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Physical Exercise and Cognitive Function in Post-stroke Patients: A Systematic Review with Meta-Analysis

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Abstract

Up to 80% of stroke survivors have cognitive dysfunction, which affects motor function and quality of life. There is a need to understand which physical activity prescription is most recommendable for cognitive function and to determine the effect of physical exercise programmes on cognitive function in post-stroke patients by identifying the best frequency, length and type of programme. The PRISMA guidelines were followed and the methodology was registered in PROSPERO (number CRD42020183529). The studies chosen were randomised controlled trials. The search was conducted in four databases, namely PubMed, Cochrane, SPORTDiscus and WOS, and concluded on 12 June 2020. Methodological quality was assessed using the PEDro scale score. The meta-analysis reveals that the experimental group had greater gains in cognitive function than the control group (SMD = 2.26; *p* .001). It shows that there is a greater effect on cognitive function in studies which include an adult population versus those that include an older adult population (SMD = 1.82; *p* = .014). Strength training provides a significantly greater gain than aerobic training (SMD= –1.88; 95% CI –3.7, –0.1; *p* = .040). A physical exercise programme significantly improves cognitive function in post-stroke patients and may have a greater effect than rehabilitation programmes. The programme should last at least six weeks, with a frequency of three sessions per week and a per-session length of at least 30 minutes.

Keywords: cardiovascular disease, combination training, endurance training, physical activity, rehabilitation, strength training.

Introduction

Stroke is one of the leading causes of disability and death worldwide (Go et al., 2014). Specifically, more than 14 million people suffer a stroke each year, and around 10% of them die (Carnesoltas et al., 2013). Suffering a stroke has a negative impact on the subsequent quality of life of those who manage to survive it, since it affects all areas of the individual: physical health and psychological state are reduced, autonomy and independence are diminished and cognitive function (executive, attention and memory) is significantly impaired (Mesa et al., 2016). Up to 80% of stroke survivors experience cognitive dysfunction, directly influencing motor function and quality of life (Sun et al., 2014), and stroke is the second leading cause of dementia worldwide (Alvarez, 2008). Although post-stroke patients may recover from the ensuing physical after-effects, cognitive impairments may restrict autonomy and independence (Gottesman & Hillis, 2010; Wagle et al., 2011). Identifying effective treatments to improve cognitive function is therefore of paramount importance (Debreceni-Nagy et al., 2019), and a multidisciplinary rehabilitation approach is needed to improve levels of motor and functional disability (Go et al., 2014).

Physical inactivity is a known predictor of stroke, as a sedentary lifestyle is associated with a higher probability of having one (Martínez-Vila & Irimia, 2000). Similarly, exercise can improve quality of life in the general population (Solà-Serrabou et al., 2019) and also be of benefit to the cardiovascular system (Betrán Piracés et al., 2003) and cognitive function in individuals after suffering a stroke in both executive functions and memory (Freudenberger et al., 2016; Vanderbeken & Kerckhofs, 2016; Yeh et al., 2019).

Some authors have conducted systematic reviews to synthesise the research on the effect of physical exercise on cognitive function in people who have had a stroke (Cumming et al., 2012; Oberlin et al., 2017). However, these studies include intervention programmes which combine physiotherapy and physical exercise and do not report which frequency, length or type of exercise has the greatest benefits for cognitive function in post-stroke patients. Therefore, the objectives of this systematic review with meta-analysis were: a) to determine the effect of physical exercise on cognitive function in post-stroke patients, and b) to synthesise the original studies on the effect of physical exercise programmes on cognitive function in post-stroke patients to identify the best frequency, length and type of programme.

Methodology

Study design

The studies included in this systematic review and meta-analysis examine the effect of various physical exercise programmes on cognitive function in post-stroke patients. The studies chosen were randomised controlled trials (RCTs). The search strategy, together with the inclusion criteria and additional information, was registered beforehand in the PROSPERO international database of prospectively registered systematic reviews (number CRD42020183529). This systematic review with meta-analysis follows the principles set out in the PRISMA (Preferred Reporting Items for Systematic Reviews) guidelines (Liberati et al., 2009; Moher et al., 2015).

Inclusion criteria

The inclusion criteria were: a) articles published in indexed journals, b) articles published in English, Spanish and Portuguese only, c) articles involving patients who had previously suffered a stroke, d) RCTs, and e) studies implementing a physical exercise programme. The exclusion criteria were: a) studies in progress, b) studies involving people with amputation/limitation of any limb that contraindicates walking/exercise, c) studies published as abstracts, notes or letters to the editor or short publications, d) studies published at conferences, and e) studies implementing physiotherapy programmes, manipulation and/or breathing techniques in conjunction with physical exercise.

Search strategies

The following search engines were used to search for information: PubMed, Cochrane, Sport Discus and WOS. The search strategy was based on the use of keywords and Boolean operators, including: *stroke* AND *physical activity*, *stroke* AND *sport*, *stroke* AND *strength training, stroke* AND *endurance training, stroke* AND *resistance training, stroke* AND *physical therapy*, *stroke* AND *aerobic training*, *stroke* AND *endurance exercise, stroke* AND *aerobic exercise, stroke* AND *strength exercise* and *stroke* AND *resistance exercise*. The search ended on 12 June 2020. The flowchart is shown in Figure 1.

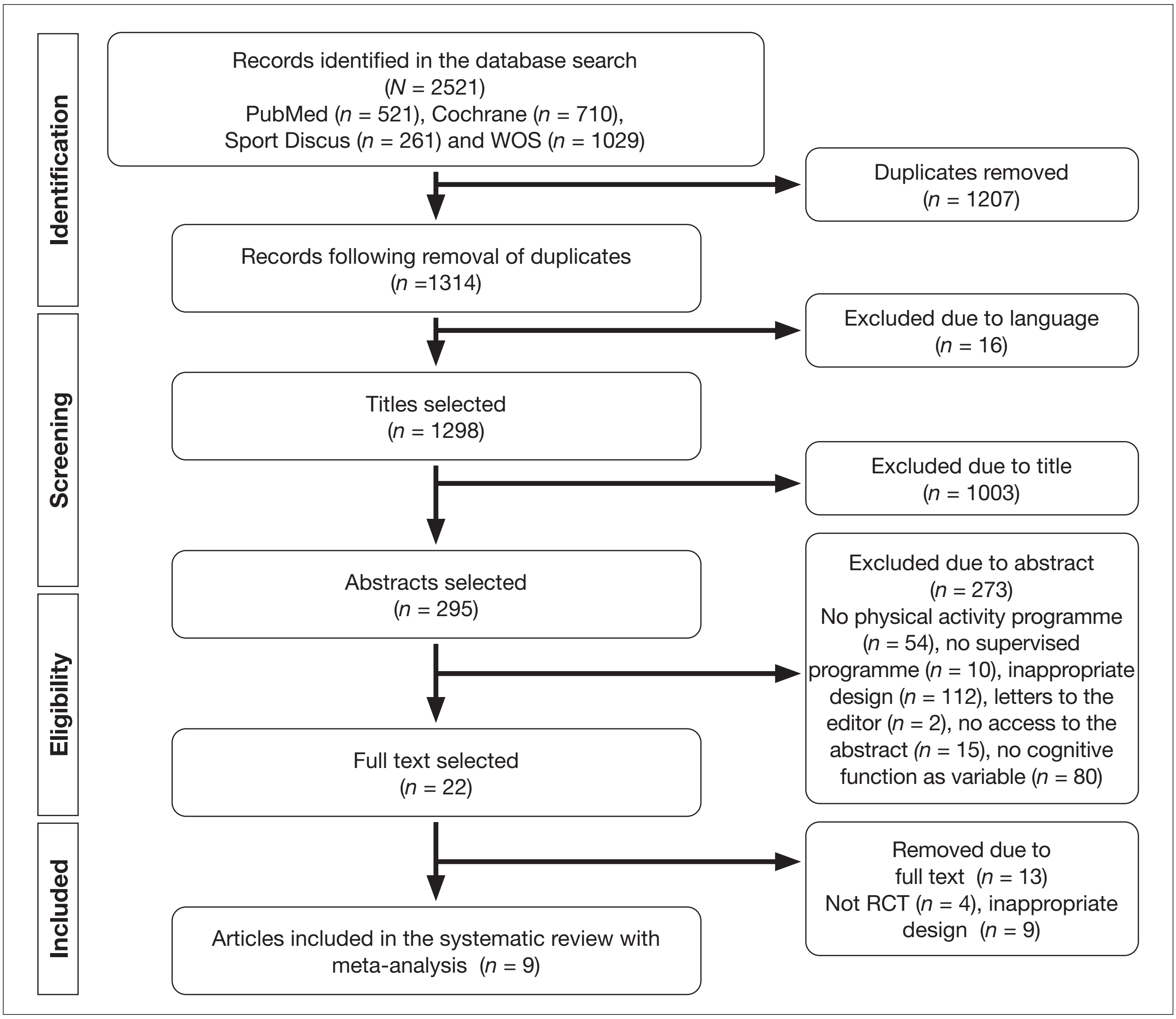

Figure 1
PRISMA flowchart.

Data extraction

Data extraction and quality assessment were performed by two reviewers (AGH and NGG) independently. Disagreements over information were resolved by repeating data extraction or unobserved assessment of information from previously conducted reviews. In this regard, Cohen's Kappa index was calculated, presenting high inter-reviewer reliability (Kappa = .810) (McHugh, 2012).

Assessment of methodological quality

The Physiotherapy Evidence Database (PEDro) scale was used to assess the methodological quality of the included studies (Maher et al., 2003). Table 1 shows the PEDro scale scores for each study, assuming values of 8, which was considered acceptable.

Data analysis

The statistical analysis and meta-analysis were performed using the Comprehensive Meta-Analysis program (version 3, Englewood, USA). For the analysis of this study, the quantitative mean and standard deviation of the pre-test and post-test, as well as the sample size, were used for the control group and the experimental group. Pre-/post-test changes were calculated for analysis. When the same study included several sub-variables of cognitive function, these were included as different cases in the analysis. If the studies did not show the necessary data, these were calculated. SEs and the CIs were used to calculate SD. The DerSimonian-Laird (Cohen's) method was used. Heterogeneity was assessed by means of Cochran's Q test (chi^2), Higgins' I^2 statistic and significance (p) to determine the most appropriate analysis: fixed or random

Table 1
Assessment of the methodological quality (PEDro scale) of the articles included.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	Total
Bateman et al. (2001)	1	1	1	1	0	0	0	1	1	1	1	8
Tang et al. (2016)	1	1	1	1	0	0	0	1	1	1	1	8
Khattab et al. (2020)	1	1	1	1	0	0	0	1	1	1	1	8
Studenski et al. (2005)	1	1	1	1	0	0	0	1	1	1	1	8
Kim and Yim (2017)	1	1	1	1	0	0	0	1	1	1	1	8
Ozdemir et al. (2001)	1	1	1	1	0	0	0	1	1	1	1	8
Quaney et al. (2009)	1	1	1	1	0	0	0	1	1	1	1	8
Immink et al. (2014)	1	1	1	1	0	0	0	1	1	1	1	8
Bo et al. (2019)	1	1	1	1	0	0	0	1	1	1	1	8

Note. C1: choice criteria were specified; C2: subjects were randomly assigned to groups (in a crossover study, subjects were randomised as they received treatments); C3: allocation was concealed; C4: groups were similar at baseline with regard to the most important prognostic indicators; C5: all subjects were blinded; C6: all therapists who administered therapy were blinded; C7: all assessors who measured at least one key outcome were blinded; C8: measures of at least one of the key outcomes were obtained from more than 85% of the subjects initially assigned to the groups; C9: results were presented for all subjects who received treatment or were assigned to the control group or, when this was not possible, data for at least one key outcome were analysed by intention-to-treat; C10: results of statistical comparisons between groups were reported for at least one key outcome; C11: the study provides point and variability measures for at least one key outcome.

effects (Ioannidis, 2008). DerSimonian-Laird (Cohen) was interpreted as small (0 to 0.2), moderate (0.3 to 0.7) or large (≥ 0.8) (Cohen, 1988). Egger's test (Egger et al., 1997) and Fail Safe N (Rosenthal, 1979) were calculated to determine publication bias. A funnel plot was created. Significance was determined at $p < .05$.

