0.008). Analysis of relative errors revealed that participants assumed the target joint position at higher inversion angles with standard socks (potentially more dangerous) compared to PST socks (p = 0.031), which error was revealed to be at lower inversion angles.

Discussion

The aim of this study was to evaluate the immediate effect of socks on the dynamic balance in the unipodal support and on the active ankle joint position sense in healthy individuals in order to understand if they can bring additional protection to the ankle, i.e., an active protective role. To achieve this goal, three different types of socks available on the market were compared: standard, compression, and PST.

Participants improved their dynamic balance with PST socks, represented by the lowest values in the global index compared to the other socks. Furthermore, the anteroposterior and mediolateral instability indexes were also lower with PST, but only when compared to the standard socks. Additionally, PST socks positively influenced the joint position sense expressed by lower absolute, maximum, and minimum errors compared to the other sock models. The relative error associated with PST socks was recorded at a significantly lower inversion amplitude when compared to the standard sock, which may be indicative of a possible protective factor.

It is necessary to consider some methodological considerations in order to analyze the results. Our sample consisted of healthy and "active" participants classified by IPAQ and we assessed their dominant limb. Thus, the interpretation of the results is dependent on these characteristics of the sample. It is not known what the results would be if the study were conducted in sedentary individuals and/or those with chronic ankle instability.

Furthermore, it is also important to mention that the preparation, maintenance and restoration of stability in both the entire body (postural stability) and the segments (joint stability) are processes underlying the execution of all motor tasks [22]. According to Riemann and Lephart [22], the process of maintaining joint stability during human movements (functional joint stability) is accomplished through a complementary relationship between static and dynamic components. Ligaments, the joint capsule, cartilage, friction and the geometry within the joint comprise the static (passive) components. Thereby, dynamic contributions arising from the feedforward/feedback neuromotor control and the use of taping, bracing or high-top shoes have been described to provide active and passive/mechanical ankle stability, respectively [22]. Thus, we believe that the results of this study, expressed by a lower CoP dispersion with the PST during dynamic balance assessment, could be explained by the ankle restraint provided by the sock model not only in terms of the mechanical support they provide (because of the higher fiber resistance in the ankle area), but also in facilitating the activation of structures responsible for proprioceptive ankle mechanisms. This mechanical support in the ankle structures seems to allow better biomechanical alignment of the ankles, thereby optimizing the functions of the proprioceptive ankle structures [2]. Similarly, active stiffness contributes to ankle and postural stability and is provided by muscle excitation, recruitment and reflex behavior [19]. Although the stability values are better in PST than in compression socks, no significant anteroposterior or mediolateral differences were found when compared with compression socks. Therefore, it may be speculated that ankle pressure could increase stiffness by activating the proprioceptive reflex system. This hypothesis is based on the fact that ankle stiffness is greatly influenced by the reflex response [25]. Furthermore, some studies that compared the effects of visual, vestibular and proprioceptive stimuli on ankle stiffness in healthy individuals concluded that proprioceptive stimulation alone could generate substantial active ankle stiffness to stabilize the standing posture [8].

In the ankle joint position sense assessment, the 15º of unloaded inversion is in accordance with existing studies, which argue that it is this amplitude that leads to a greater risk of ankle sprain [21]. The PST globally presented the lowest values in the evaluated variables (absolute difference, maximum and minimum errors) of measurement in comparison with compression and standard socks. Spanos et al. [25] evaluated the ankle joint position sense, with and without an elastic bandage on the ankle, in a population of 4 women and 16 men, with an average age of 23 years and with a history of grade 1 or 2 sprains. They evaluated the plantar flexion (10º and 30º) and inversion (5º and 20º) movements of the ankle through an electrogoniometer (XM 180) in an unloaded position. The results with the use of anelastic bandage presented a reduction in the dispersion values, i.e., better sensation of the ankle position, compared to the participants who did not use a bandage.

The PST socks have a heterogeneous physical structure (Table 1) compared to compression socks and standard socks. The tensile strength provided by the PST material and the tension bands it presents, limiting inversion/eversion movements, possibly make the ankle limited to a dynamic range of motion. Thus, it is hypothesized that skin contact with PST may enable a tactile sensory input that stimulates cutaneous mechanoreceptors [3]. This input vertically ascends through the dorsal spinal cord to later be projected to the brainstem, cerebellum and cerebral cortex, via the thalamus [3]. At the cortical level the tactile information is processed, organized, and interpreted, resulting in descending commands that adjust the motor behavior [3]. According to Kennedy [14], cutaneous mechanoreceptors are preferentially sensitive to time-space stimuli, such as velocity, acceleration and intensity, thus contributing to a decrease in mechanical oscillations of the ankle joint [28]. According to Cordova [4], this increase in skin information and feedforward mechanisms are responsible for a pre-activation of the peroneus longus, leading to an increased dynamic control of the ankle joint during the movement. Although muscle mechanoreceptors and cutaneous receptors are known to be responsive to pressure, it was impossible to elucidate the relative functional contribution of pressure to different sensory receptors [1].

The PST socks also have an anti-slip surface at their base, which may allow for more continuous afferent stimuli to be sent, possibly improving the proprioceptive response. Therefore, these preliminary results, consistent with those obtained by Kobayashi et al. [16], suggest that dynamic postural stability could be improved by wearing a "special sock".

This study had the following limitations. First, the difficulty in ensuring participant blindness regarding the socks while they wore them. Second, the small sample size compared to studies of similar methodology [29]. Third, muscle recruitment patterns, such as the peroneal and anterior tibial muscles through electromyography, that were not measured in this study, may have contributed to active joint stiffness and may be used for control of stiffness and stability [5]. It is important to evaluate participants with a history of previous ankle sprain injury to understand the level of stability achieved. Future research is required to determine the relative contribution of the selective tensile strength on the active protection of the ankle.

Conclusions

This study concludes that PST socks seem to positively influence global instability index values during dynamic balance evaluation, as well as the active ankle joint position sense. Thus, it seems to indicate that socks may play an active role in ankle sprain protection. However, further studies on PST and other socks should be conducted to provide insight into these mechanisms.

Conflict of Interests

The authors declare no conflict of interest.

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ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2021; 28(**2**): 137-145
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.2-7

Relationships between the technique index and performance in 60-m hurdle indoor races in elite male heptathletes

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Abstract

A practical assessment of the hurdle clearance technique was carried out applying the technique index (T_{INDEX}), namely the difference between performance in a hurdle race and performance in a respective race without hurdles. The aim of the present study was to examine T_{INDEX} of combined events athletes that competed in all World and European Indoor Athletics Championships. The analysis included the heptathletes who won (n = 84) or did not win (n = 192) a medal, the progress of T_{INDEX} per decade (1990s: n = 75; 2000s: n = 97; 2010s: n = 104) and its correlation with performance (total points won) in heptathlon for a total of 276 cases from the heptathlon 60-m sprint and 60-m hurdle races held from 1993 to 2019. Results revealed that medal winners (median [interquartile range] = 0.99 [0.20] s) had significantly ($p < 0.001$) lower T_{INDEX} compared to non-medal winners (1.10 [0.24] s). No significant ($p > 0.05$) T_{INDEX} differences were observed among the cases in the examined decades. Finally, a significant negative correlation ($\tau_b = -0.27$, $p < 0.001$) was observed for T_{INDEX} and performance in heptathlon. In conclusion, hurdle clearance with the minimum time loss is a precondition for success in indoor combined events.

KEYWORDS: sprint, track and field, performance, time analysis, heptathlon, time differential.

Received: 4 December 2020
Accepted: 4 February 2021

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Introduction

The 60-m hurdle race is a part of indoor track and field combined events for both men (heptathlon) and women (pentathlon). These events were included in major indoor competitions for the first time in the early 1990s. Performance in the combined events is highly related with fast times in the hurdle event in outdoor athletics combined events [21]. Research in the indoor hurdle event has shown that male combined event athletes (heptathletes) display a similar average speed pattern with hurdlers despite being significantly slower [20]. Biomechanical studies [2, 18] have investigated the differences between hurdlers and heptathletes. Those studies revealed that the hurdle clearance distance and height are greater in decathletes and result in longer hurdle clearance time of the decathletes compared to hurdlers. These lead to reduced velocity during hurdle clearance [18], which is suggested to be an essential parameter for better performance [12]. Another disadvantage of the hurdling technique exhibited by combined event athletes is connected with the more upright body position compared to hurdlers at the instant of landing after the hurdle [2]. This body posture is not favourable for the fast transition from hurdle clearance to the sprinting action towards the next hurdle [3, 27].
As mentioned above, the hurdle clearance time depicts the effectiveness of the hurdling technique [12]. Thus, the importance of hurdle clearance is also evident when comparing combined event athletes and hurdlers by means of time analysis. For example, time analysis of the indoor 60-m hurdle race revealed a small event-specific difference of the hurdle clearance time, since

heptathletes were inferior compared to hurdlers, especially when clearing the third hurdle [20]. It can be concluded that an efficient hurdle clearance technique, widely assessed by the hurdle clearance time, is a crucial factor for the optimisation of performance in combined events.