Results

Characteristics of the studies

The article selection and search strategy employed in this systematic review with meta-analysis resulted in a total of nine articles.

The included articles were RCTs, and they featured a total of 355 participants in the experimental group and 362 in the control group. The analysed articles were published between 2001 and 2020.

The characteristics of the included studies are shown in Table 2.

Effect of physical exercise on post-stroke patients

The meta-analysis reveals that the effect of physical exercise programmes on cognitive function in post-stroke patients is significantly more beneficial than the effect of any other programme or no programme (Figure 2) (OR = 2.26; 95% CI = 1.0 to 3.5; Z = 3.63; p = < .001).

To examine whether there were differences by possible contaminating variables, subgroups were established by age, length of the intervention in weeks, frequency of sessions per week, length of sessions, type of physical exercise programme and participant age. The age variable was divided between adults (< 65 years) and older adults (≥ 65 years). To make the groups for frequency and length of the programme, the medians of the weeks of intervention, weekly frequency and session length variables were analysed, obtaining 12 weeks, three sessions per week and 60 minutes per session, respectively. The type of physical exercise variable was divided into aerobic, strength or combined training. For the purpose of comparison, changes were transformed into percentages. Table 3 shows the analysis of the effect of the physical exercise programmes included in this systematic review on cognitive function according to the aforementioned classifications. It shows that there is a greater effect on cognitive function in the studies that include the adult population versus those that include the older adult population. When the subgroup with extreme gains in the variable is removed (Ozdemir et al., 2001), the results remain significant (SMD = 1.96; 95% CI 0.4, 3.6; p = .016). A difference is observed in relation to the type of programme implemented significantly favouring strength training over aerobic training. However, this difference is no longer significant after the group presenting an extreme change in the variable is removed (Ozdemir et al., 2001).

Table 2
Characteristics of the included studies.

Author	Sample	Age	Inclusion criteria	Cognitive function measurement tool	CG programme	EG programme	Time Frequency Length
Bateman et al. (2001)	EG = 70 CG = 72	16-65 years; EG = 41.7 ± 14.3; CG = 44.7 ± 13.3	Brain injury	Trail Making Part B (seconds)	Relaxation	AT (cycloergometer) (60-80% HRmax)	30 min 3 days 12 wk
Tang et al. (2016)	EG = 25 CG = 20	50-80 years; EG = 66 (62-71); CG = 64 (62-75)	> year STR; no aneurysms, tumours or infections	Trail Making Part B (seconds)	FFL and balance (<40% HRres)	AT (cycloergometer) (80% HRres)	60 min 3 days 24 wk
Khattab et al. (2020)	EG = 25 CG = 25	50-80 years; MEG= 66.2; FEG = 65.6; MCG = 64.8; FCG = 70.1	>1 year STR; W ski; 50-80 years		FL and balance (<40% HRres)	AT (walking, ergometer, step-ups, etc.) (40-80% HRres)	60 min 3 days 24 wk
Studenski et al. (2005)	EG = 44 CG = 49	EG = 68.5 ± 9.0 CG = 70.4 ± 11.3	30-150 days post STR; W ski 25 steps	FIM	Usual care: physiotherapy and health recommendations	ST with resistance bands, balance and AT (ergometer))	60 min 3 days 12 wk
Kim & Yim (2017)	EG = 14 CG = 15	EG = 50.71 ± 14.81; CG = 51.87 ± 17.42	3 months post STR, cognitive skills in good condition, W ski 10 m	KMOCA	Conventional physical therapy	Conventional physical therapy + physical exercise (ST of the upper limbs and AT with ergometer)	60 min 3 days 6 wk
Ozdemir et al. (2001)	EG = 30 CG = 30	43-80 years; EG = 50.71 ± 14.81; CG = 51.87 ± 17.42	Patients with STR	MMSE	Recommendations for the home	ST and FL	120 min 5 days 8 wk
Quaney et al. (2009)	EG = 19 CG = 19	EG = 64.10 ± 12.30; CG = 58.96 ± 14.68	> months post STR; mobility both H	Trail Making Tests Parts A and B	FL in the home	AT (cycloergometer) (70% HR max)	45 min 3 days 8 wk
Immink et al. (2014)	EG = 11 CG = 11	EG = 56.1; CG = 63.2	>1 year STR	Stroke Impact Scale domains	None	Yoga	90 min 6 days 10 wk
Bo et al. (2019)	EG = 42 CG = 47	EG = 65.12 ± 2.56; CG = 64.36 ± 2.31	>6 months STR; conscious to understand verbal instructions, no serious medical conditions	Trail Making Part B	Cognitive training	AT, ST and balance (Borg scale 13-15)	50 min 3 days 12 wk

Note. EG: experimental group; CG: control group; MEG: male experimental group; FEG: female experimental group; MCG: male control group; FCG: female control group; H: hemispheres; ski: skills; AT: aerobic training; ST: strength training; FL: flexibility; STR: stroke; W: walking; min: minutes; wk: weeks.

	Experimental group			Control group			SMD	95% IC	*p*
	N	M	SD	N	M	SD			
Bateman et al.	70	4.20	0.44	72	3.20	0.42	2.33	1.9; 2.8	<.001
Tang et al.	25	2.70	3.53	25	2.50	3.93	0.05	-0.5; 0.6	.850
Khattab et al.-1	11	19.50	5.67	15	36.30	4.77	-3.25	-4.5; -2.1	<.001
Khattab et al.-2	8	10.80	4.15	10	0.60	3.66	2.63	1.3; 3.9	<.001
Studenski et al.	44	0.40	0.24	49	0.40	0.25	0.00	-0.4; 0.4	1.000
Kim & Yim	14	2.64	1.00	15	0.84	0.81	1.99	1.1; 2.9	<.001
Ozdemir et al. (MMSE)	30	4.83	5.03	30	2.03	2.12	0.73	0.2; 1.3	.007
Ozdemir et al. (FIM)	30	59.63	14.19	30	12.30	12.30	3.56	2.7; 4.4	<.001
Quaney et al.	19	7.95	2.31	19	0.90	2.18	3.14	2.2; 4.1	<.001
Immink et al.	11	11.50	1.74	11	-2.50	1.93	7.62	5.1; 10.1	<.001
Bo et al.	42	11.95	1.09	47	3.36	1.15	7.66	6.4; 8.9	<.001
Total							**2.26**	**1.0; 3.5**	**<.001**

I^2=97% (95% CI=96% to 98%); Rosenthal tolerance index=1336
Overall effect test: Z = 3.63 (p=.00028)

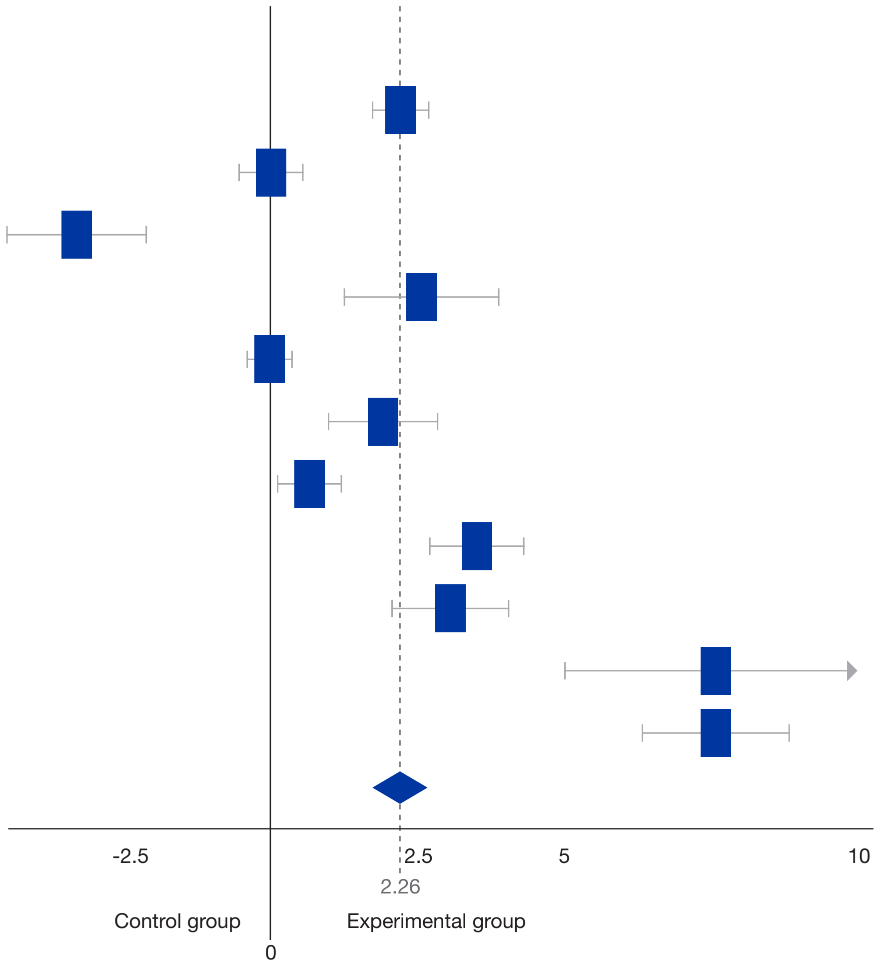

Figure 2
Effects of physical exercise programmes on cognitive function versus control programmes in post-stroke patients.
Note. *N*: sample size; M: mean; SD: standard deviation; SMD: standardised mean difference; 95% CI: 95% confidence interval; *p*: *p* significance value.

Table 3
Analysis of the effect of physical exercise programmes on cognitive function by length in weeks, weekly frequency, session length and type of physical exercise programme implemented.

	Authors	G	SMD	95% CI	SMD	95% CI	*p*
Age							
< 65 years	Bateman et al. 2001; Kim & Yim, 2017; Ozdemir et al. 2001; Immink et al. 2014	5	23.47	7.3; 39.6	1.82	0.4; 3.3	.014
≥ 65 years	Tang et al. 2016; Khattab et al. 2020; Studenski et al. 2005; Quaney et al. 2009; Bo et al. 2019	6	4.47	–2.8; 12.3			
Weeks							
< 12 wk	Kim & Yim, 2017; Ozdemir et al. 2001; Quaney et al. 2009; Immink et al. 2014	5	21.97	4.4; 39.6	1.33	0.0; 2.7	.051
≥ 12 wk	Bateman et al. 2001; Tang et al. 2016; Khattab et al. 2020; Studenski et al. 2005; Bo et al. 2019	6	6.02	–3.3; 15.3			
Frequency							
3 ses/wk	Bateman et al. 2001; Tang et al. 2016; Khattab et al. 2020; Quaney et al. 2009; Bo et al. 2019	7	6.66	–1.0; 14.3	–1.16	–2.5; 0.2	.091
> 3 ses/wk	Kim & Yim, 2017; Ozdemir et al. 2001; Immink et al. 2014	4	24.83	1.6; 48.1			
Session length							
< 60 minutes	Bateman et al. 2001; Quaney et al. 2009; Immink et al. 2014; Bo et al. 2019	4	9.35	–7.9; 26.6	–0.44	–1.7; 0.8	.492
≥ 60 minutes	Tang et al. 2016; Khattab et al. 2020; Studenski et al. 2005; Ozdemir et al. 2001; Kim & Yim, 2017	7	15.51	1.9; 29.8			
Exercise type AT *vs*. ST (groups)							
AT	Bateman et al. 2001; Tang et al. 2016; Khattab et al. 2020; Quaney et al. 2009	5	10.46	3.3; 17.6	–1.88	–3.7; –0.1	.039
ST	Ozdemir et al. 2001; Immink et al. 2014	3	28.87	–8.1; 65.9			
Exercise type AT *vs*. AT+ST (groups)							
AT	Bateman et al. 2001; Tang et al. 2016; Khattab et al. 2020; Quaney et al. 2009	5	10.46	3.3; 17.6	1.11	–0.5; 2.7	.163
AT+ST	Studenski et al. 2005; Kim & Yim, 2017; Bo et al. 2019	3	2.34	–21.5; 26.2			
Exercise type ST *vs*. AT+ST (groups)							
ST	Ozdemir et al. 2001; Immink et al. 2014	3	28.87	–8.1; 65.9	2.12	–0.1; 4.3	.056
AT+ST	Studenski et al. 2005; Kim & Yim, 2017; Bo et al. 2019	3	2.34	–21.5; 26.2			

Note. G: groups; AT: aerobic training; ST: strength training; ses: sessions; wk: week.