Apart from the biomechanical characteristics and the hurdle clearance time, an alternative measure of the efficiency of hurdle clearance is the percentage ratio of the difference in average velocity of a hurdle race with a sprint of the same distance to average velocity of the hurdle race [15]. Nevertheless, the most common practical quantitative measure for the effectiveness of the hurdling technique among practitioners is the technique index (T_{INDEX}). The latter is calculated as the difference between performance in a hurdle race and performance in a respective race without hurdles [26]. Decrease of the T_{INDEX} indicates a faster hurdle clearance [17] and, consequently, a more effective hurdle clearance technique. It is common practice to use the personal best performance during an official event for the calculation of T_{INDEX} [3], as it is believed that the maximal effort of an athlete is achieved during participation in a competition. As such, T_{INDEX} for elite female athletes ranges from 0.30 s to 0.79 s in the indoor 60-m hurdle race and from 0.47 s to 1.54 s in the outdoor 100-m hurdle race [3, 26]. As presented above, T_{INDEX} is used to evaluate female rather than male athletes. This is due to the fact that, in outdoor competitions, the official racing distances are identical in women (100-m dash/100 m-hurdle race), but not in men (100-m dash/110-m hurdle race). However, the assessment of T_{INDEX} is a useful tool for the evaluation of the hurdling technique in heptathletes, as both the dash and the hurdle races are of equal distance (= 60 m). Another advantage of using T_{INDEX} for the evaluation of the hurdling technique in heptathletes is the fact that both the 60-m dash and the 60-m hurdle races are performed in the same competition. Due to this fact, the calculation of T_{INDEX} is more accurate, as the physical conditioning of the heptathletes when executing these two events is the same. The advantage of calculating T_{INDEX} in heptathletes might provide further insight when studying their overall performance. This is because the hurdle event is considered to be the key event in the combined events [21]. Thus, it is of importance to examine the relationship of T_{INDEX} with performance in the heptathlon.

Aim of Study

The purpose of the present study was to examine the relationship between the T_{INDEX} and performance of elite male combined events athletes, who competed in major indoor athletics events. Specifically, the aims were: a) to compare the T_{INDEX} of elite male heptathletes who won or did not win a medal in major competitions, b) to check the progression of T_{INDEX} per decade, and c) to examine the possible relationship between T_{INDEX} and overall performance in the men's heptathlon.

Material and Methods

Study design

Performance data from elite male heptathletes who competed in major Indoor Championships were collected. For the purposes of the study, major Indoor Championships were the World Athletics Indoor Championships and the European Athletics Indoor Championships, where the men's heptathlon was inaugurated in 1993 and 1992, respectively. The retrieved performance data were classified depending on: a) the connection with overall heptathlon performance (total points won), b) the relation to winning or not winning a medal in the Championship, and c) the decade from which the data were retrieved, i.e. from a Championship held in the 1990s (1992-1999), 2000s (2000-2009) or 2010s (2010-2019). In total, 333 cases were collected from 14 World Athletics Indoor Championships and 14 European Athletics Indoor Championships. From the initial 333 cases, 35 were excluded as the heptathletes did not finish both 60-m and 60-m hurdle races, thus T_{INDEX} could not be calculated. Another 22 cases were also excluded despite the availability of T_{INDEX}, as no overall heptathlon performance was recorded due to disqualification or withdrawal from the competition. In total, 276 cases involving 157 male heptathletes were selected for further analysis, since both inclusion criteria were satisfied. The study was conducted in accordance with the ethical standards of the Institutional Research Committee Guidelines and the recommendations of the Declaration of Helsinki, with the exception that no informed consent needed to be obtained, as the data were based on publicly available resources.

Procedure and data analysis

Performance data of the heptathlon events in the World Athletics Indoor Championships held from 1993 to 2018 were obtained from Wikipedia (https://en.wikipedia.org/wiki/0000_IAAF_World_Indoor_Championships_%E2%80%93_Men%27s_heptathlon; where 0000 is the year of the competition) after checking the validity of the presented information with the official results published in the public databases of the World Athletics (formerly named the International Association of Athletics Federations IAAF; https://www.worldathletics.org/competitions/world-athletics-indoor-championships/history/). In addition, performance data of the heptathlon events in the European Athletics Indoor Championships held from 1992 to 2019 were also collected from Wikipedia (https://en.wikipedia.org/wiki/0000_European_Athletics_Indoor_Championships_%E2%80%93_Men%27s_heptathlon; where 0000 is the year of the competition) after checking the validity of the presented information with the official results contained in the public databases of the European Athletics (https://www.european-athletics.org/competitions/european-athletics-indoor-championships/history/). Inclusion criteria were: a) the athlete was not banned for doping for the period where his performance was documented, b) both 60-m dash and 60-m hurdle race official times (T60 and T60H, respectively) were provided, and c) the athlete had completed the heptathlon and his overall heptathlon performance (point score) was available.

T_{INDEX} was calculated as T60H minus T60. The percentage contribution of T_{INDEX} to T60mH (T%) was calculated as $T_{INDEX} \times 100 / T60H$. The points earned by the heptathletes in the 60-m dash and 60-m hurdle races (P60 and P60H, respectively) were also documented, as well as their percentage referred to the total points won (P60% for the 60-m dash and P60H% for the 60-m hurdle race).

Statistical analysis

Normality of distribution and the equality of variance were assessed using the Shapiro–Wilk test ($p > 0.05$) and Levene's test ($p > 0.05$), respectively. According to the results of the Shapiro–Wilk test (Table 1), an Independent Samples T-test and a one-way ANOVA with Tukey's HSD post hoc test were run for T60m and P60mH regarding the comparison of medal winners and non-medal winners and the comparison of the 1990s, 2000s and 2010s, respectively. The respective analyses for total points won, T60H, T_{INDEX}, P60, P60%, P60H% and T% were conducted with the Mann–Whitney U test and the Kruskal–Wallis H test. A Kendall's tau-b (τ_b) correlation was run to determine the relationship between T_{INDEX} and overall heptathlon performance. The effect sizes were checked as follows [28]: a) the Hedges' *g* for the Independent Samples T-test (with values of <0.2, <0.5, <0.8 and ≥0.8 being considered as trivial, small, medium and large, respectively), b) the Wilcoxon–Mann–Whitney *r* for the Mann–Whitney U test (with values of <0.1, <0.3, <0.5 and ≥0.5 being considered as trivial, small, medium and large, respectively), c) the partial eta squared (η_p^2) for the one-way ANOVA (with values of <0.01, <0.06, <0.14 and ≥0.14 being considered as trivial, small, medium and large, respectively), and d) the epsilon-squared estimate of effect size (ε_R^2) for the Kruskal–Wallis H test (with values of <0.01, <0.08, <0.26 and ≥0.26 being considered as trivial, small, medium and large, respectively). All statistical analyses were conducted with the use of the IBM SPSS Statistics v.25 software (International Business Machines Corp., Armonk, NY), with the level of significance set at $\alpha = 0.05$.

Results

The results of the examined parameters are presented in Table 1. The overall performance of the examined cases was about 97.7% of their personal best.

Medal winners vs non-medal winners

Medal winners comprised 30.4% of the analysed cases. The results of the analyses concerning the comparison between medal winners and non-medal winners are presented in Table 2. All parameters, with the exception of P60% and P60H%, were significantly different between groups.

Medal winners were faster in both disciplines, as they had significantly smaller T60 and T60H compared to non-medal winners. Medal winners performed the 60 m hurdle race with a significantly lower T_{INDEX} and T% than non-medal winners. Both medal winners and non-medal winners scored higher in the 60-m hurdle race than in the 60-m dash. P60% was about 14.6% ± 1.0 of total points won, whereas P60H% contributed to 15.9% ± ± 1.0 of the overall heptathlon performance.

Performance progression

Table 3 depicts the results of the analyses for the 1990s, 2000s and 2010s. The only significant differences were observed for P60H and P60H%, as significantly higher values in these parameters were scored in the 2010s compared to the 2000s.

Despite being non-significant ($p > 0.05$), a trend to perform the examined events with faster T60 and T60H was shown in the 2010s compared to the previous two decades. This non-significant trend was also evident for T_{INDEX}. Descriptive statistics showed that the lowest average T% was observed in the 2010s compared to the previous two decades.

Relationship between T_{INDEX} and performance in heptathlon

The results of the examination of the relationship between T_{INDEX} and overall heptathlon performance are

Table 1. Descriptive statistics and results of the normality test for the examined parameters (n = 276)

Parameter	min	max	mean	SD	median	interquartile range	95% confidence interval		*skewness*	*kyrtosis*	Shapiro–Wilk	
							lower bound	upper bound			*W*	*p*
T60 (s)	6.61	7.46	7.04	0.14	7.05	0.19	7.02	7.06	–0.161	0.509	0.990	0.068[a]
T60H (s)	7.64	8.91	8.14	0.22	8.13	0.28	8.11	8.17	0.374	0.107	0.990	0.048[b]
T_{INDEX} (s)	0.71	2.02	1.10	0.20	1.07	0.26	1.08	1.12	0.913	1.260	0.953	<0.001[b]
T%	8.8	22.7	13.5	2.1	13.1	2.80	13.2	13.7	0.741	0.765	0.967	0.001[b]
Points	4135	6645	5974.6	295.9	6001.0	319.00	5939.5	6009.7	–1.697	6.817	0.984	<0.001[b]
P60	706	1026	868.1	50.8	865	67.00	862.0	874.0	0.167	0.717	0.988	0.020[b]
P60H	766	1074	948.6	54.1	949	72.00	942.3	955.1	–0.325	0.007	0.992	0.122[a]
P60%	11.8	22.0	14.6	1.0	14.5	1.0	14.4	14.7	2.128	11.867	0.871	<0.001[b]
P60H%	12.6	24.5	15.9	1.0	15.9	1.0	15.8	16.0	2.829	21.402	0.811	<0.001[b]

Note: T60 – official time in the 60 m dash; T60H – official time in the 60 m hurdles race; T_{INDEX} – technique index; T% – percentage contribution of T_{INDEX} to T60H; Points – overall points in heptathlon; P60 – points won in the 60 m dash; P60H – points won in the 60 m hurdles race; P60% – percentage of P60 referred to Points; P60H% – percentage of P60H referred to Points
[a] parametric data; [b] non-parametric data