Discussion

The first objective of this systematic review with meta-analysis was to determine the effect of physical exercise on cognitive function in post-stroke patients.

The meta-analysis revealed that physical exercise has a significant positive effect on cognitive function compared to the control group. These results are in line with other research (Cumming et al., 2012; Oberlin et al., 2017). Cumming et al. (2012) conducted a systematic review including 12 studies. Their meta-analysis of nine of the studies showed an improvement in favour of the experimental group, although it was not significant (SMD= 0.20; $p = .719$). Oberlin et al. (2017) performed their meta-analysis including a total of 14 RCTs. These authors also found a significant improvement (SMD = 0.304; $p < .001$).

It should be noted that both Cumming et al. (2012) and Oberlin et al. (2017) featured physiotherapy intervention programmes in their inclusion criteria in addition to physical exercise programmes. In this regard, this meta-analysis has a larger effect size on cognitive function than these studies. Similarly, two of the studies included in this systematic review (Kim & Yim, 2017; Studenski et al., 2005) used a physiotherapy programme in the control group. Studenski et al. (2005) show the same results after applying both programmes, while Kim and Yim (2017) obtained significantly better results in the physical exercise group. These findings suggest that a physical exercise programme can reduce the cognitive decline caused by stroke and its effect may be greater than that achieved with a physiotherapy programme.

The second objective of this systematic review with meta-analysis was to synthesise the original studies on the effect of physical exercise programmes on cognitive function in post-stroke patients by identifying the best frequency, length and type of programme.

As for the age of the participants in this research, four studies implemented their physical exercise programmes in adults (<65 years) (Bateman et al., 2001; Immink et al., 2014; Kim & Yim, 2017; Ozdemir et al., 2001) while five studies used programmes in older adults (≥65 years) (Bo et al., 2019; Khattab et al., 2020; Quaney et al., 2009; Studenski et al., 2005; Tang et al., 2016). The eexamination of whether there were differences in the effect of the physical exercise programme on cognitive function by age suggests that adults improved significantly more than older adults. This might be due to the relationship between age and cognitive decline. Cognitive decline is considered an inevitable part of ageing and can range from mild cognitive impairment to chronic neurodegenerative disease (Karantzoulis & Galvin, 2011). Programmes aimed at older post-stroke patients should probably include other aspects. A systematic review of healthy older adults showed greater improvements in cognitive function after programmes that combined physical exercise and cognitive training compared to those that featured only physical exercise (Gheysen et al., 2018). The paper by Bo et al. (2019) compared a combined training programme with a cognitive training programme and found that the combined training programme yielded greater cognitive function benefits than the cognitive training programme. Consequently, programmes that include a multi-component approach and cognitive training are recommended.

The mean length of the programmes was 13.6 weeks, with an average frequency of 3.8 sessions per week and 55.5 minutes per session. In this regard, the analysis showed that there was no difference between using a programme of more than 12 weeks or a shorter one, and that a frequency of more than three sessions per week or a longer session length does not lead to greater improvements in cognitive function. These results are in line with a recent meta-analysis on the effect of physical exercise on cognitive function in healthy older adults (Gheysen et al., 2018). The meta-analysis by Oberlin et al. (2017) indicated greater improvements in studies which conducted an intervention lasting less than three months. Our results exhibit the same tendency, although it is not significant. These findings might be due to non-compliance with the training principles used in exercise programmes targeting post-stroke patients, in particular the principle of progression. A recent systematic review showed that the training principles employed in physical exercise programmes in this population are inconsistent (Ammann et al., 2014). Accordingly, it is recommended that physical exercise programmes in post-stroke patients designed to improve cognitive function pay special attention to training principles and last at least six weeks with a frequency of three sessions per week and a per-session length of at least 30 minutes.

In relation to the type of physical exercise programme, five subgroups used aerobic exercise programmes (Bateman et al., 2001; Khattab et al., 2020; Quaney et al., 2009; Tang et al., 2016), three subgroups applied strength programmes (Immink et al., 2014; Ozdemir et al., 2001) and three employed combined programmes (Bo et al., 2019; Kim & Yim, 2017; Studenski et al., 2005). The analysis shows that sessions implementing strength exercises were more beneficial than those that included aerobic exercise work. However, this difference ceases to be significant after the group presenting an extreme change in the cognitive function variable is removed (Ozdemir et al., 2001). Similarly, the group of studies using strength programmes does not include older adults, compared to the aerobic training group, which includes four studies with older adults (Bateman et al., 2001; Khattab et al., 2020; Quaney et al., 2009; Tang et al., 2016), and the combined training group, which includes one (Studenski et al., 2005). These results are in line with those produced by the meta-analysis conducted by

Oberlin et al. (2017). These authors show that aerobic-only training did not show positive results in terms of cognitive function, whereas strength training did. However, they do not indicate whether these differences between groups were significant. Thus, aerobic training increases cerebral blood volume (Pereira et al., 2007), while strength training fosters greater vascularisation and improves essential supply to the brain, meaning that they both improve cognitive function (Tsai et al., 2015). Similarly, an increase in brain-derived neurotrophic factor (BDNF) protein has been linked to exercise in the improvement of cognitive function (Winter et al., 2007). The number of RCTs needs to be increased so as to identify the type of exercise which is most recommended for improving cognitive function in stroke patients.

Practical application

This systematic review with meta-analysis shows that a physical exercise-only programme delivers significant positive results for cognitive function in post-stroke patients. However, other variables such as participant age and training principles need to be addressed in order to maximise the benefits. These results herald a new finding for doctors and physical trainers with regard to reducing cognitive decline in these patients and thus improving their quality of life. It is recommended that a physical exercise programme in post-stroke patients intended to enhance cognitive function should pay special attention to training principles, be based mainly on strength exercises and last at least six weeks with a frequency of three sessions per week and a per-session length of at least 30 minutes.

Limitations

The main limitation of this systematic review with meta-analysis is the small number of RCTs conducted to date. This aspect constrains comparisons between groups and means that the number of original RCT investigations needs to be increased. Another limitation is that all the studies do not all use the same tool to assess cognitive ability and the results had to be translated into percentages in order to draw comparisons.

Conclusions

A physical exercise programme significantly improves cognitive function in post-stroke patients and its effect may be greater than that of rehabilitation programmes.

Combined programmes of physical exercise and cognitive training will probably be needed in post-stroke older adults compared to younger and middle-aged adults due to age-related cognitive impairment.

It is recommended that a physical exercise programme in post-stroke patients with the aim of improving cognitive function pay special attention to training principles and last at least six weeks with a frequency of three sessions per week and a per-session length of at least 30 minutes.

There is moderate evidence that suggests that strength training programmes are the most beneficial in improving cognitive function in this population. However, more research is needed to indicate which type of physical exercise programme is most helpful for post-stroke patients.

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Active Breaks and Cognitive Performance in Pupils: A Systematic Review

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Abstract

The purpose of this study was to conduct a systematic review of interventions using active breaks (ABs) in the school setting to identify the key characteristics (duration of the AB, intensity and type of activities) that an active break needs to have to deliver greater cognitive performance, such as concentration and attention in pupils. A systematic review was conducted following the PRISMA method with the following inclusion criteria: a) studies published between 2010 and 2020 (both inclusive), b) written in Spanish or English, c) active breaks as the main topic, d) articles written in the school setting. The Web of Science, Scopus and PubMed databases were queried. A total of 19 articles were included, all of them showing improvements in pupils' attention and concentration after the implementation of an active break intervention programme in a school setting. The significant influence of the intervention duration, type and intensity variables on the improvement of pupils' cognitive performance was observed. Finally, it was concluded that greater benefits were found in active breaks with a short duration, vigorous intensity and through an activity with a higher cognitive load.

Keywords: active breaks, physical activity, review, school.

Introduction

Physical activity (PA) is a key health factor (WHO, 2020) in children's physical and psychological development (Blanco et al., 2020; Strong et al., 2005), as it improves motor development (Williams et al., 2008), self-esteem (Ulrich, 1997) and cardiorespiratory fitness (Okely et al., 2001). Similarly, sedentary lifestyles and physical inactivity are also associated with different health problems such as coronary heart disease, musculoskeletal pathologies, high blood pressure, high cholesterol, diabetes, depression and anxiety (Piercy et al., 2018). World Health Organisation (WHO, 2020) data show that 84% of girls and 78% of boys aged between 11 and 17 years do not meet the recommended daily PA for this age group, *i.e.* 60 minutes of moderate-to-vigorous physical activity (MVPA) every day of the week and including at least two minutes of muscle strengthening (WHO, 2010). These data are mirrored in Spain by the PASOS study (2019), which shows that 63.3% of the child and adolescent population does not comply with the recommendations, while 40.6% of schoolchildren between 6 and 9 years of age are overweight, a problem which gets worse as they grow older, and more so in girls than in boys.

This declining PA performance seems to be partly related to our society's sedentary lifestyles (Watson et al., 2019; Janssen & Leblanc, 2010), albeit also to a school syllabus packed with contents that are not very hands-on and highly sedentary, in which most of the educational process unfolds in the classroom (Brindova et al., 2014). This has contributed towards a change in children's lifestyles, steering them away from options which allow them to be physically active. This is crucially important at school age, seen as a sensitive stage in which they acquire many of the habits that they will maintain in the course of their lives (Buhring et al., 2009).

This situation would appear to lie at the opposite end of the spectrum to those that regard schools as an ideal environment for promoting PA. This is because in spite of the data presented, the school setting provides great possibilities, such as being a venue for shared interaction that affords ideal learning opportunities and facilitates interaction with the immediate surroundings. However, there are also significant barriers, to wit the aforementioned syllabus and the meagre time spent on experimentation or experiential learning, compounded by cramped learning spaces (Center on Education Policy, 2007). Curricular demands in the so-named instrumental areas of learning cover a large part of the school timetable, which has led authors such as Van Stralen et al. (2014) to observe that children aged 6 to 12 years spend 64% of their school time in sedentary activities and only 5% in MVPA. It is therefore clear that PA levels need to be stepped up in the school setting, where there are different times and spaces for being active, such as physical education classes, playtime, active breaks and commuting to school, which are significant in terms of the weekly amount of physical activity performed by schoolchildren (Pastor-Pradillo, 2007; Martínez-Martínez et al., 2012), although it is also true that they are determined by conditioning factors specific to each educational community.

These healthy times and spaces for action include active breaks (AB), which are short periods of PA (Martínez-López et al., 2018) built into the school timetable, providing pupils with high PA levels. This should not have a negative impact on their learning time; on the contrary, it can improve cognitive performance (Contreras-Jordán et al., 2020). The paper by Hillman et al. (2011) shows how acute bouts of PA appear to improve children's attentional performance. Altenburg, Chinapaw and Singh (2016) found that pupils who were given two 20-minute ABs per week improved in selective attention compared to the control group with only one AB. Similarly, the research by Mavilidi et al. (2019) also uncovered beneficial effects of shorter active breaks in improving attention, task concentration and working memory. Cognitive functions (attention, concentration, working memory) therefore seem to be improved after ABs. Here, it is important to make a distinction between cognitive and executive functions. Cognition refers to a set of mental processes that human beings are capable of carrying out. On the other hand, executive functions are a construct used to shape a series of cognitive capacities involved in controlling thought and behaviour (Zelazo & Carlson, 2012, 2020), including skills such as suitable target selection, initiation and maintenance of a plan of action and flexibility in strategies to achieve a goal (Banich, 2009; Soprano, 2003). They are also essential for adapting to the environment and for appropriate social functioning.