Table 2. Results for comparisons between medal winners and non-medal winners

Parameter	Medal winners (n = 84)	Non-medal winners (n = 192)	*t*	*U*	*p*	*effect size*	
T60 (s)[a]	6.96 [0.14]	7.08 [0.13]*	6.455	–	<0.001	0.90	large
T60H (s)[b]	7.99 [0.26]	8.19 [0.29]*	–	649.500	<0.001	0.45	medium
T_{INDEX} (s)[b]	0.99 [0.20]	1.10 [0.24]*	–	3486.500	<0.001	0.25	small
T%[b]	12.5 [2.2]	13.5 [2.8]*	–	5958.500	0.001	0.21	small
Points[b]	6215.5 [173.0]	5906.0 [252]*	–	5523.500	<0.001	0.73	large
P60[b]	895.0 [77.0]	858.0 [59.0]*	–	4582.500	<0.001	0.34	medium
P60H[a]	983.3 [47.2]	933.5 [50.0]*	7.781	–	<0.001	1.02	large
P60%[b]	14.3 [1.2]	14.5 [0.9]	–	6868.000	0.050	0.12	small
P60H%[b]	15.8 [0.8]	15.9 [1.0]	–	7475.000	0.334	0.06	trivial

Note: T60 – official time in the 60 m dash; T60H – official time in the 60 m hurdles race; T_{INDEX} – technique index; T% – percentage contribution of T_{INDEX} to T60H; Points – overall points in heptathlon; P60 – points won in the 60 m dash; P60H – points won in the 60 m hurdles race; P60% – percentage of P60m referred to points; P60H% – percentage of P60H referred to points
[a] parametric data (group comparisons with Independent Samples T-test; descriptive statistics: mean [standard deviation]; effect size: Hedges' *g*); [b] non-parametric data (group comparisons with Mann–Whitney's U test; descriptive statistics: median [interquartile range]; effect size: Wilcoxon–Mann–Whitney *r*)
* $p < 0.05$

Table 3. Results for comparisons between cases in different decades

Parameter	1990s (n = 75)	2000s (n = 97)	2010s (n = 104)	*F*	*H*	*p*	*effect size*	
T60 (s)[a]	7.04 [0.16]	7.05 [0.12]	7.03 [0.14]	1.233	–	0.141	0.226	large
T60H (s)[b]	8.08 [0.34]	8.16 [0.31]	8.12 [0.25]	–	5.510	0.064	0.013	small
T_{INDEX} (s)[b]	1.06 [0.29]	1.10 [0.25]	1.05 [0.25]	–	3.854	0.146	0.007	trivial
T%[b]	13.1 [3.1]	13.5 [2.7]	13.0 [2.6]		3.224	0.199	0.004	trivial
Points[b]	6023.0 [304.0]	5984.0 [334.0]	5997.0 [329.0]	–	1.033	0.597	0.004	trivial
P60[b]	868.0 [81.0]	861.0 [56.0]	868.0 [67.0]	–	1.454	0.483	0.002	trivial
P60H[a]	950.0 [60.3]	937.4 [52.3]	958.5 [49.5]*	3.762	–	0.024	0.283	large
P60%[b]	14.4 [1.1]	14.4 [0.8]	14.5 [1.2]	–	1.669	0.434	0.001	trivial
P60H%[b]	15.9 [1.0]	15.7 [0.9]	16.0 [1.0]*	–	7.739	0.021	0.021	small

Note: 1990s – cases recorded from 1992 to 1999; 2000s – cases recorded from 2000 to 2009; 2010s – cases recorded from 2010 to 2019; T60 – official time in the 60 m dash; T60H – official time in the 60 m hurdles race; T_{INDEX} – technique index; T% – percentage contribution of T_{INDEX} to T60H; Points – overall points in heptathlon; P60 – points won in the 60 m dash; P60H – points won in the 60 m hurdles race; P60% – percentage of P60m referred to Points; P60H% – percentage of P60H referred to Points

[a] parametric data (group comparisons with Independent Samples T-test; descriptive statistics: mean [standard deviation]; effect size: partial eta squared [η_p^2]); [b] non-parametric data (group comparisons with Mann–Whitney's U test; descriptive statistics: median [interquartile range]; effect size: epsilon-squared estimate of effect size [ε_R^2]

* $p < 0.05$ compared to 2000s

Table 4. Kendall's τ_b coefficients for the relationship between T_{INDEX} and overall points won in the heptathlon

Examined group	T_{INDEX} (s)	*points*	τ_b	*p*
All heptathletes (n = 276)	1.07 [0.26]	6000.0 [317.0]	–0.27*	<0.001
All medal winners (n = 84)	0.99 [0.20]	6215.5 [173.0]	–0.18*	0.019
All non-medal winners (n = 192)	1.10 [0.24]	5904.0 [252.0]	–0.23*	<0.001
1990s heptathletes (n = 75)	1.06 [0.29]	6023.0 [304.0]	–0.20*	0.013
1990s medal winners (n = 24)	0.99 [0.25]	6219.5 [191.0]	0.06	0.691
1990s non-medal winners (n = 51)	1.09 [0.27]	5939.0 [239.0]	–0.27*	0.006
2000s heptathletes (n = 97)	1.10 [0.25]	5984.0 [334.0]	–0.34*	<0.001
2000s medal winners (n = 30)	0.99 [0.18]	6202.5 [174.0]	–0.27*	0.040
2000s non-medal winners (n = 67)	1.13 [0.29]	5884.0 [266.0]	–0.25*	0.003
2010s heptathletes (n = 104)	1.05 [0.25]	5993.0 [329.0]	–0.24*	<0.001
2010s medal winners (n = 30)	0.99 [0.16]	6232.0 [191.0]	–0.34*	0.008
2010s non-medal winners (n = 74)	1.09 [0.25]	5932.0 [242.0]	–0.16*	0.049

Note: T_{INDEX} – technique index; points – overall points in heptathlon; results are presented as median [interquartile range]

*$p < 0.05$

presented in Table 4. With the exception of the medal winners in the 1990s, a significant negative correlation was found between T_{INDEX} and performance in the heptathlon (τ_b coefficients ranging from –0.16 to –0.34).

Discussion

The study was conducted to examine the relationship of T_{INDEX} with overall performance in the men's indoor heptathlon. In addition, possible differences in T_{INDEX}

between medal winners and non-winners, as well as the T_{INDEX} progression over time were examined. Results revealed that a significant moderate negative correlation was observed between T_{INDEX} and total points won in heptathlon and that medal winning heptathletes had significantly lower T_{INDEX} compared to non-winning athletes. On the other hand, no significant changes of T_{INDEX} were observed for the three examined decades.

Results of time analysis studies revealed a common performance structure of the 60-m hurdle event that is independent of the level of performance and hurdling specificity in high level athletes [20]. However, the examined heptathletes had lower official hurdle race times than hurdlers analysed in previous major Indoor Athletic Championships [20, 24]. It was found that male heptathletes present a reduced capability to maintain high levels of speed as the 60-m hurdle race progresses compared to hurdlers [20]. In addition, previous research showed that combined event athletes clock faster in a separate 110-m hurdle race compared to races within the decathlon [22]. Although race time is not considered as a good representation of hurdle clearance comparable to horizontal clearance velocity [25], T_{INDEX}, as the difference between the athlete's best times for the dash and the hurdle races, is believed to reflect the contribution of good hurdle technique to performance [3]. This can be confirmed in the present study, since T_{INDEX} was significantly correlated with overall performance in the heptathlon. Specifically, the obtained correlation coefficients indicated the existence of a weak to moderate significant negative relationship between those two parameters in a vast majority of the subgroups examined. This finding provides further evidence to previous research findings that the hurdle event is among the key events for success in the combined events [21].

The heptathletes that won a medal had significantly lower T_{INDEX} compared to non-winning competitors. Medal winning heptathletes were also significantly faster both in the 60-m dash and the 60-m hurdle races than the rest of the athletes. This finding implies that apart from sprinting speed, an efficient hurdling technique is essential for success in the combined events. The level of performance has an impact on the temporal factors of different segments of the 60-m hurdle race, as it was found to differentiate the intermediate hurdle unit time [9, 19]. Differences due to the performance level are also observed for the sprint after the last hurdle, as lower level hurdlers were found to be slower compared to elite level athletes [9, 20]. Another significant difference is the hurdle clearance time, as lower level hurdlers [13] or not event-specific athletes [20] perform the clearance with a longer flight time. For the indoor 60-m hurdle race, slower athletes performed the hurdle clearance with a lesser mean horizontal velocity of the body center of mass [25].

Despite the significant difference between medal winners and non-medal winners, there was no difference concerning the contribution of the points won in the 60-m dash and the 60-m hurdle races on the total point score won in the heptathlon. This can be attributed to the fact that, in the hurdle events, the sprinting and hurdling techniques are similarly important for the performance in the hurdle events [3]. In addition, a high level male decathlete gains additional 50 points by an improvement of his performance in the hurdle event two times greater than the improvement of his performance in the sprint event [29]. For the improvement of performance in the hurdle events, the athletes have to perform the hurdle clearance with a forward body lean, a low clearance of the hurdle without an unnecessary loss of horizontal velocity, and an active downward movement of the lead leg for the landing, as these were suggested to be among the key technique elements [27]. Studies have shown that male combined event athletes do not execute these technique elements with the efficiency observed in hurdlers [2, 18]. Thus, adding the fact that the hurdling clearance spatiotemporal parameters are adapted to the specific demands of each hurdle-unit [10], it is of importance to prepare the athletes to optimise their technique accordingly. It has also been suggested that training to acquire an optimal technique and focusing on the movements and postures of the athlete in every hurdle session is essential [3].