However, although ABs are known to improve cognitive functions such as attention and concentration (Donnelly & Lambourne, 2011), there is some uncertainty about their structure (Chacón-Cuberos et al., 2020). This is because the literature reviewed does not clearly stipulate the recommended duration or frequency of interventions or the intensity or type of activity to be done in ABs (Laberge et al., 2012; Janssen et al., 2014), even although the importance of these variables as moderators of the proposal are known (De Greeff et al., 2017). In this regard, a study by Hillman et al. (2011) did not find any positive effects for interventions based on simple aerobic exercise, although they did for cognitively demanding activities. Therefore, in view of the existing literature, there would appear to be no consensus on the features that active breaks should have in order to improve cognitive functions.

Consequently, the purpose of this study was to conduct a systematic literature review based on the PRISMA methodology, about school-based interventions using ABs to identify the key features (duration of the AB, intensity and type of activities) required to improve cognitive performance.

Methodology

The information in this study was compiled by means of a systematised review in the Web of Science, Scopus and PubMed databases. The first two were selected because they are the multidisciplinary databases with the largest number of articles included, while the third was chosen because it is the most specific database for health-related articles. The search was performed following the main PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) steps, including the PICO strategy for sourcing articles in each one of the databases: participants (e.g. primary, pupils, children), intervention (e.g. programme, test), comparators (e.g. physical education, sport setting), outcomes (e.g. screening, selection). The search strategy used for these databases consisted of the following: (*cognitive* OR *attention* OR "*executive function**") AND ("*Primary School*") AND ("*physical activity*" OR "*active breaks*"). Subsequently, the four main steps of the PRISMA method were followed: identification, screening, eligibility and inclusion (Moher et al., 2009). This strategy yielded 425 articles (Web of Science-147; Scopus-205; PubMed-73), plus another three articles that were included from external sources, making a total of 428 articles for our literature review.

Selection criteria were applied to all the articles found. The inclusion criteria for this literature review were: a) studies published between 2010 and 2020 (both inclusive), b) written in Spanish or English, c) active breaks as the main topic, d) articles written within the school setting. In addition, qualitative and quantitative articles were included to broaden the range of available articles and thus obtain a greater amount of information on the topic to be studied.

All the articles were exported to Mendeley Reference Manager. After filtering for duplicates, the total number of articles was 301 (127 articles eliminated). After this second filtering, and based on our inclusion criteria, a total of 237 articles were discarded after the year, title and abstract had been reviewed. Finally, 64 articles remained for a full reading to ascertain whether they fulfilled all the inclusion criteria. After this last step, 19 articles were finally selected and used for the in-depth literature review, and 45 papers which following the exhaustive analysis did not meet the inclusion criteria were ultimately discarded.

Articles that did not meet the publication date were discarded in the first step. All the articles that met our inclusion criteria were selected for the review. The resulting PRISMA flowchart is shown in Figure 1 below.

Results

The 19 articles selected for inclusion in this review are presented in Table 1, which details the sections on authors and year of publication of the article, main objective of the study, sample (age and number), instrument for measuring the variables, variables to be studied and research outcomes.

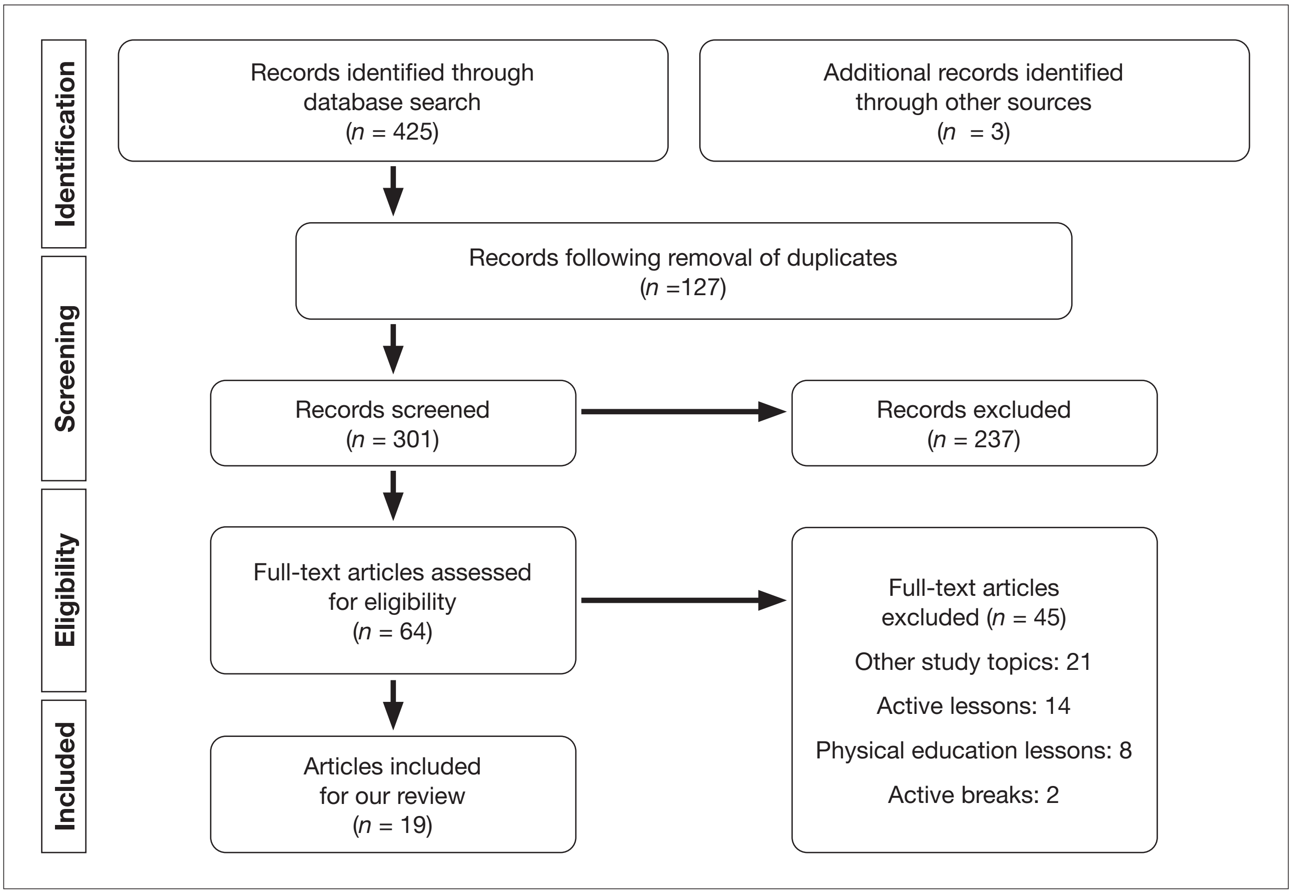

Figure 1
Literature selection flowchart.

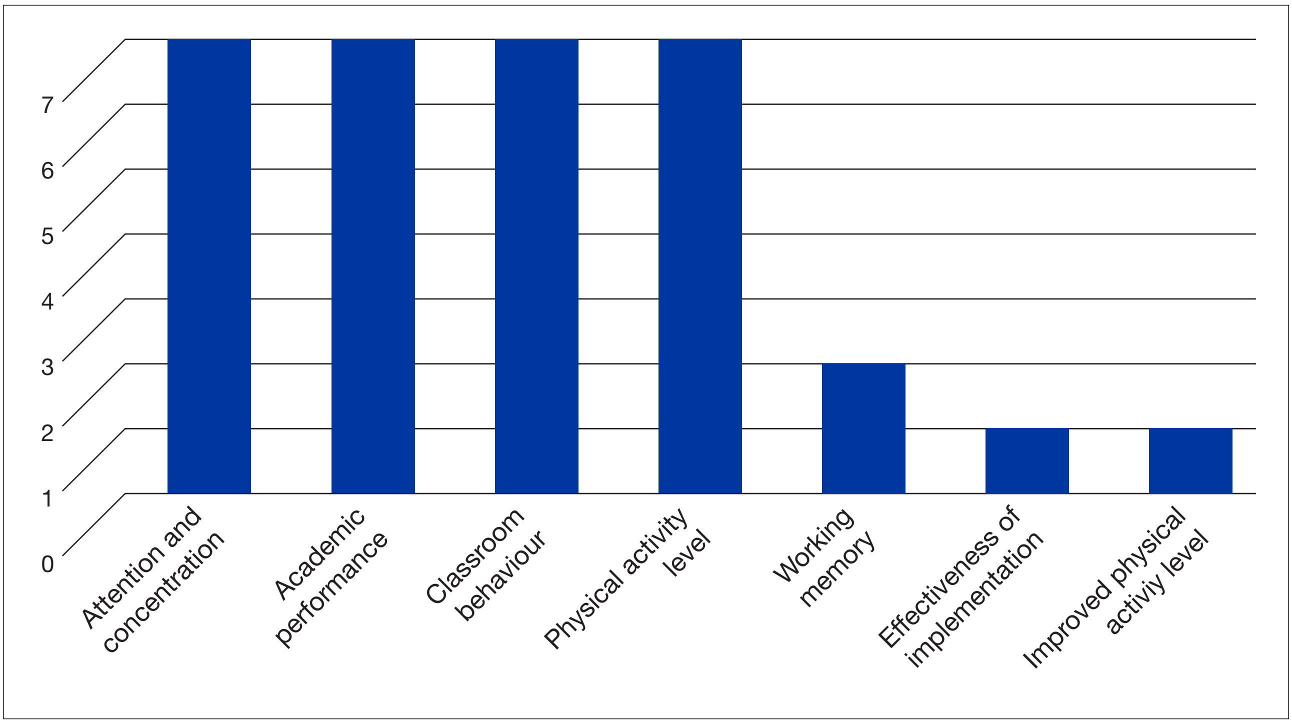

Figure 2
Number of publications grouped by subject matter addressed in the articles included in the review.

Table 1
Characteristics of the articles analysed.

Article	Study objective	Sample	Measurement instrument	Variables	Outcomes
Contreras-Jordán et al. (2020)	Ascertain the influence of AB on children's attention and concentration	*N* = 73 children aged 9-11 years	d2 Test of Attention	Attention and concentration	Significant improvement in attention and concentration after 10 sessions of 15 minutes of AB.
Watson et al. (2019)	Assess the feasibility and efficacy of a 6-week active break pilot programme on academic achievement, class-room behaviour and physical activity.	*N* = 374 children aged 8-10 years	Wheldall Assessment of Reading Passages (WARP) Test Westwood One Minute Test of Basic Number Facts ActiGraph GT3-X accelerometer Direct Behaviour Rating Scale	Academic achievement PA Classroom behaviour	On-task behaviour at the individual level was shown to increase in the intervention group, with greater improvements observed in boys. However, there was no intervention effect on classroom on-task behaviour at whole class level. No intervention effects were found for mathematics, reading or PA during the school day.
Janssen et al. (2014)	The objective of this study was to gain an insight into the acute effects of a short bout of physical activity on selective attention in primary school children.	*N* = 123 children aged 10-11 years	TEA-Ch test	Attention in the classroom	Attention scores after the PA break were significantly better ($p < .001$) than after the 'no break' condition. Attention scores were best after the moderate intensity PA break.
Egger et al. (2019)	The objective of the study was to examine the effects of AB with high physical exertion and high cognitive engagement (combo group), high physical exertion and low cognitive engagement (aerobic group), or low physical exertion and high cognitive engagement (cognition group).	*N* = 142 children aged 7-9 years	Self-Assessment Manikin ActiGraph GT3X Eriksen flanker task Heidelberger Rechentest Hamburger Schreib-Probe (HSP 1–10) Salzburger Lese-Screening PAQ-C	PA level Academic performance Cognitive outcomes (mathematics, spelling and reading, etc.)	The combo group benefited by showing improved cognitive demand. The cognition group benefited only in terms of academic performance, while the aerobic group remained unaffected. The inclusion of cognitively engaging PA breaks seems to be a promising way to enhance schoolchildren's cognitive functions.
Mok et al. (2020)	Evaluate the effectiveness of a programme in changing children's attitudes toward PA.	*N* = 3036 pupils aged 8-11 years	Attitudes toward Physical Activity Scale (APAS)	Attitudes toward doing PA	This study provides evidence about improvements in terms of learning experience, attitudes towards PA and personal motivation.

Table 1 (Continuation)
Characteristics of the articles analysed.

Article	Study objective	Sample	Measurement instrument	Variables	Outcomes
Schmidt et al. (2016)	Ascertain the separate and/or combined effects of physical exertion and cognitive engagement induced by physical activity breaks on primary school children's attention.	*N* = 92 children aged 11-12 years	D2 Test PANAS-C	Pupils' attention	Physical exertion had no effect on any measure of children's attentional performance. Cognitive engagement was the crucial factor leading to increased focused attention and enhanced processing speed.
Suarez-Manzano et al. (2018)	Analyse studies assessing the effect of integrated PA performance during school breaks on attention in children and adolescents.	Systematic review		Pupils' attention	All the studies used physical exercise of moderate-vigorous intensity lasting between 5 and 30 min. Seven studies showed improvement and two showed no change. Differences were found according to sex. Finally, the influence of the duration and intensity of the intervention was observed.
Paschen et al. (2019)	Investigate the effects of exercise with low and high cognitive demands on speed of processing and accuracy of performance in tasks examining inhibition, working memory and cognitive flexibility in children.	Systematic review		Working memory Inhibition Cognitive flexibility	Ten studies with a total of 890 participants revealed positive effects on working memory performance after exercise with low cognitive demands compared to seated rest, mixed results for inhibition after exercise with high and low cognitive demands and mixed results for cognitive flexibility with low cognitive demands.
Mavilidi et al. (2020)	Investigate whether physical activity could decrease anxiety levels and improve maths test performance in sixth-grade children.	*N* = 68 children aged 11-12 years	The Cognitive Anxiety test Questionnaire Math Test	Anxiety levels Academic performance	Low-anxiety level pupils performed better in the maths test than high-anxiety level children. No differences were found for any of the variables between the activity break condition and the control condition.

Table 1 (Continuation)
Characteristics of the articles analysed.

Article	Study objective	Sample	Measurement instrument	Variables	Outcomes
Mavilidi et al. (2019)	This study examined the effects of different types of classroom physical activity breaks on children's ontask behaviour, academic achievement and cognition.	*N* = 87 pupils aged 9-11 years	Behaviour observation of pupils in schools The Applied behaviour analysis for teachers Individual Basic Facts Assessment Tool The Flanker test	On-task behaviour Academic performance Executive functions	Significant effects were found for on-task behaviour. Academic performance in mathematics was improved. No effect on executive functions was found.
Schmidt et al. (2019)	Investigate the effects of specifically designed physical activities on foreign language vocabulary learning and attentional performance.	*N* = 104 children aged 8-10 years	Cued Recall Test D2 Test	Academic performance Attention	Embedded learning with PA was more effective in teaching children new words than the control condition. However, children's focused attention did not differ across the three conditions.
Masini et al. (2020)	Investigate the effects of AB on PA levels, classroom behaviour, cognitive functions and academic performance in primary school children.	Systematic review		PA level Classroom behaviour Cognitive functions Academic performance	A significant effect was found in increasing PA levels in primary school children. Regarding classroom behaviour, time spent on task during lessons significantly increased. On the other hand, the effects on cognitive functions and academic achievement (mathematics, reading) were not conclusive.
Mazzoli et al. (2019)	Assess the feasibility of implementing a cognitively challenging motor task as an AB in schools.	*n* = 12 teachers and *n* = 34 pupils	Interviews	Effect of implementing ABs in classrooms	Teachers viewed the cognitively challenging motor task as appropriate and potentially beneficial for children. Children reported enjoying the ABs. Teachers in special schools viewed the task as complex and potentially frustrating for children.
Buchele-Harris et al. (2018)	This study examined the effects of 4-week, daily 6-minute ABs on attention and concentration in school-aged children.	*N* = 116 pupils age 10 years	D2 Test	Attention and concentration	Significant increases in processing speed and attention span were found compared to the control group. There was significant improvement in the pupils' concentration performance.

Table 1 (Continuation)
Characteristics of the articles analysed.

Article	Study objective	Sample	Measurement instrument	Variables	Outcomes
Mahar (2011)	The study's objective was to describe the measurement of on-task behaviour and review the research on the effects of short physical activity breaks on attention-to-task in primary school pupils.	Systematic review		Attention	The limited evidence suggests a small improvement in attention-to-task following PA breaks. Pupils who participated in classroom-based physical activities that incorporate academic concepts demonstrated significantly better improvements in attention-to-task than control group participants.
Routen et al. (2017)	The aim of this study was to determine the extent to which ABs are implemented and also investigate how they affect school performance.	5 classes of 9-10 year-olds	The Children's Activity Rating Scale The School Physical Activity Promotion Competence Questionnaire Actigraph accelerometer (GT3X or GT3X+) D2 Test	Cognitive functions PA level	No results were found, as the programme has not been implemented.
Rizal et al. (2019)	The purpose of this study was to measure the effect of this programme on the stages of change, decisional balance, processes of change, self-efficacy and leisure-time exercise among Malay ethnic primary school children.	*N* = 322 children aged 10-11 years	Godin Leisure-Time Exercise Questionnaire (GLTEQ) The process of change questionnaire Plotniko 10-item decisional balance scale The three-factor, 18-item self-efficacy scale originated from Bandura	Processes of change Decisional balance Self-efficacy	It showed significant changes in cognitive processing. In addition, a significant interaction effect was observed for stages of change.
Morris et al. (2019)	Show improvements in PA and educational benefits such as executive function and academic performance using The Daily Mile (TDM).	*N* = 303 8.99 ± 0.5 years	EF tests (Trail Making Task; Digit Recall; Flanker; Animal Stroop) Maths fluency test (Maths Addition and Subtraction, Speed and Accuracy Test). GT9X, GT3X + accelerometers	Executive functions Academic performance PA	TDM revealed significantly greater PA (+10.23 min) and reduced sedentary time (–9.28 min) compared to control. Academic performance improved significantly.
Ruiz-Hermosa et al. (2019)	Evaluate the link between active commuting to and from school and academic achievement in children and adolescents.	Systematic review		Cognitive performance and academic achievement	No differences were found in executive functions. There was insufficient evidence regarding the relationship between active commuting to and from school and cognitive performance and academic achievement.

Objectives

The main study objective of seven of the 19 articles was ABs and their impact on pupils' attention and concentration (Contreras-Jordán et al., 2020; Janssen et al., 2014; Schmidt et al., 2016; Suarez-Manzano et al., 2018; Schmidt et al., 2019; Buchele-Harris et al., 2018; Mahar, 2011). In addition, another seven articles studying the effect of ABs on academic performance, classroom behaviour and PA level were identified (Routen et al., 2017; Watson et al., 2019; Egger et al., 2019; Mavilidi et al., 2020; Morris et al., 2019; Mavilidi et al., 2019; Masini et al., 2020). Finally, five studies on different topics examined the influence of ABs on improving PA performance (Mok et al., 2020) and working memory (Rizal et al., 2019; Paschen et al., 2019) and also explored the effectiveness of their implementation (Mazzoli et al., 2019), with the exception of a final article assessing the relationship between active commuting to and from school and cognitive performance (Ruiz-Hermosa et al., 2019).

Sample

Five of the 19 selected articles have a sample size of less than 100 pupils (Contreras-Jordán et al., 2020; Schmidt et al., 2016; Mavilidi et al., 2020; Mavilidi et al., 2019; Mazzoli et al., 2019).

Similarly, seven of the studies selected present a sample of between 100 and 400 pupils (Watson et al., 2019; Janssen et al., 2014; Egger et al., 2019; Schmidt et al., 2019; Buchele-Harris et al., 2018; Rizal et al., 2019; Morris et al., 2019). Conversely, only one of them has a sample size of over 400 pupils (Mok et al., 2020). Finally, there were five systematic reviews (Paschenet al., 2019; Suarez-Manzano et al., 2018; Masiniet al., 2020; Mahar, 2011; Ruiz-Hermosa et al., 2019), hence their sample sizes are unknown. In addition, all the articles were included in the primary education stage, mostly between 8 and 12 years of age.

Measurement instruments

Excluding the five systematic reviews (Paschenet al., 2019; Suarez-Manzanoet al., 2018; Masini et al., 2020; Mahar, 2011; Ruiz-Hermosa et al., 2019), six of the 19 selected articles used these instruments to measure attention, such as the d2 Test, the TEA-Ch Test and the PANAS-C. ActiGraph GT3-X accelerometers were also used to measure PA level. To observe academic performance, five articles used different instruments, including the Wheldall Assessment of Reading Passages (WARP) test and the Westwood One Minute Test of Basic Number Facts, Maths Test and the Cued Recall Test. Moreover, two articles examined PA level using PAQ-C and the School Physical Activity Promotion Competence Questionnaire. Finally, two studies utilised other tools such as interviews or the Attitudes toward Physical Activity Scale (APAS) questionnaire.

Variables

Seven of the 19 articles selected included attention as a variable. Similarly, seven articles included academic performance as one of their variables. In addition, five articles included PA level as one of their main variables. There were five articles for executive cognitive functions. Finally, other variables included attitude towards PA, working memory and inhibition, the effect of implementing ABs (Mazzoli et al., 2019) and change and self-efficacy processes.

Results

Ten of the 19 studies found improvements in attention following AB implementation (Contreras-Jordán et al., 2020; Janssen et al., 2014; Suarez-Manzano et al., 2018; Mahar, 2011; Buchele-Harris et al., 2018; Masini et al., 2020; Morris et al., 2019; Rizal et al., 2019; Schmidt et al., 2016; Egger et al., 2019). However, Schmidt et al. (2019) found no effect on attention in their study. Another five studies observed improvements in academic performance (Paschen et al., 2019; Mavilidi et al., 2020; Mavilidi et al., 2019; Mahar, 2011; Schmidt et al., 2019). Conversely, three studies found no benefits in academic performance after AB implementation (Masiniet al., 2020; Watson et al., 2019; Ruiz-Hermosa et al., 2019). Finally, improvements were identified in four studies in terms of pupils' PA level (Mavilidi et al., 2019; Masiniet al., 2020; Mazzoli et al., 2019; Moket al., 2020).

Discussion

The purpose of this study was to conduct a systematic review of the use of ABs in primary school as a strategy to improve pupils' cognitive performance. To this end, Web of Science, Scopus and PubMed were used as the main databases to source articles published in the last 10 years related to this topic, leading a total of 19 articles to be included.

Most of the published articles found evidence that an AB helps to improve pupils' attention in the classroom, as is also demonstrated by other studies that focused on improving this variable using this kind of break (Donnelly & Lambourne, 2011; Wilson et al., 2016). These PA breaks also generated positive effects on academic performance (Paschenet al., 2019; Mavilidi et al., 2020; Mavilidi et al., 2019; Mahar, 2011; Schmidt et al., 2019).

An AB's impact on attention is most effective shortly after a moderate PA break. This effect is related to the inverted-U hypothesis, which establishes that cognitive performance is significantly improved with a moderate level of arousal (McMorris & Graydon, 2000). The optimal level of arousal for adult attention is reached after a bout of moderate PA (Brisswalter et al., 2002). Arguably, this optimal level is the same in children because attentional control is fully developed from the age of 7 years (Rueda et al., 2005). It could therefore be inferred that attention and PA are closely related to be able to generate a positive effect.

As mentioned above, there are several aspects which directly influence the variables to be studied about an AB, such as its duration, type (cognitive or mechanical) and intensity.

In terms of the duration of these breaks, authors such as Kubesch et al. (2009) examined changes in cognitive aspects after 5 and 30-minute breaks, showing that improvements were generated after five minutes at vigorous intensity compared to 30 minutes at moderate intensity. Furthermore, when the effect of including PA in breaks for at least four minutes was studied, short-term improvements in attention were found (Ma et al., 2014). Consequently, this may suggest that greater benefits are gained through a short break (5-10 minutes) at high intensity than through a moderate 30-minute AB.

Coe et al. (2006) measured the effect of break intensity through MVPA interventions in ABs in 214 children aged 10-11 years, observing that the moderate-intensity group presented no change, whereas the vigorous intensity group showed significant improvements compared to the control group. It might therefore be interpreted that a vigorous intensity PA bout produces greater improvements in pupils compared to moderate intensity.