Despite observing relatively similar average official times for the 60-m dash through the examined decades, a considerable, non-significant faster average 60-m hurdle time was clocked in the 2010s. This resulted in a slightly lower T_{INDEX} in the past decade. Nevertheless, no significant change of T_{INDEX} through the three decades examined was observed. This might be due to the fact that, as the hurdle race is among the highest score gaining disciplines [21], attention is given to other events. Taking the women's heptathlon as an example, the hurdle event is not considered among the disciplines with the most scope for improvements such as i.e. the jumping events and the javelin throw [4]. However, the contribution of points won in the 60-m hurdle event in the overall performance in heptathlon by competitors in the 2010s was significantly higher compared to the one in the 2000s. In the present study, the points won contributed to approximately 15.9% of the overall heptathlon performance, which is the highest percentage of point contribution among the other events. This might indicate the emphasis given to the hurdle event because it is among the key events for success in the combined events [21].

It is worth mentioning that 17.1% of the competitors who started the event did not finish the race. The percentage of competitors not finishing the event is higher than that reported for major indoor competitions in the last decade [6]. Of the 57 cases when the athletes did not complete the event, 38.6% stopped at the last two events. It has been observed that there is an even distribution of the occasions, when athletes stop the competition during both days of the competition and that these drop-outs occured prior the disciplines with high technique demands, such as the hurdles and the pole vault [5]. Injuries are more frequent in combined event athletes and comprise one of the main reasons for not completing the event [7]. Injuries in indoor men's heptathlon are more frequent than in the other combined events in athletics [8] and are associated with lower odds of winning a medal [6]. In general, the combined events comprise a demanding discipline in athletics where loss of motivation (i.e. a low chance to achieve the goal set for the competition) and fatigue contribute to drop-outs [7].

As for the limitations of the study, the reaction time at the starting blocks was not extracted from the official results in the 60-m hurdle race and the 60-m dash. This was due to the fact that the reaction time was not provided for each analysed competition. In the Olympic decathlon, reaction time was found to be different for the 110-m hurdle race and the 100-m dash [1]. Nevertheless, studies has shown that there is no correlation of the reaction time and the official hurdle race time in both outdoor [23, 30] and indoor competitions [20]. In addition, sprinting performance and reaction time are suggested to be improved equally in the recent past [23]. Another limitation of the study was connected with the effect of contacting the hurdle during its clearance. This factor was not considered. Hitting the hurdle during its clearance is related with a decrease in velocity during the hurdle clearance phase and with a lower sprinting speed after landing behind the hurdle [16], leading to the loss of the rhythm in the following hurdle unit [11]. Despite the fact that hurdle clearance velocity is a determining factor for performance [12, 19], there are biased results regarding the importance of the average hurdle clearance time on hurdle race performance, as it was found to be related with official 60-m hurdle race times [24] but not with official times in the 110-m hurdle race [30]. Finally, the anthropometric characteristics (i.e. leg length, height of the centre of mass, etc.) affect hurdle clearance time [14], but a possible relationship of these characteristics with the performance data was not examined. Future studies should take under consideration the above factors to establish the magnitude of their effect in the evaluation of the hurdle clearance technique using indicators such as T_{INDEX}. Concerning the output for practitioners and coaches, the findings of the present study suggest that an appropriate emphasis should be given to the hurdle clearance technique and the effective transition to sprint the intra-hurdle distance in combined event athletes.

Conclusions

The technique index, namely the difference between performance in a hurdle race and performance in a respective race without hurdles, seems to be an important indicator of performance in 60-m hurdle indoor races in elite male heptathletes. Lower values in the technique index indicate less time spent for hurdle clearance. As the present results showed that a significant negative correlation exists between the technique index and total points won in the heptathlon and that medal winners had a significantly lower technique index than non-medal winners, hurdle clearance comprises a precondition for success in indoor combined events. Thus, it is suggested that the appropriate hurdle clearance technique that results in minimum time loss should be applied by male heptathletes in order to further improve their overall performance in the event.

Conflict of Interests

The authors declare no conflict of interest.

Acknowledgments

The first two authors contributed equally to this study. The authors wish to thank the anonymous Reviewer for the valuable and constructive feedback on an earlier version of the manuscript.

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ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2021; 28(**2**): 147-151
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.2-8

The effect of cannabidiol (CBD) on simple and complex reaction times

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Abstract

Introduction. CBD activates many different receptors in the body and thus has a wide range of effects, including relief from anxiety and depression, sedative effects, a calming and relaxing effect, antipsychotic effects, help with insomnia and relief of chronic pain. Aim of Study. The aim of our work was to determine the effect of the reaction time of an individual depending on a visual stimulus when applying a dietary supplement with a 10% CBD content. Material and Methods. This study addresses the improvement of an individual's reactivity after ingestion of a food supplement – 10% CBD Enecta oil, and whether there is an improvement in reactivity after ingestion. In doing this work we wanted to expand existing studies on food supplements and prove that oil with a 10% content of this substance affects the response time. Results. Between the measured values in SRT (simple reaction time) after ingestion of oil with a 10% CBD content and the placebo, we found that there is no significant difference between them (p = 0.293). For CRT (complex reaction time) we found that there was also no significant difference between the measured values after ingestion of the oil with a 10% CBD content and the placebo (p = 0.057). The results show that there was no significant difference in the reaction time between the measured values of SRT and CRT. Conclusions. We concluded that the dietary supplement from this substance did not prove to be a stimulant when tested for simple and complex reaction times. After ingestion, there was no expected reduction in reaction time in most test subjects. In view of this deduction, we cannot recommend this product as a suitable means for achieving faster or slower responses to a visual stimulus with the help of authorized substances, which could then be used in various sports or in driving.

KEYWORDS: CBD, t-test, simple reaction time, complex reaction time, CBD oil.

Received: 25 November 2020
Accepted: 27 January 2021

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Introduction

Cannabidiol (CBD) is a phytocannabinoid, i.e. a substance found in Cannabis plants, that lacks the psychoactive effects of Δ9-tetrahydrocannabinol (THC) [3, 4, 5]. CBD is often described as the second most abundant substance in cannabis after THC or tetrahydrocannabinol, but in reality its level depends on the specific strain of cannabis as they all have a different cannabinoid profile [1]. The most significant difference between these cannabinoids is the fact that, unlike THC, CBD does not cause any psychoactive effects [5]. There are two central cannabinoid receptors in the human body, CB1 [12] and CB2 [14]. THC binds to and activates the cannabinoid receptor CB1 in the body, causing euphoria. CBD does not favour either of these receptors, as it binds to both. However, CBD does not activate CB1, it only weakly binds and alters its structure, which will prevent THC from binding to it and causing its activation. Therefore, CBD is non-psychoactive [4, 5, 10].

CBD activates many different receptors in the body and thus has a wide range of effects, including relief from anxiety and depression, sedative effects, a calming and

relaxing effect, antipsychotic effects, help with insomnia and relief of chronic pain [4, 5, 10]. When receptors are activated, they cause analgesic and sedative effects, soothe pain, reduce respiration, and may have a positive effect on anxiety and depression [11, 16]. Further studies showed that cannabinoid-based compounds which participate in the key steps, carry endocannabinoids based on their potential abilities to reduce the motor effects or provide neuroprotections that then directly affect the structures of the basal ganglia [6].
Unlike its psychoactive counterpart (THC – tetrahydrocannabinol), CBD has negligible side effects [8]. We found no effects among them that would affect essential vital functions. These are the effects that commonly occur in the case of almost all pharmacological products [12]. Moreover, they are not strong at all and affect a small percentage of people, so it could be said that they are preferably an exception. Moreover, even in this small percentage of people these effects appear only if the compound is applied in a disproportionately high dose [4, 7].
Interestingly, although CBD is a new substance, and further research is still being conducted, there are already many commercially available products that contain this substance. In today's hectic times, when people are facing increasing demans and challenges, they have to do more work and faster. There is a need to maintain consistently great performance levels and surprisingly, the number of people who actively take care of their bodies and what they eat is growing. They are willing to spend more money on natural, organic products, as they are more confident that the consumption of these products will not introduce harmful chemicals into their bodies. We think that in the future, with increasing studies and promotion in the media, interest in buying and using CBD products could increase, but so far the price is too high and knowledge concerning these products is low. The real advantage is that they are available in different variants, so consumers can choose the one that suits them best. They may be used both at home and on the road. A wide range of CBD-containing products is commercially available, including e.g. oils, sweets, capsules, teas, pastes, liquids, crystals, chewing gum and tinctures [10, 16, 18].
Based on the knowledge gained from the publications used for our study, we found that CBD and other substances contained in the Enecta CBD oil affect our body in a relatively wide range [3, 5, 11]. Cannabinoids bind to particular receptors in the body, mainly in the brain, and affect a range of functions through the endocannabinoid system. All the substances contained in CBD oil work in a kind of synergy and together bring effects such as soothing, relaxing, relieving pain, anxiety, depression or stress [3, 5].
According to the manufacturers of CBD products, one should feel relaxed and calm after applying the oil [18]. As some of the substances in the CBD oil cause muscle relaxation and promote sleep [11], it was assumed in this study that the oil would also affect a person's reaction time. On the other hand, the effects of CBD are implied in relatively vague hypotheses and not based on the results of precise analyses, methodologies and factors determining positively or negatively the effect of this extract. For this reason, we decided to contribute this research to solve this problem.

Aim of Study

The aim of our work was to determine the effect of the reaction time of an individual depending on a visual stimulus when applying a dietary supplement with a 10% CBD content.

Material and Methods

Participants

The study involved 16 participants (men) ages 21-24 (Table 1), based on two measurements during one week. All participants were in good physical shape and healthy during testing without any subjective issues; however, no kinesiology analysis of the test subjects was included in the study. The overall data sample was obtained via purposeful selection.

Table 1. Basic characteristics of the tested group

Basic characteristics	Age/SD [years]	Height/SD [m]	Weight/SD [kg]
	22.7/0.8	178.1/8.6	75.7/6

Note: SD – standard deviation

Procedure

The experiment was conducted twice, with a one-week interval between measurements. Individuals always abstained for 48 hours from substances that have a compelling character (e.g. caffeine, taurine, etc.). The participants were asked not to perform physically or mentally demanding activities the day before and after the measurement. This was due to a possible reduction in attention, which could subsequently affect the speed of reaction. They were asked to observe an ideal sleep time of 7-8 hours the day before the measurement. Fatigue and excipients could affect the measurement results.

The participants were administered a dose sublingually (under the tongue) of the tested oil produced by the manufacturer (Enecta), in which the recommended dose was 0.11 ml (11 mg), which corresponds to 4 drops of CBD oil. Placebo was administered in the same manner under the test subject's tongue – 4 drops of oil (0.11 ml). (The placebo sample produced contained 18 g of olive oil, 6 g of Iberogast, 1 g of dried wormwood. Iberogast and wormwood were added to mimic the very pronounced specific and bitter taste of CBD oil). This composition had the same taste as the CBD oil or at least very similar. The participants were instructed that it was essential to hold the sample under their tongue for at least 60 seconds before swallowing. This was to ensure a faster absorption of the substance.
Thirty minutes after applying the oil, the participant was tested with a reactometer for simple and complex reaction times. This time was chosen based on the recommendation of the CBD oil manufacturer. After one week the second test was conducted; the test subject ingested the opposite pattern of CBD oil or the placebo. All measurements were performed under standardized conditions in the KTVS UJEP laboratory in Ústí nad Labem based on the recommendations from the Balko research study [2].
When measuring the simple response time to a visual stimulus, the participant was sitting in an immovable chair at a table (eyes 60 cm away from the monitor) with the preferred hand 4 cm above the plate. His gaze was directed at the monitor. At various intervals after the start of the test a green circle symbol was displayed in the centre of the monitor on a white background. At each display the participant had to respond by touching the plate 20 times in a row. When measuring the complex reaction time, the procedure was identical, with the difference only in the number of plates and the types of symbols displayed. The tested person had to respond to the type of symbol by pressing the assigned plate, also 20 times in a row.
The plates were arranged in a square with a four-centimetre gap. The first plate represented a red square, the second a green circle, the third a blue triangle and the fourth a yellow cross. The stimulus was always displayed in the centre of the monitor, similarly as it was when testing the simple response time. In this test both hands were used with a starting position of 4 cm above the worktop, the left hand being 3 cm from the left plates and the other hand 3 cm from the right plates. A reactometer and the Fitro Agility Check & Reaction 2.0 software (Fitronic, s. r. o.) were used for the measurement of the reaction itself.

The installed software generated stimuli in the range of 500-3000 ms on the computer monitor and recorded the reaction time of the participant (contact with the plate). Errors were not included in the resulting data.
For the simple reaction time the range of a valid experiment was set at 100-1500 ms, while for the complex reaction time it was 150-2000 ms. The tested participants were not affected by any interfering elements during the measurement.

Data collection and analysis
When testing the normality of the data using the Shapiro–Wilk test it was found that the measured values for simple and complex reaction times have an average frequency distribution, and therefore parametric methods of statistical analysis were applied. For statistical data processing a paired t-test was used, which compares the dependent selections. The level of statistical significance was set at $p < 0.05$ [9, 13].

Results
This chapter presents the measured results from testing simple and complex reaction times using a reactometer. Figure 1 shows the measured results of the simple reaction

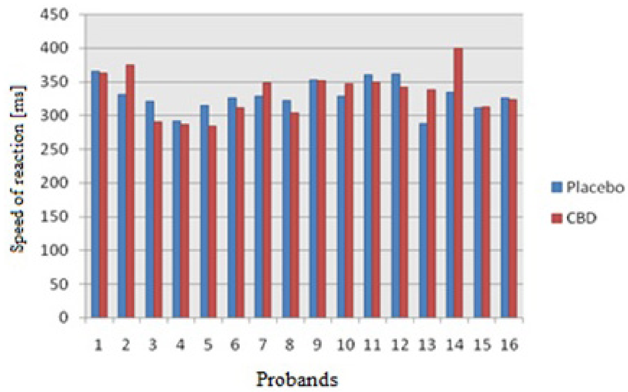

Figure 1. Simple reaction time

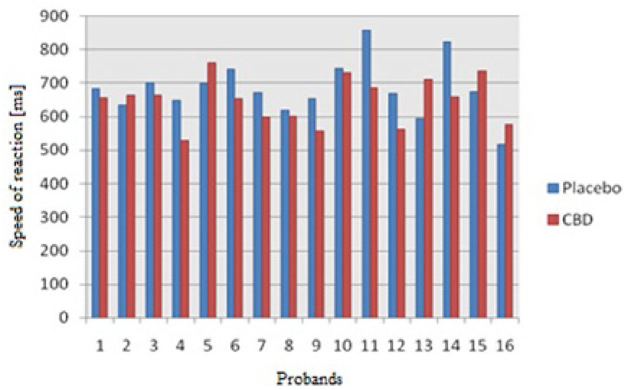

Figure 2. Complex reaction time

time (medians) for individual participants after ingestion of 10% CBD oil and the placebo. Figure 2 shows the measured results for the complex reaction time.
Between the measured values of SRT (simple reaction time) after ingestion of oil with a 10% CBD content and the placebo no significant differences were found between them (p = 0.293). The results are given in Table 2.
For CRT (complex reaction time) also no significant differences were recorded between the measured values after ingestion of the oil with a 10% CBD content and the placebo (p = 0.057). Material significance was not calculated based on statistical findings.

Table 2. Reaction time following the consumption of placebo and oil containing 10% CBD

	Placebo [med]	10% CBD [med]	p
SRT	333.125	329.187	0.293
CRT	646.812	682.812	0.057

Note: SRT – simple reaction time; CRT – complex time reaction, p – probability of an error in rejecting the null hypothesis

The above results show that there was no significant difference in the reaction time between the measured values of SRT and CRT, for which the effect of the test substance was determined.

Discussion

After the calculations it turned out that there was no significant statistical change in any of the monitored variables. For this reason we can further conclude that a 10% CBD oil extract cannot reduce the response time to a visual stimulus after ingestion both at simple and complex reaction rates. We can therefore confirm that the product cannot be used as a stimulant of the reaction time. We did not compare the results with other similar research due to the lack of scientific work dealing with our topic. Research on CBD focuses mainly on the effects on human health (treatment of diseases, etc.) and not on reaction time.
Reaction studies have been performed on other substances such as caffeine [15] and taurine [17]. Interestingly, no similar conclusions were reached for these substances. Of course, we are aware that we cannot draw clear conclusions concerning the product from this study. The results in individual tests could be influenced by other variables influencing the performance of an individual, e.g. by the psyche of individual participants. It would undoubtedly be necessary to repeat or confirm this testing at least once more on a larger sample of participants to confirm the result. However, this finding is undoubtedly exciting.

Conclusions

We wanted to find out if in our study the reaction time can be influenced depending on a visual stimulus when applying a food supplement with a 10% CBD content. We concluded that the dietary supplement from this substance did not prove to be a stimulant when tested for simple and complex reaction times. After ingestion there was no expected reduction in the reaction time in most test subjects. In view of this conclusion we cannot recommend this product as a suitable means for achieving faster or slower responses to a visual stimulus with the help of authorized substances, which could then be used in various sports or in driving.

Conflict of Interests

The authors declare no conflict of interest.

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ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2021; 28(**2**): 153-158
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.2-9

Variations of technical actions among playing positions in male high level volleyball

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Abstract
Introduction. **Volleyball is a team sport in which a mistake made by a player on one team gives a point to the opponent. This fact requires coaches to think of all volleyball skills as having the same level of importance.** Aim of Study. **The purpose of this study was to analyze and compare variations of the technical actions of players' in-game role in terms of total points, breaking points, and the point/error relationship during one professional season.** Material and Methods. **The study included 80 matches played by 14 teams participating in the male First Division Portuguese Championship during the 2017/2018 season. The study analyzed 295 sets with a total of 85,233 actions. Data was collected using the statistical programs Data Volley and Click & Scout after video recording the matches. Results. Considering breaking points, moderate decreases were found for middle blockers vs opposites, and small increases were found for outside hitters vs middle blockers. Also, small increases were found for outside hitters vs opposites. Considering the point/error relationship, small decreases were found for middle blockers vs opposites and for outside hitters vs opposites. Trivial differences were found between outside hitters and middle blockers.** Conclusions. **The main differences portrayed in the study show that to have success, during practice, coaches need to focus on improving players' efficiency in different game actions in the counter-attack phase.**

KEYWORDS: match analysis, player role, elite players, notational analysis, performance.