Another key factor may be the type of activity carried out, *i.e.* whether it is more cognitive or mechanical. In a study included here, Watson et al. (2019) used mostly cognitive load activities and found significant improvements, although this was not conclusive since they were not compared with other more PA-focused activities. Similarly, Schmidt et al. (2016) compared groups with AB, another with AB and cognitive load and another group with cognitive exercises only and concluded that cognitive engagement was the key factor in greater attention and improved processing speed, rather than PA load. Furthermore, in their study, Buchele-Harris et al. (2018) found improvements in processing speed, attention and concentration through coordinated-bilateral PA breaks. This study also concluded that pupils who participated in non-cognitive activities with a physical load did not differ from the control group. It can therefore be inferred that cognitive load is a crucial factor in significantly improving attention and concentration in pupils.

This makes sense to the extent that Ruiz-Hermosa et al. (2019) argue that MVPA has a direct impact on cerebral function. Thus, improving cardiorespiratory capacity triggers angiogenesis, *i.e.* the physical process that forms new blood vessels from existing ones, thereby increasing blood flow and improving cerebral vascularisation (Hillman et al., 2008). Moreover, doing PA also fosters an increase in brain-derived neurotrophic factor, which regulates cell survival and brain plasticity (Huanget al., 2014), leading to an improvement in cognitive elements (Leckieet al., 2014). Accordingly, doing PA would apparently help to increase levels of attention and concentration, thus supporting the need to add PA to the school syllabus.

Conclusion

The results of this systematic review suggest that ABs are a good strategy to achieve higher cognitive performance. Furthermore, differences were found by duration, type and intensity, whereby an AB lasting 5-10 minutes was more suitable than an AB of 20 minutes, at vigorous versus moderate intensity and with the type of activity having a more cognitive than mechanical load. It could therefore be argued that the benefits that ABs appear to deliver in terms of cognitive performance might enable pupils to improve their classroom attention and concentration and gain in academic performance and even in motivation. Moreover, in specific domains such as sports, these cognitive improvements play a role in the successful completion of numerous tasks that have to be tackled during physical activity.

Finally, this research has one minor limitation, although it also holds some potential. The limitation is that few articles have been published in the last 10 years on the implementation of AB programmes, *i.e.* most, or the bulk of them, have been published since 2017, as can be seen in this literature review. Similarly, there is the potential and a need to continue to work in this field, since including ABs in the classroom is associated with the emerging methodologies and the boom in new technologies. Furthermore, it should also be remembered that although the physical education syllabus is firmly established, it is not easy to work in this field due to the number of variables that have to be taken into consideration and are sometimes difficult for teachers to control, not to mention the need for a clear commitment by all the stakeholders to carry out this type of intervention programme (Romero-Cerezo, 2007).

Practical applications

The results found are designed to continue this research strand in PA and cognitive performance. This PA has been embodied in ABs. Thus, the first practical application of this paper is to provide a foundation for other researchers focusing on this research strand to be able to replicate the outcomes reported here and thus contribute knowledge to this field. Secondly, these results should be given due consideration by primary school teachers so that they can follow the guidelines for the appropriate implementation of an effective AB. Aspects such as intensity, duration and frequency should be reviewed when an AB programme is implemented. Thirdly and finally, education policymakers should be mindful of the benefits of ABs for pupils' cognitive performance so as to deliver training courses on AB programmes for schools.

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Segmental Body Composition in Athletes with Spinal Cord Injury: A Pilot Study

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Abstract

The purpose of this study was to compare the anthropometric methods by body segment with the values predicted by dual energy radiological absorptiometry (DXA) in athletes with spinal cord injury. Eight quadriplegic and six paraplegic athletes participated in this study. Body circumferences were measured at seven sites, skinfold thickness was measured at nine sites (on the right side of the body), and body composition was measured using DXA. Linear regression analysis was used to verify the associations between body composition and anthropometric measurements. Segmental measures that best explain fat mass as predicted by DXA were: a sum of the skinfold thickness in the arm (R^2 = .66; p < .01); in the trunk, subscapular (R^2 = .75, p < .01), midaxillary axillary (R^2 = .67, p < .01) and abdominal skinfolds (R^2 = .67, p < .01), and sum of trunk skinfold thickness (R^2 = .67, p < .01); and in the leg, the calf skinfold and the sum of the skinfolds of the leg (R^2 = .70, p < .01; R^2 = .68, p < .01). The circumferences of the relaxed and tensed arms showed relevant relationships (R^2 = .52, p < .01, and R^2 = .57, p < .01, respectively) with the fat mass predicted by DXA. This suggests that segmental analysis of body composition through circumferences and skinfold thickness may be a good option for the accurate determination of body composition in athletes with spinal cord injury. The sum of cutaneous folds per segment strongly and significantly expressed fat mass predicted by DXA.

Keywords: anthropometry, body composition, spinal cord injuries.

Introduction

The search for sports excellence is a common objective in both adapted and conventional sports, and among the factors that interfere with the desired sports performance is body composition (Borges et al., 2016; Nikolaidis, 2013), which is positively associated with regular sports practice (Cavedon et al., 2020; Gorla et al., 2016).

The evaluation and monitoring of body composition is strongly related to sports performance because it establishes goals, identifies the development of athletes, and plans for subsequent work. In the spinal cord injury (SCI) population, the importance of body composition assessment and monitoring is even greater because after the injury there is a "redistribution" of the components of the body composition represented by the increase and accumulation of fat (Beck et al., 2014),decrease of the lean mass in the central regions (trunk) and lower extremities, and increased lean mass (Maggioni et al., 2003; Yarar-Fisher et al., 2013) and decreased fat mass higher regions; determining the relevance of assessing body composition in a segmented way, that is, by body segment (arms, trunk and legs).

Among the numerous methods of evaluation of body composition, we highlight the dual energy radiological absorptiometry (DXA) method which is considered valid for analysis of body composition in individuals with SCI (Jones et al., 1998) and the anthropometric method of skinfold thickness, which stands out for its low cost and easy applicability, which makes it possible to obtain large samples and set parameters (Heyward & Stolarczyk, 2000).

However, prediction equations through skinfold thickness validated for athletes with different injury levels (paraplegia and quadriplegia) have not yet been described in the literature. In addition, the generalized prediction equations validated for people without disabilities have underestimated the percentage of body fat in the population with SCI (Maggioni et al., 2003; Spungen et al., 1995); however, there is evidence that the sum of skinfold thickness can predict changes in body fat in this population (Goosey-Tolfrey et al., 2020; Willems et al., 2015). In this context, the aim of this study was to compare the anthropometric methods of body circumference and skinfold thickness by body segment with the values predicted by DXA in athletes with spinal cord injury.

Materials and Methods

Participants

Fourteen male athletes with SCI of which eight tetraplegic athletes of wheelchair rugby and six paraplegic athletes practicing wheelchair handball. Participant characteristics are presented in Table 1.

Table 1
Characteristics of the participants.

Participants	Age (years)	Level of injury	Duration of injury (years)	Body mass (kg)	Heigth (m)	BMI (kg/m²)
1	25	C6-C7	4	62.15	1.78	17.46
2	38	C6-C7	11	65.20	1.76	18.52
3	29	C5-C6	10	57.80	1.70	17.00
4	27	C6-C7	6	64.15	1.75	18.33
5	35	C6-C7	12	62.40	1.70	18.35
6	38	C6-C7	5	75.00	1.86	20.16
7	24	C6-C7	7	60.00	1.69	17.75
8	25	C5-C6	4	92.00	1.82	25.27
9	29	L1	5	71.95	1.70	21.16
10	35	T8-T12	17	83.75	1.57	26.67
11	34	T7	11	42.80	1.69	12.66
12	43	T7-T8	30	83.75	1.72	24.35
13	44	T8	7	96.00	1.85	25.90
14	37	T3	18	86.60	1.71	25.30
Mean	33.10		10.50	71.70	1.74	20.60
±SD	6.60		7.20	15.10	0.08	4.20

Note. BMI: Body Mass Index.

Athletes were required to practice sports at least three times a week with the minimum duration of a two-hour training session. In addition, they were required to have had at least one year of practice in the modality.

This study was approved by the Ethics Committee of the Faculty of Medical Sciences of the State University of Campinas (no. 3.092.352) in 2018 and all participants provided written informed consent prior to participation in this study.

Anthropometry

Body mass (kg) was measured using a digital wheelchair scale (Líder®) with a capacity of 500 kg and a reading scale of 50 g. To verify body mass, athletes first measured their mass in their wheelchair, and then the mass of the wheelchair was measured separately. The weight of each athlete was calculated by the difference between these measurements, that is, the subtraction of the total mass and the wheelchair mass. The height (m) of the participants was evaluated using a stadiometer with a reading scale in millimeters, in the supine position.

Body circumferences

Circumferences were assessed using an anthropometric tape with a reading scale in millimeters (Gulick-WCS, Cardiomed). For segmental analysis, the arm circumference of the tensed arm (point of greatest circumference of the fully tensed arm), the relaxed arm (average distance between the most lateral edge of the acromion and the olecranon), and the forearm (point of greatest circumference of the forearm) were related to the body composition predicted by DXA of the arm region. The waist circumference (average distance between the last rib and the iliac crest, in a horizontal plane) and abdominal circumference (point of greatest anterior bulge of the abdomen usually on the umbilical scar) were related to the trunk region. The thigh circumference (the average distance between the inguinal line and the upper edge of the patella) and medial calf circumference (point of greater leg circumference, that is, greater perimeter of the calf muscle) were related to the leg region. Three measurements were made at each point by a single evaluator, and the abdominal and supra iliac skinfolds were measured in the supine position.

Skinfold thickness

Skinfold thickness was measured using Harpenden calipers (John Bull, British Indicators Ltd., St Albans, UK) at nine sites on the right side of the body. The skinfold thickness of triceps (mean distance between the superolateral edge of the acromion and the olecranon process of the ulna) and biceps (point of greatest apparent circumference of the biceps) were used to analyze the body composition of the upper arm region. The skinfold thickness of the middle axillary (obliquely at the point of intersection between the mid-axillary line and an imaginary transverse line at the height of the xiphoid appendage of the sternum), chest (mean distance between the anterior axillary line and the nipple), subscapular (obliquely to the longitudinal axis, in the portion immediately below the lower edge of the scapula, on average 2 cm), supra iliac (above the antero-superior iliac crest, at the height of the mid-axillary line) and abdominal (approximately 2 cm to the right of the lateral border of the umbilical scar) regions represented the trunk region. The skinfold thickness of the thigh (over the rectus femoris muscle, in the upper third of the distance between the inguinal ligament and the upper border of the patella) and calf (performed laterally at the point of greatest leg circumference) represented the leg region.

Dual-energy X-ray absorptiometry

Body composition was measured using dual-energy X-ray absorptiometry (Hologic QDR 4500A, software version 11.1:3, Waltham, MA, USA). The bone mineral content, lean mass, and fat mass in grams were measured throughout the body and by segment (trunk, leg, and arm). All measurements were performed with individuals instructed to wear light clothing, and their shoes were removed before the test. The athletes were asked to remove all metal objects (e.g., rings, necklaces, etc.). The measurements of all the athletes were performed in the afternoon between 2 and 3 pm.

Statistical analysis

The data were tabulated using Microsoft Excel 2007® package. The normality analysis of all study variables was performed using the Shapiro-Wilk test, and non-normal variables were inserted into the logarithmic transformation (Log^{10}). In addition to descriptive statistics, mean, and standard deviation, the relationship between anthropometric and body composition variables was analyzed using Pearson's correlation coefficient. The inclusion criteria for regression analysis were used to verify the relationship between the two variables. The data were analyzed using R-Plus Software version 2.15.0® (2012) for Microsoft Windows® through the R-Studio® graphical interface. The significance value was set at $p < .05$.

Table 2
Mean (±SD) of anthropometric variables and body composition.