Received: 13 October 2020
Accepted: 27 January 2021

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Introduction

Volleyball is a team sport, in which an error made by a player on one team gives a point to the opponent. This fact requires coaches to think of all volleyball skills as having the same level of importance. In this sense, the literature has revealed that predictors of success in volleyball include skill efficacy (attack, serve, reception, set, block, and dig) [1, 2, 8]. Apart from game action efficacy, both scoring skills and non-scoring skills also predict a team's success or defeat in a volleyball game [19, 12]. Unsurprisingly, studies have shown that the main reasons for success in volleyball result from better technical and tactical performance of a team [4], as well as the efficacy of points in the Complex II phase (i.e. when the team is going to serve and has the opportunity to score the breaking point – regarding service actions, block points, and counter-attack efficacy), which improves a team's chance of winning [13]. Furthermore, in a study that tried to determine the technical elements that could lead to a prediction of winning or losing a match by taking into account the differences of the technical elements recorded among the teams that participated in the Japan 2006 World Volleyball Championship showed that the attack error and power jump serve aces led to the prediction of the match outcome, whereas attack after reception and

the first tempo attack emerged as the decisive factors for team success [21].
In the same way, studies on game actions in elite volleyball teams such as in Spain or in the European League [11, 17] and Portugal [13] have indicated that different players' in-game roles demand different actions from players. In this sense, literature has revealed that the opposite (i.e. the player who acts on the right side of the net) usually performs the most attack actions, but is not the most efficient player. Meanwhile, the middle blocker (i.e. the player who acts in the middle of the net) executes most blocks and has the fastest attack tempo, while the outside hitter (i.e. the player who acts on the left side of the net) is the most demanded in the reception action and is the most effective player regarding the attack action [14, 17, 29].
Additionally, a study that tried to determine the technical elements leading to a prediction of winning or losing a volleyball match during the CEV Men's Champion League in 2018 showed that volleyball coaches should focus more on the individual and team offensive techniques and tactics without neglecting defensive skills [22].
Nevertheless, it is necessary to understand not only the game actions of players individually, but also the effect of players' in-game roles on the point outcome and its relevance in the Complex II and Complex I phases (i.e. side-out transition – reception, set and attack action) [19]. In this sense, when evaluating skill performance a comparison between Complex I and Complex II in elite volleyball teams suggests that the reception, set and attack actions in Complex I should not be treated in the same way as the service, block, dig, and break-point actions in Complex II [7, 15, 26]. This is justified by the team's overall performance depending on the technical actions of Complex II (aces, block points and counter-attack efficacy) [13].
In this sense, the rationale of this study relies upon the fact that such comparative studies are scarce. Moreover, although the performance of the teams in European competitions has been improved through research, little is known about Portuguese volleyball specifically. Therefore, the purpose of this study is to analyze and compare variations in technical actions of players' in-game roles in terms of total points, breaking points (counter-attack – when the team tries to block or dig the ball) as well as the point/error relationship in the Portuguese Volleyball First Division league during the 2017/2018 season.

Material and Methods

The study included the fourteen teams that participated (100% of the teams) in the male First Division Portuguese Championship during the classification phase of the 2017/2018 season (October to March). This study included 80 matches (with a total of 295 sets) and analyzed 131 athletes. We opted to select only the players who participated in the game and performed at least one technical action included in the match report.
The study followed the ethical recommendations of the Declaration of Helsinki for the study of humans.
In each game the players' in-game roles (positioning) were determined and classified by two independent observers with a coaching license (level I) and 5-year experience in volleyball. The in-game roles were classified as: (i) outside hitter (the player who hits and blocks on the front left side of the court); (ii) middle blocker (a player at the net in the middle of the court among two outside blockers); and (iii) opposite (a player on the right side in the front and back row). The players' in-game roles were defined as independent variables of the present study.
The data of game action (total points, points obtained in breaking points and the point/error) made by players were collected using the Data Volley and Click & Scout statistical programs after video recording the matches. The total points represented the total points obtained in the match, the breaking points represented the points obtained in the break-point phase; the relationship between winning points and errors was determined as point/error. It was defined as an error when the athlete misses a serve or an attack. The reception error was not included in the analysis, because it is not a terminal action.
The data were collected using the Data Volley and Click & Scout statistical programs after video recording matches with a SONY FDR-AX33 camera, which was positioned behind the volleyball court (Figure 1).

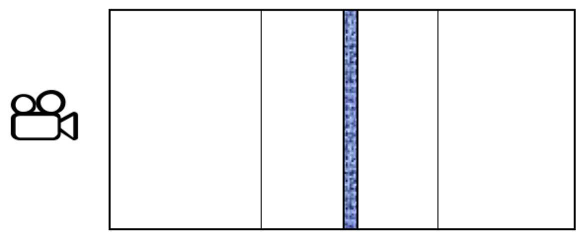

Figure 1. Video Cam SONY FDR-AX33 positioned behind the pitch

Data Volley is a statistical program that is used by top volleyball teams, because it can analyze game actions by player, skill, and rotation. It also provides the general statistics of teams and a video analysis program is integrated into the software [5]. The Click & Scout statistical software is an important tool for analyzing the game actions of a team and its opponents [28]; it also provides feedback concerning matches [25].

Coleman [3] suggested that these software packages allow users to achieve intra-observer reliability values of 0.96-1.00 and inter-observer reliability values of 0.98-1.00. In our case, 5% of the full data set was used to test observers' intra- and inter-reliability. The test-retest was performed for the first games of the season, which took place over a 30-day interval during the beginning of the data collection period. The intra-class correlation test (ICC), two-way mixed and absolute agreement tests revealed good intra-reliability (ICC = 0.76) and inter-reliability values (ICC = 0.81). These values were consistent with those recorded in other studies [10, 25].

All the data were obtained from official match reports of the matches played in the male First Division Portuguese Championship between September 2017 and April 2018. These match reports included analyses of the following variables: total points (total points scored during the match), points obtained in the break-point phase and the relationship between winning points and errors (attack, service, and reception errors).

The results are presented in the form of means and standard deviations. The data were tested for the normality and homogeneity of variance before the inferential statistical tests. After the assumptions of normality and homogeneity ($p > 0.05$) were compared using the Kolmogorov–Smirnov and the Levene tests, respectively, one-way ANOVA was executed to analyze the variations in actions of players' in-game roles. Additionally, the Tukey post-hoc test was used for pairwise comparisons. These statistical procedures were executed in the SPSS software (version 24.0, IBM, Chicago, USA) for $p < 0.05$. For the pairwise comparisons the standardized differences of effect size (ES) with 95% confidence interval (CI) were also calculated [25]. The following scale was used to interpret the magnitude of differences [25]: [0.0; 0.2] trivial; [0.2; 0.6] small; [0.6-1.2] moderate; [1.2] large. The computation of statistical procedures was performed in a specific spreadsheet of Hopkins et al. [9].

Results

Descriptive statistics can be found in Figure 2. Opposites scored more 5.89 and 3.66 total points than middle

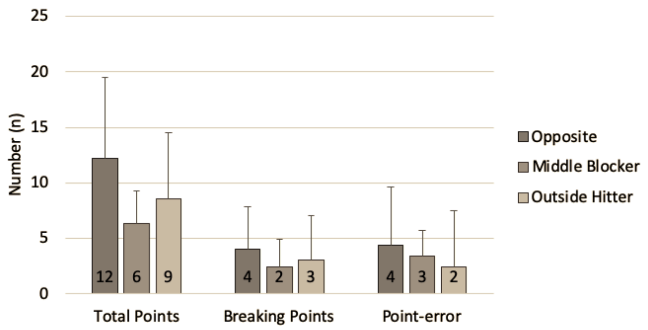

Figure 2. Descriptive statistics (M ± SD) of the total points, breaking points and point/error relationships made by match between in-game role (average per player)

Table 1. Total points, breaking points and point-error relationships made by match between in-game roles

	% difference [95%CI]	Pairwise p-value	ES [95%CI] and magnitude
Total Points			
outside hitter vs middle blocker	31.4 [20.3; 43.5]	<0.001	0.39 [0.27; 0.52] small ES
outside hitter vs opposite	−30.6 [−37.5; −22.9]	<0.001	−0.52 [−0.67; −0.37] small ES
middle blocker vs opposite	−47.1 [−52.4; −41.3]	<0.001	−0.91 [−1.05; −0.76] moderate ES
Breaking Points			
outside hitter vs middle blocker	26.8 [16.2; 38.3]	<0.001	0.36 [0.23; 0.49] small ES
outside hitter vs opposite	14.6 [1.6; 29.3]	<0.001	0.20 [0.02; 0.38] small ES
middle blocker vs opposite	−33.9 [−40.5; −26.5]	<0.001	−0.61 [−0.77; −0.46] moderate ES
Point/Error			
outside hitter vs middle blocker	4.0 [−7.1; 16.4]	0.021	0.05 [−0.10; 0.21] trivial ES
outside hitter vs opposite	−21.5 [−31.7; −9.8]	<0.001	−0.31 [−0.48; −0.13] small ES
middle blocker vs opposite	−24.5 [−33.8; −14.0]	0.064	−0.36 [−0.52; −0.19] small ES

Note: 95%CI – confidence interval of 95%; ES – effect size (standardized effect size of Cohen) blockers and outside hitters, respectively. Moreover, opposites executed more 1.58 and 0.9 breaking points than middle blockers and outside hitters, respectively. Finally, middle blockers and outside hitters scored 0.98 and 1.94 point/error units fewer than the opposite.

One-way ANOVA revealed significant differences among in-game roles in the variables of breaking points ($F_{(2;918)} = 27.680$; p = 0.001), point/error ($F_{(2;918)} = 10.512$; p = 0.001) and total points ($F_{(2;918)} = 77.190$; p = 0.001). Pairwise comparisons of the total points, breaking points and point/error by in-game roles can be found in Table 1.

Discussion

This paper aimed to analyze and compare variations in different technical actions of players' in-game roles in terms of total points, breaking points as well as the point/error relationship in the Portuguese Volleyball First Division league during the 2017/18 season. The findings provide insights that could elucidate the current trends seen in the elite of volleyball teams. The main results demonstrated that considering total points moderate decreases were found for middle blockers vs opposites, while small decreases were found for outside hitters vs opposites, and finally small increases were found for outside hitters vs middle blockers. Therefore, game action position roles can be analyzed during matches in the Portuguese league and other national and international leagues in the same way.