Anthropometric								
Arm			Trunk			Leg		
BS (mm)	7.03	(± 3.30)	MS (mm)	19.66	(± 12.54)	TS (mm)	19.73	(± 9.61)
TS (mm)	11.49	(± 6.99)	CS (mm)	9.84	(± 6.09)	CalfS (mm)	16.70	(± 8.83)
∑AS (mm)	18.60	(± 9.70)	SiS (mm)	23.32	(± 11.95)	TC (mm)	42.87	(± 6.41)
CAT (cm)	33.68	(± 4.32)	AS (mm)	27.35	(± 13.16)	CC (mm)	30.28	(± 3.60)
CAR (cm)	30.57	(± 4.26)	SubS (mm)	19.62	(± 11.03)	∑LS (mm)	36.44	(± 17.97)
FC (cm)	27.36	(± 2.74)	∑TS (mm)	99.82	(± 49.31)			
			WC (cm)	89.26	(± 8.31)			
			AC (cm)	95.52	(± 11.35)			
Body composition								
Arm			Trunk			Leg		
FM (kg)	1.18	(± 0.58)	FM (kg)	9.45	(± 4.43)	FM (kg)	3.78	(± 1.89)
LM (kg)	3.86	(± 1.01)	LM (kg)	23.57	(± 3.60)	LM (kg)	6.23	(± 1.93)
TM (kg)	5.26	(± 1.54)	TM (kg)	33.72	(± 6.91)	TM (kg)	10.32	(± 3.13)
%BF	21.48	(± 6.02)	%BF	27	(± 7.85)	%BF	35.5	(± 11.2)
BMC (kg)	0.22	(± 0.06)	BMC (kg)	0.70	(± 0.21)	BMC (kg)	0.31	(± 0.14)
BMD (g/cm²)	0.891	(± 0.08)	BMD (g/cm²)	1.124	(± 0.392)	BMD(g/cm²)	0.996	(± 0.15)

Note. BS: bicipital skinfold; TS: tricipital skinfold; ∑AS: sum of the arm (bicipital and tricipital) skinfolds; CAT- circumference of arm tensed; CAR: circumference of arm relaxed; FC: forearm circumference; MS: midaxillary skinfold; CS: chest skinfold; SiS: suprailiac skinfold; AS: abdominal skinfold; SubS: subscapular skinfold; ∑TS: Sum of the trunk (midaxillary, chest, suprailiac and abdominal) skinfolds; WC: waist circumference; AC: abdominal circumference; TS: thigh skinfold; CalfS: calf skinfold; TC: thigh circumference; CC: calf circumference; ∑LS: Sum of the leg (thigh and calf) skinfolds; FM: fat mass; LM: lean mass; TM: total mass; %BF: percent body fat; BMC: bone mineral content; BMD: bone mineral density.

Table 3
Linear regression models comparing body composition variables of the predicted DXA and anthropometry (Arm and Leg).

Arm					
Model	Cor (*p*)	Int.	B	R^2	SEE (kg)
FM~Log BS	.81**	2.24	0.61	.64**	0.35
FM~Log TS	.80**	2.00	0.82	.61**	0.36
FM~∑AS	.83**	0.05	0.26	.66**	0.37
FM~CAR	.75**	0.10	1.94	.52**	0.40
FM~CAT	.77**	0.10	2.35	.57**	0.38
%BF~ Log BS	.70**	0.20	0.01	.46**	4.43%
%BF~SSA	.71**	0.44	0.01	.47**	4.39%
TM~Log BS	.76**	5.55	0.82	.55**	1.02
TM~Log TS	.72**	4.73	0.53	.47**	1.11
TM~∑AS	.73**	0.12	3.09	.50**	1.08
TM~RAC	.73**	0.26	2.83	.50**	1.08
TM~ACC	.72**	0.26	3.39	.48**	1.10

Note. The symbol ~ represents the relationship between the variables being the left side of the table (dependent variable) and right side of the table (independent variable). COR: Correlation; INT: Intercept; B: Beta; FM: fat mass; SEE: standard error of estimate; Log BS: logarithm bicipital skinfold; Log TS: logarithm tricipital skinfold; ∑AS: sum of the arm (bicipital and tricipital) skinfolds; CAR: circumference of arm relaxed; CAT: circumference of arm tensed; %BF: percent body fat; TM: total mass;
** Denotes significant correlation of $p < .01$.

Table 3 (Continuation)
Linear regression models comparing body composition variables of the predicted DXA and anthropometry (Arm and Leg).

			Leg		
Model	Cor (*p*)	Int.	B	R^2	SEE (kg)
BMC ~ CalfS	.72	0.01	0.13	.48**	0.10
BMC ~ TC	.71	0.02	-0.35	.47**	0.10
BMC ~ CC	.72	0.03	-0.53	.49**	0.10
FM ~ TS	.79	0.16	0.69	.60**	1.19
FM ~ CalfS	.85	0.18	0.73	.70**	1.03
FM ~ ∑LS	.84	0.09	0.54	.68**	1.06
FM ~ TC	.71	0.21	-5.23	.46**	1.38
FM ~ CC	.78	0.41	-8.65	.57**	1.23
LM ~ CC	.73	0.39	-5.73	.50**	1.36
TM ~ CalfS	.70	0.25	6.13	.46**	2.30
TM ~ TC	.82	0.40	-7.00	.66**	1.82
TM ~ CC	.95	0.83	-14.91	.91**	0.92

Note. The symbol ~ represents the relationship between the variables being the left side of the table (dependent variable) and right side of the table (independent variable). COR: Correlation; INT: Intercept; B: Beta; SEE: standard error of estimate; FM: fat mass; BMC: bone mineral content; CalfS: calf skinfold; ∑LS: Sum of the leg (thigh and calf) skinfolds; TC: thigh circumference; CC: calf circumference; TS: thigh skinfold; LM: lean mass; TM: total mass.
** Denotes significant correlation of $p < .01$.

Table 4
Linear regression models comparing body composition variables of the predicted DXA and anthropometry (TRUNK).

Model	Cor (*p*)	Int.	B	R^2	SEE (kg)
BMC ~ SubS	.78**	0.01	0.41	.57**	0.13
BMC ~ MS	.81**	0.01	0.44	.63**	0.13
BMC ~ SiS	.71**	0.01	0.41	.47**	0.15
BMC ~ AS	.79**	0.01	0.36	.59**	0.13
BMC ~ ∑TS	.75**	0.00	0.38	.54**	0.14
FM ~ SubS	.87**	0.35	2.52	.75**	2.20
FM ~ MS	.83**	0.30	3.63	.67**	2.51
FM ~ SiS	.71**	0.27	3.23	.47**	3.21
FM ~ AS	.83**	0.28	1.76	.67**	2.54
FM ~ ∑TS	.83**	0.08	1.96	.67**	2.54
FM ~ AC	.71*	0.28	-17.22	.47**	3.22
LM ~ SiS	.70**	0.21	18.60	.45**	2.65
LM ~ AS	.75	0.21	17.92	.53**	2.46
LM ~ ∑TS	.73	0.05	18.25	.49**	2.56
TM ~ SubS	.93	0.58	22.26	.85**	2.61
TM ~ MS	.90	0.50	23.86	.81**	2.99
TM ~ SiS	.85	0.49	22.24	.70**	3.79
TM ~AS	.95	0.50	20.04	.89**	2.20
TM ~∑TS	.93	0.13	20.59	.87**	2.49
TM ~ AC	.70	0.43	-7.21	.45**	5.11
%BF ~ SubS	.73	0.52	16.7	.50**	5.54%

Note. The symbol ~ represents the relationship between the variables being the left side of the table (dependent variable) and right side of the table (independent variable).
COR: Correlation; INT: Intercept; B: Beta; SEE: standard error of estimate; BMC: bone mineral content; SubS: subscapular skinfold; MS: midaxillary skinfold; SiS: suprailiac skinfold; AS: abdominal skinfold; ∑TS: Sum of the trunk (midaxillary, chest, suprailiac and abdominal) skinfolds; FM: fat mass; AC: abdominal circumference; LM: lean mass; TM: total mass; %BF: percent body fat.
** Denotes significant correlation of $p < .01$

Results

The descriptive statistic was used in order to identify the anthropometric characteristic of the participants, who had average body mass of 71.70 ± 15.10 kg, height 1.74 ± 0.08 m, body mass index 20.60 ± 4.20 kg/m² and body fat percentage 28.30 ± 7.40 %.

The anthropometric and segmental body composition variables are presented in Table 2.

To analyze the relationship between anthropometric variables and body composition (DXA), a correlation matrix was created. Variables with a correlation > .70 (*r*) were included in linear regression models to verify the possible predictors of segmental body composition. This value was chosen because it is considered acceptable for the validation of measurement instruments according to Guedes & Guedes (2006). The results of the linear regressions for the body composition variables of the arm region and leg are presented in Table 3.

Through the analysis we can observe that the biceps, triceps skinfolds, and the sum of these skinfolds can best explain the fat mass predicted by DXA ($R^2 = 64$, $p < .01$; $R^2 = .61$, $p < .01$; and $R^2 = .66$, $p < .01$, respectively) in the arm region.

In the leg region, an expressive relationship was observed between calf skinfold and the sum of leg skinfolds ($R^2 = .70$. $p < .01$, and $R^2 = .68$, $p < .01$, respectively) with the leg fat mass, where the calf circumference presented the smallest measurement error (SEE = 0.92 kg).

Regarding trunk variables, it is worth mentioning that the results of the Subscapular skinfolds ($R^2 = .75$, $p < .01$) and the sum of the trunk skinfolds ($R^2 = .63$, $p < .01$) can predict trunk fat mass by DXA, however, they showed high estimation error values.

Discussion

The present study aimed to analyze the applicability of anthropometric methods of body circumference and skinfold thickness per body segment in comparison with the results predicted by DXA. Thus, the study showed that models of body composition prediction can be created in a segmental way, mainly through the sum of skinfold thickness of each region that expresses strong degrees of determination with the fat mass.

In the arm region, we can identify that the biceps, triceps skinfolds, and the sum of these skinfolds represent more than 60 % of the fat mass predicted by DXA, but with considerable estimation error. The relationship between these skinfolds and fat mass has been widely explored, since it is used as a reference for the risk of obesity in children and adolescents and in predictive equations in adults without disabilities (Marrodán et al., 2017; Nickerson et al., 2020; Wang et al., 2000). The significant estimation error observed may be related to the heterogeneity of the sample, which showed, for example, a large standard deviation for the sum of skinfolds of 18.6 ± 9.7 mm.

In reference to the prediction of body composition by skinfolds in the trunk region, it was initially observed that the subscapular, middle axillary, abdominal skinfolds, and sum of the trunk skinfolds were possible predictors of fat mass in this region. However, it showed significant estimation errors, which may also be closely related to heterogeneity of the sample, which showed significant values of standard deviation for the subscapular (19.6 ± 11 mm), abdominal (27.3 ± 13.2 mm), middle axillary skinfolds (19.7 ± 12.5 mm), and the sum of skinfolds (99.8 ± 49.3 mm).

Moreover, in the trunk region, only the subscapular skinfold showed a correlation greater than $R^2 = .70$, with trunk fat mass. According to Willett (2012), subscapular skinfolds can be used as an indicator of central adiposity in addition to expressing centralized fat in the trunk. It was inserted in the equation of Steinkamp et al. (1965), which was used in the study by Spungen et al. (1995), where no significant difference in the percentage of fat predicted by DXA was observed in individuals with quadriplegia.

In the lower limbs, calf skinfold thickness and calf circumference should be highlighted ($R^2 = .70$, $p < .01$; $R^2 = .57$, $p < .01$) which can predict the change in leg fat mass. However, significant estimation errors of calf skinfold thickness (SEE = 1.03 kg) and calf circumference (SEE = 1.23 kg) were identified, which may be related to muscle atrophy in the thigh and calf region and the greater fat accumulation, which raises the measurement error due to the difficulty in "separating" subcutaneous fat from muscle mass.

These results are relevant because they present an alternative of low-cost body composition evaluation, easy applicability, and segmental analysis, which is fundamental in people with SCI, as after acute and chronic SCI, there are numerous changes in body composition (Beck et al., 2014; Cirnigliaro et al., 2013; Dionyssiotis et al., 2009) that are directly related to the affected limbs. Whether focused on the sports or the health of these individuals, reliably identifying the body region in which changes occur is essential for diagnosis, monitoring, and effective intervention.