Similar results were found in other studies that analyzed variations in the technical actions and their efficacy as well as probabilistic relationships predicting outcomes relating to attack players in elite-level men's volleyball [2,14]. Regarding previous studies, the opposite is the player most solicited in attack actions and who has the greatest and the most efficacy attack contribution followed by the outside hitter and finally by the middle blocker [11]. In this way, knowing such patterns will enhance the rate of success for the defending teams, while the attacking teams should try to create strategies of using each set of game constraints in a different manner. Consequently, this result might be considered sensible; thus, while the opposite player must have solid resources to attack under difficult situations [1], the outside hitter is a double-task player (receiving and attacking), so he needs to focus on more than one action [16]. In turn, the middle blockers require a strong reception quality to attack, this player is not solicited often when a team does not have high quality receptions [15].

During the breaking point phase as the total point variable result, the opposite player is the most requested player when compared with the middle blockers and outside hitters. The results could be justified by the breaking-point phase when often the team with ball possession plays with only two options to finish the rally. As a result, despite the unfavorable conditions the outside hitters manage to execute power attacks in the majority situations and score a high frequency of attack points [1]. Likewise, a study that compared the total attacks, points in the defense phase and attack efficiency players' in-game roles in Portuguese men's volleyball teams revealed that the opposite player is the one that scores more total attacks and total points in a game than any other player [13].

Regarding the point/error ratio variable, small decreases were found for middle blockers vs opposites and outside hitters vs opposites. Also, small differences were found for outside hitters vs middle blockers.

In the same line of thought, a study that tried to identify the performance indicators during the Complex II phase found that the best predictors of team success are related to the sequences of defending, setting and counter-attacking [24]. Consequently, in counter-attacks (after defense) the setter rarely has a perfect ball, so the first-priority player to hit the ball is the opposite, while the second-priority player to hit the ball is the outside hitter [1].

Although as previously mentioned, this study did not predict wins or losses; instead, it revealed the importance of counter-attack actions from different players' in-game roles. Some studies have showed that the relationships between digs, sets and counter-attacks predict match outcomes [18, 23, 27]. Furthermore, same studies have revealed that attack efficacy and service actions could also predict best performance in Complex II, so teams which improve their actions during this phase tend to increase their probability of scoring a point and consequently win the match. Regarding Complex I, several studies that tried to identify play structure variables between top-level teams and second-level teams in international men's volleyball, revealing that there are no differences between these types of teams regarding side-out actions [6, 13, 20]. Such results show a general trend and indicate the importance of coaches having their teams spend more time practicing Complex II actions regardless of the team level.

This study has some limitations. Only one national league was analyzed and possibly inferences should be carefully generalized. In addition to the comparison between players' in-game roles, it would be interesting to analyze the influence of game actions on the final result of the match. Further research is needed to compare technical actions and different game phases (Complex I and II) between players' in-game roles in different leagues.

Conclusions

Our findings indicate that the opposite is the player who scores the most points. The opposite has greater point/error values than the outside hitter and middle blocker. Meanwhile, outside hitters scored slightly more breaking points than opposites and middle blockers. The patterns found in this study could guide coaches in planning their practice-design strategies. Coach strategies can be improved by adjusting the block position to the opposite opponent player instead of the middle blocker or the outside hitter during the break-point phase. Moreover, coaches need to focus their practices on improving the efficacy of the attack in the counter-attack and transition phases for both outside hitter and opposite players.

Conflict of Interests

The authors state no conflict of interest.

Acknowledgments

This study made part of one curricular unit of Sports and Leisure Degree at Escola Superior de Desporto e Lazer, Instituto Politécnico de Viana do Castelo, Portugal.

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ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2021; 28(**2**): 159-163
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.2-10

Expecting to teach promotes motor learning of a golf putting task in children

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Abstract
Introduction. Researchers have shown that the learners achieve higher levels of learning when they learn with the aim and expectation of teaching their content to others. Recently some motor behavior researchers have also examined this learning method, and have indicated that expecting to teach others improves motor learning in adults. The purpose of the present study was to examine the effect of expecting to teach others on the learning of a golf-putting task in children. Material and Methods. Participants consisted of 24 children (all males; M_{age} = 9.58; SD = 0.50 years) who were randomly assigned into two experimental groups. Participants in the group expecting to teach others were instructed as follows: "given that you have to teach golf putting to some people the day after the acquisition phase, you have the opportunity to practice this skill carefully today and tomorrow". Participants in the group expecting to be tested received the following instructions; "you have the opportunity to practice this skill carefully today and tomorrow expecting to be tested in this skill". Results. The results showed that the children in the group expecting to teach others had better accuracy scores relative to children in the group expecting to be tested in the retention phase ($p \leq 0.05$). Conclusions. The findings of this study suggest that promoting the expectation to teach others would improve motor learning in children.

KEYWORDS: expecting to teach, golf putting task, motor learning, children.

Received: 24 September 2020
Accepted: 26 January 2021

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Introduction

When you try to learn new information, you usually set a specific goal to use that information in the future. For example, learners often learn with the goal of increasing their future performance; in contrast, educators (teachers and coaches) learn primarily with the goal of enabling themselves to convey educational material more effectively to learners [13]. One of the new ways to learn is to combine these two goals.
Researchers have shown that the learner achieves higher levels of learning when he/she learns with the aim and expectation of teaching his/her content to others [2, 3, 5, 10, 11]. As one of the first studies in this field, Bargh and Schul [2] introduced three main and important components in the teaching process: preparing to teach, providing the teaching material, and receiving the feedback while answering learners' questions. They believed that engaging in the first stage of the teaching process, i.e. preparing to teach, is an important element in the teaching process. In other words, the results of their pioneering study showed that a person achieves higher learning outcomes when he/she prepares him/herself to teach that material to others. This finding has been confirmed by further studies [3, 13].
For example, Nestojko et al. [13] in another study found similar results. They had two groups of participants in their experiment. The first group was told, "you will study the text and material and immediately after that, you should teach what you have learned to another group of learners without access to the material". In contrast, there was a second group who were told "you will study the text and material and immediately

after that, you would take an exam". The results showed that the participants in the group expecting to teach group had a better recall of the text and answered more questions concerning the text than the other group. Those researchers believed that when learners think they should teach what they are learning to others, they engage in more effective processes and strategies of learning and therefore achieve higher learning outcomes. Benware and Deci [3] also reported similar findings.

However, some findings have shown that this learning approach may not necessarily achieve high levels of learning efficacy for all individuals [11, 14]. For example, Renkl [14] found that people who studied with an expectation to teach others were not superior to those, who studied with an expectation to be tested. The researcher attributed the probable reason for this lack of superiority to the stress and anxiety of people in the first group. Fiorella and Mayer [11] also reported that learning by expecting to teach can only improve learning in the short term. In a study conducted by the researchers, participants learned a lesson concerning the Doppler effect under two conditions of expecting to teach it to others (without real teaching) or expecting to be tested. Individuals who were instructed to expect to teach others performed better than the other group in short-term learning. However, these individuals did not perform better in the long-term learning that occurred the previous week.

Major research in this field has focused on cognitive learning and academic information. Academic information is based on declarative knowledge, while learning motor skills and motor perceptual skills are more based on procedural knowledge that has a different mechanism [4]. Therefore, the expectation of teaching effects can be different in motor skill learning, so examining this new practice method in motor skill learning can be important.

Recently, Daou et al. [6] in one of the first studies in the field of motor skills learning directly examined the effect of learning by expecting to teach in a golf putting task compared to the learning by expecting to be tested. In their study there were two groups of adults, one group practiced a golf putting task expecting to teach it to others (the teaching group) and the other group practiced the golf putting task expecting to be tested (the test group). The purpose was to determine whether learning by expecting to teach improves motor learning. Their results showed that learning by expecting to teach directly improves motor skill learning. In other words, these practice methods had the ability to improve procedural knowledge.

In another study, Daou et al. [9] examined this effect using a similar method. In their study they sought to find basic mechanisms that provide the advantage of learning by expecting to teach others and examined the key concepts related to movement in a free recall test. However, motivation and anxiety have nothing to do with the benefit of learning with the expectation to teach, but due to the improvement of declarative knowledge during this new method the recall of key skill-related concepts was improved. This group of researchers in several studies indicated benefits of learning by expecting to teach compared to other test groups [6-9]. However, some studies have shown that learning by expecting to teach will not be effective in situations under high psychological pressure. For example, Daou et al. [7] in another study examined the effectiveness of learning by expecting to teach in stressful situations. They sought to examine whether the advantage created by the expectation to teach is sustainable in certain situations, such as high psychological pressure, and concluded that the motor skill learning efficacy deteriorated in the situations when people practice in a group with expectation to teach. Since this method enhances the learner's declarative knowledge in accordance with the reinvestment theory [12], it causes a decline in performance in certain situations such as stress and high psychological pressure. Of course, this decline in performance is manifested in a way that they perform similarly to someone who has practiced the skill without expecting to teach [7]. Given that this research topic in the field of motor learning is relatively new, there are still many ambiguities in this area. For example, can this new practice method improve children's motor learning in the same way as adults? Since children follow different patterns in the process of motor skill learning than adults and in order to generalize and examine the findings of the above-mentioned studies in other age groups as well, the present study seeks to investigate the effect of this new practice method on learning of a golf putting task in children.

Material and Methods

Participants

The present study was a quasi-experimental study and was conducted in two experimental groups over three days. Participants included 24 children (all males; M_{age} = 9.58; SD = 0.50 years) who were recruited and randomly assigned to one of two experimental groups: motor skills practice by expecting to teach versus skills practice by expecting to be tested in it. The criterion for estimating the sample size was according to the previous studies in this area [15]. The inclusion criteria for participation in the study were as follows: 1. not having any previous experience in performing the golf putting task, 2. being in good health, 3. being right-handed. The criteria for exclusion from the study were as follows: 1. lack of desire to continue cooperation in research, 2. having any skeletal and neurological disorders and problems. The participants were unaware of the purpose of the study. Informed consent forms were completed by parents of the participants based on the conscious consent to participate in the research and being able to leave the study freely. All experimental methods were approved by a university Institutional Review Board.

Task

The target was an artificial putting mat with the dimensions of 400-cm length and 100-cm width, a hole at the center of a target. The putting task required children with the right-hand dominance to put a standard golf ball towards a hole at the center of the target. The starting line was placed 200 cm away from the hole at the center of the target. The dimensions of the ground, the ball, and the target point were selected based on previous researches [1]. The task goal was to stop the ball as close as to the center of the target as possible. The distance between the target center and the edge of the ball was used as a radical error (RE) index after each trial to measure the accuracy of golf putting.

Procedure

All the participants completed the experiment individually. After consenting to participate, they completed a demographic questionnaire. They also completed the Edinburgh Handedness Inventory to determine their handedness. The experiment took place during a free time activity in an elementary school. Participants then completed 10 practice trials of the golf putting skill for an initial assessment of their motor function. In particular, in the present study, based on previous research [6], the participants were randomly assigned into two experimental groups in the acquisition phase of golf putting and performed 6 blocks of 10 trials per day with a 5-minute break between blocks for two days. One group practiced the skill by expecting to teach it to others, so the participants received instructions prior to starting each practice block: “given that you have to teach golf putting to some people the day after the acquisition phase, you have the opportunity to practice this skill carefully today and tomorrow” (the teach group), while the other group received instructions prior to starting each practice block: “you have the opportunity to practice this skill carefully today and tomorrow expecting to be tested in this skill” (the test group). These instructions were approximately similar with previous research in this area [6, 9]. As soon as the third day of the test started, participants in the teach group were told “the participants who you were going to teach did not show up today, so you will actually be tested on your putting instead”. In this way, both the teaching and testing groups performed retention tests (10 trials). The groups performed a transfer test (10 trials) from the starting line, which was placed 300 cm away from the hole.

Data analysis

Parametric tests such as an independent t-test, mixed ANOVA, one-way ANOVA and the Bonferroni post hoc test were used to compare the groups at the acquisition phase, retention and transfer tests, respectively. Alpha levels were set to 0.05 for all the tests using the SPSS software, version 24. To calculate the strength of the results, partial-eta-squared was applied. These effect-sizes were defined as follows: $\eta_p^2 = 0.01$ as small, $\eta_p^2 = 0.06$ as medium and $\eta_p^2 = 0.14$ as large [4].

Results

Table 1 shows the mean and standard deviations of some of the individual variables of participants in the experimental groups at the beginning of the study. The results of the t-test indicated that the outcome performance was not significant between the groups in the pretest ($p = 0.53$).

Table 1. Demographic characteristics of group participants

Characteristics	Groups (Mean ± SD)		p-value*
	Teach	Test	
Age (year)	9.58 ± 0.51	9.50 ± 0.52	0.69
Height (cm)	138.00 ± 7.27	136.83 ± 6.75	0.68
Weight (kg)	38.25 ± 7.59	38.92 ± 7.05	0.82
Golf putting task (pretest [cm])	55.33 ± 18.59	50.50 ± 19.13	0.53
Gender	Male	Male	

* The significance level was set as $p \leq 0.05$

Motor performance

Acquisition

The results of 2 (two experimental groups) by 6 (the number of practice blocks) mixed ANOVA on the accuracy of golf putts in the acquisition phase showed that although the main effect of the acquisition block was significant ($F(5,110) = 4.72$, $p = 0.001$, $\eta_p^2 = 0.17$), the main effects of the group ($F(1,22) = 0.002$, $p = 0.96$, $\eta_p^2 = 0.001$) and the interaction effect ($F(5,110) = 0.81$, $p = 0.53$, $\eta_p^2 = 0.003$) was not significant. In other words, it was found that participants in both experimental groups experienced significant improvements during the practice trials, but no significant difference was observed between the two groups (Figure 1).

Retention and transfer

The results of one-way ANOVA in the retention test showed that there is a significant difference between the two experimental groups ($F(1,23) = 5.82$, $p = 0.02$, $\eta_p^2 =$ $= 0.20$) and the performance of the teach group is higher than that of the test group. However, the results of one-way ANOVA in the transfer test showed that there is no significant difference between the two experimental groups ($F(1,23) = 0.34$, $p = 0.56$ $\eta_p^2 = 0.01$) and the performance levels of the teach group and the test group were the same.

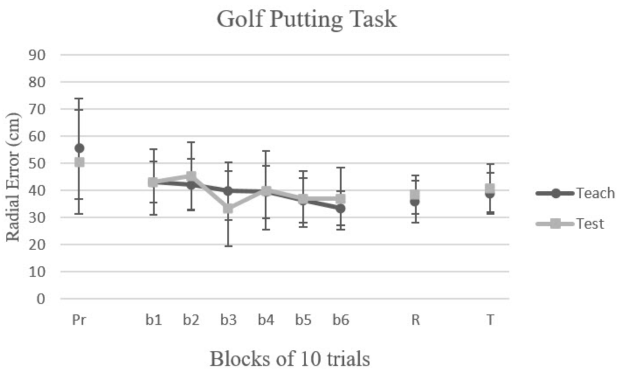

Figure 1. Radial error (RE) during pretest, acquisition, retention and transfer test (all bocks of 10 trials) for two experimental groups

Discussion

The aim of the present study was to compare the effect of two learning methods, i.e. learning by expecting to teach versus learning by expecting to be tested, on motor learning of a golf putting task in children. It was predicted that expecting to teach could increase motor learning. The findings of this study showed the performance of the children that have been practicing a golf putting task for two days by expecting to teach was better than that in the learning by expecting to be tested group in retention tests, but they showed no significant superiority in the acquisition phase or the transfer phase. To the best of our knowledge, these findings are one of the first findings on the impact of learning by expecting to teach on motor performance and learning in children and they are in line with previous studies in the field [2, 3, 6, 7, 9, 13].

There are several mechanisms to explain the superiority of learning by expecting to teach in research literature. Some researchers in their first explanation of the superiority of learning by expecting to teach versus learning by expecting to be tested attribute to the increase of learners' motivation due to their awareness of how effective they are in improving other people's behavior. For example, some studies have directly shown that learning by expecting to teach increases learner's motivation [11]. One of the limitations of the present study was the lack of a direct measurement of participants' motivation; however, according to the previous proposed mechanisms the superiority of the learning group by expecting to teach can be attributed to the expected improvement of participants' motivation [13].

In the second explanation, especially in learning of academic information, it is stated that the participants in the learning by expecting to teach group identify more key concepts related to skills because teaching requires summarizing important and effective points [13]. In other words, learning by expecting to teach increases free recalling of the main points in the text. Therefore, this mechanism can also explain the superiority of learning in the teaching group with the expectation of learning in the present study.

The findings of the present study are consistent with the major research conducted with respect to the superiority of the learning group by expecting to teach compared to the learning group by expecting to be tested in motor learning in the retention and transfer tests [6, 9]. For example, Daou et al. [9] concluded in a study that the learning method by expecting to teach improves motor learning and also increases information process prior to any practice trial. However, it is not clear what kind of information is processed during the preparation period. Therefore, the reason for a possible superiority of the learning group with the expectation to teach can be interpreted as the fact that participants in the motor preparation may have thought more about the effects of movement on the environment (adopting an external focus of attention) and have focused less on generating movement (adopting an internal focus of attention). It is worth noting that most previous research on the focus of attention has reported the superiority of the external focus of attention over the internal focus of attention [16, 17].

Conclusions

In summary, the findings of the present study showed that teaching golf putting with an expectation to teach others improved the motor learning of children rather than teaching golf putting with an expectation to be tested. Therefore, it is suggested that this new method of practice should be used more in educational environments such as coaching. However, the present study also had some limitations. For example, the number of participants as well as the duration of the skill practice can be considered as a limiting factor for the positive effects of learning with expectation to teach. Therefore, it is recommended that researchers conduct more research in this area by eliminating the above-mentioned limitations. This study involved children and a golf putting task, so it is recommended that future studies should use other age groups such as the elderly as well as other activities.

Conflict of Interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Acknowledgments

We would like to thank all of the participants, their families and the schools who took part in this study.

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The size of original and review articles should not exceed 20 pages, including references, tables, figures, and abstract (standard page – 1800 characters). No more than 30 references (in review articles 45) should be provided.
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3. Article published electronically ahead of the print version: Yu WM, Hawley TS, Hawley RG, Qu CK. Immortalization of yolk sac-derived precursor cells. Blood. 2002 Nov 15;100(10):3828-3831. Epub 2002 Jul 5.

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1. Gardiner PF. Advanced neuromuscular exercise physiology. Champaign: Human Kinetics; 2011.

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References to book chapters should include surname(s) of the author(s) of the chapter with first name initials without periods (list the first six authors followed by et al.), chapter title, and after indicating In: surname(s) of the author(s)/editor(s) with first name initials, the title of the book, number of edition (not required for the first edition), city and name of the Publishing House and year of publication followed by page numbers of the chapter, e.g.

1. Renson R. Sport Historiography in Belgium. Status and Perspectives. In: Renson R, Lämmer M, Riordan J, editors. Practising Sport History. Sankt Augustin: Akademia Verlag Richarz; 1987. pp. 1-18.

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Use only standard abbreviations and symbols. The expansion of an abbreviation should precede its first use

Table 1. Descriptive statistics and comparative analysis of maximal oxygen uptake (VO_2max in $ml/kg \cdot min^{-1}$) 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

in the text and be repeated in the legend under a figure or a table in which the abbreviation is used.
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