Regarding the circumference, it can be verified whether they can also be used in models of prediction of fat mass by body segment, although they have lower correlations than skinfold thickness. The central circumferences already have scientific support for its use in the population with SCI, highlighting the waist circumference that can be used as an indicator of cardiovascular disease risk, having a strong correlation with body fat mass, abdominal fat, and biomarkers (Ravensbergen et al., 2014; Sumrell et al., 2018; Sutton et al., 2009). In our study, the abdominal circumference (measured 1 cm above the umbilical line) represented 50 % of the trunk fat mass variation, which emphasizes the feasibility of using circumference as a predictor of central fat.

Concerning the low correlations of lean mass predicted by DXA with skinfolds of all body regions, it may be explained by the fact that the skinfolds estimate the total body fat, as approximately half of the total body fat content is located in the adipose deposits directly under the skin, i.e. the subcutaneous tissue (McArdle et al., 2016).

Through this study, it was observed that segmental prediction models can be created that use skinfolds thickness and circumferences to determine fat mass. However, it is not possible to propose an equation using such variables, since for prediction, it is recommended to have 10 to 20 participants per predictive variable (Pedhazur, 1997), which would necessitate a sample of 30 to 60 subjects.

The main limitation of this study is the small sample size, which may have a negative impact on the statistical analysis. However, it is worth mentioning the innovative character of this study, which is the first to analyze the body composition of athletes with spinal cord injury segmentally.

Conclusion

In summary, segmental analysis of body composition through circumferences and skinfold thickness may be appropriate for the accurate determination of segmental body composition in athletes with spinal cord injury, especially the sum of segmental skinfolds that strongly and significantly expressed fat mass predicted by DXA.

Further studies with larger representative samples and segmental analyses that include evaluations of the largest number of measurements (circumferences, skinfolds, lengths, and bone diameters) in each body segment for the creation of subsequent predictive models may provide more expressive results.

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Media Representation of Women Athletes at the Olympic Games: A Systematic Review

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Abstract

The purpose of this paper was to conduct a systematic review of the literature on the coverage of women at the Olympic Games. A total of 144 records were collected from the Web of Science database which were screened to $n = 58$ for in-depth examination. A content analysis was performed with the data gathered based on the following thematic categories: evolution of scientific publications by years; types of studies carried out; countries and regions with the longest track record in the topic; citations, authors and main findings, and future research strands. The results showed that the studies were mainly performed in the United States, especially in recent years, and with a strong incidence in 2015, in areas such as the social sciences and communication and with a greater focus on television, albeit with a growing interest in the new digital media. In general, they continue to report a lack of fairness in the amount of coverage, coupled with gender differentiation in the representation of women's sport. Further studies are suggested to reveal whether such imbalances persist or progress is being made towards greater fairness.

Keywords: media, Olympic Games, sport, systematic review, women.

Introduction

Since their beginnings, studies on sports media coverage have found a meagre female presence, since sportswomen have been excluded or sidelined in the media, especially in routine news coverage (Toffoletti, 2016), but also during major events such as the Olympic Games (Delorme & Testard, 2015; Salido-Fernandez, 2020). This is because the media, particularly the sports media, are a male-dominated space which affords priority to sports played by men and which are broadcast to a largely male audience. Women are underrepresented in these media (Billings et al., 2010; Jones, 2013) and need to attain major accomplishments to achieve any kind of presence. Moreover, when they do appear, they are portrayed in a trivialised, biased and stereotypical way, with comments about their emotions, physical appearance and family life (Eagleman, 2015; Ravel & Gareau, 2016).

Research on the representation of women in sport in the media began in the United States in the 1980s, although it was not until the 1990s that it became more widespread. In this regard, particular mention may be made of the work by Duncan (1990), focusing on the 1984 and 1988 Games, who found photographic coverage images that downplayed sportswomen's achievements in the form of comments on their beauty or attire. Meanwhile, Lee (1992) discovered highly unequal coverage in both text and pictures at these same Games, coupled with biological differentiation by sex including a tendency to trivialise and sideline sportswomen. Towards the end of the 1990s, Toohey (1997) analysed the 1988 and 1992 Games and confirmed this quantitative female inferiority, with a media presence of 30 %-32 % compared to a prominent 60% male presence. These figures became less pronounced in the following Games, as female coverage on NBC at Barcelona 1992 reached 44 %, albeit still with biases which emphasise sports regarded as appropriate for women, i.e., the more aesthetic and mainly solo sports, such as gymnastics (Daddario, 1997). These coverage figures dropped to around 30 %-33 % again at the Sydney 2000 and Athens 2004 Games (Capranica et al., 2005; Capranica et al., 2008; Greer et al., 2009), although they rose to 40 % in Beijing.

In recent years, studies have continued to show an imbalance between participation data and media coverage, as demonstrated by the Global Media Monitoring Project (GMMP, 2015), which points to a worldwide female presence in the general media (radio, press and television) of 24 % and of barely 4 % in the sports media, although women's participation in sport amounts to 40 % (UNESCO, 2020). In contrast to these figures, more recent studies found a much more equal female coverage of the Rio 2016 Games of 58.5 % on the US NBC network (Billings et al., 2017). This progress has been fostered by the national and international institutions and organisations over the years, as they have begun to call for greater levels of equality in sport and its media coverage, most notably the efforts of the International Olympic Committee, which has advocated gender equality through the continuous updates of its Olympic Charter (IOC 2020a). Indeed, its forecast for the Tokyo Games is a women's participation of 49 % (IOC 2020b).

Therefore, and despite an increasingly more balanced quantitative coverage of both sexes, researchers and sportswomen alike continue to perceive an invisibilisation and the existence of stereotypes such as beauty, physical appearance and sexuality (Coche & Tuggle, 2016; Martínez-Abajo et al., 2020), infantilisation and victimisation, as well as female emotion, passivity and weakness (Eagleman, 2015; Jones, 2013) in comparisons with male athletes, ambivalence and trivialisation (Lichfield, 2018). These forms of disparate representation extend to the digital media, where coverage of women is also scant, and biases and stereotypes identical to those of the legacy media continue to persist (Johnson et al., 2020; Lichfield & Kavanagh, 2019). This is coupled with a growing presence of female profiles defined exclusively by their romantic ties to male athletes which undercut women athletes' media presence (Gómez-Colell, 2015; Muñoz-Muñoz & Salido-Fernandez, 2018).

The purpose of this paper was to gain an insight into how the coverage of women's sport in the media during the Olympic Games has evolved by reviewing the research conducted in this field from the early 2000s to the present day in order to pinpoint the most prolific years, the main areas addressed by these studies, their authors and current research strands, as well as the proposals for the future.

Methodology

This study conducted a systematic review of the main published research on women's representation in the media during the Olympic Games. For this purpose, a search was carried out in the Web of Science (WOS), the database which compiles the leading scientific publications in all fields, including the social sciences.

Search strategy

This study followed the approach taken in other systematic reviews (Castillo & Hallinger, 2018; Cruz-González et al., 2020) and criteria focused on the appropriateness of the topic, time evolution, thematic areas, countries, authorship and research approach were used to select the articles. Thus, the following exclusion and inclusion criteria were established: articles or reviews published in scientific journals from the year 2000 onwards to ascertain the evolution over the last 20 years, also focussing on the study of the media representation of women athletes during the Olympic events held from that year onwards in the social sciences and humanities.

The keywords used in the search equation were: TSS=(wom*n AND Olympic AND media).

Data screening and extraction

As shown in Figure 1, the search yielded a total of 144 specific records in WOS. The search was then refined through a review of the articles to remove any prior to the cut-off date, those related to the Paralympic Games, as their characteristics did not match the analysis, or studies addressing the effects of unequal media coverage on audiences or elite athletes, as their objectives did not tie in with this research. This left a total of 112.

Following this screening, the final data extraction process consisted firstly of an in-depth reading of the abstracts to reduce the number of records to 92 and then of the full articles to rule out any that were not relevant to the research as they did not fulfil the study objective. Hence *n* = 58 articles were finally included in the analysis.

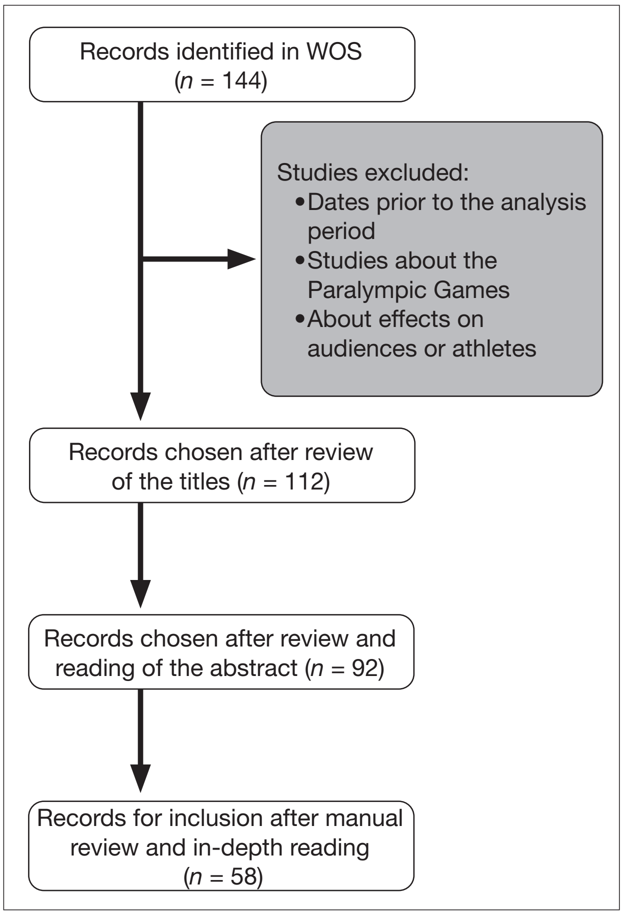

Figure 1
Study selection. Source: authors.

After the records to be included in the analysis had been defined, the articles were compared and examined in depth based on their characteristics (areas, source, authorship, etc.) and main findings (Okoli & Schabram, 2010), which led the following thematic categories to be established:

1. Evolution by years of the scientific output on women's Olympic coverage (the first studies, the most prolific years, etc.).
2. Type of analyses conducted (by areas of knowledge).
3. Countries and regions with the greatest influence and track record in research.
4. Citations, authorship and most relevant findings.
5. Future research strands.

Results

Evolution of research on women's Olympic coverage

Studies on gender and the Olympics in the media have clearly grown, as is shown in Figure 2. They have increased from a mere one or two publications per year in the early 2000s to a significant expansion since the London 2012 Olympic Games, with four publications per year in the two years following the Games, reaching an all-time high of a total of 11 publications in 2015, tapering off to just two studies in 2017 and levelling off to around four publications per year in subsequent years.

If researchers' interest in each Olympic event is examined, there was only one publication on the Barcelona 1992 and Atlanta 1996 Games (Higgs et al., 2003), which was also the case for Sydney 2000, with one specific publication (Capranica et al., 2005). This figure rose to three for Athens 2004 (Billings, 2007; Capranica et al., 2008; Greer et al., 2009), there were none for Turin 2006, and Beijing 2008 yielded nine studies, including those by Billings et al. (2010), Li (2011), Tang and Cooper (2012), Amara (2012) and Jones (2013). Vancouver 2010 was covered by Angelini et al. (2012) again, as well as by Jones and Greer (2012) and Smith (2016).

From 2012 onwards, publications on women's Olympic coverage flourished as it was the year of the London Games, called "the women's Games" due to the high levels of participation and success achieved by women. This sparked great interest among researchers, with 15 specific studies on the Games, including the papers by Ravel and Gareau (2016), Frank and O'Neill (2016), Delorme and Testard (2015), Eagleman (2015) and Godoy-Pressland and Griggs (2014). The Winter Games were also found to warrant increasingly greater attention, generating four studies for Sochi 2014 (Delorme & Pressland, 2016;

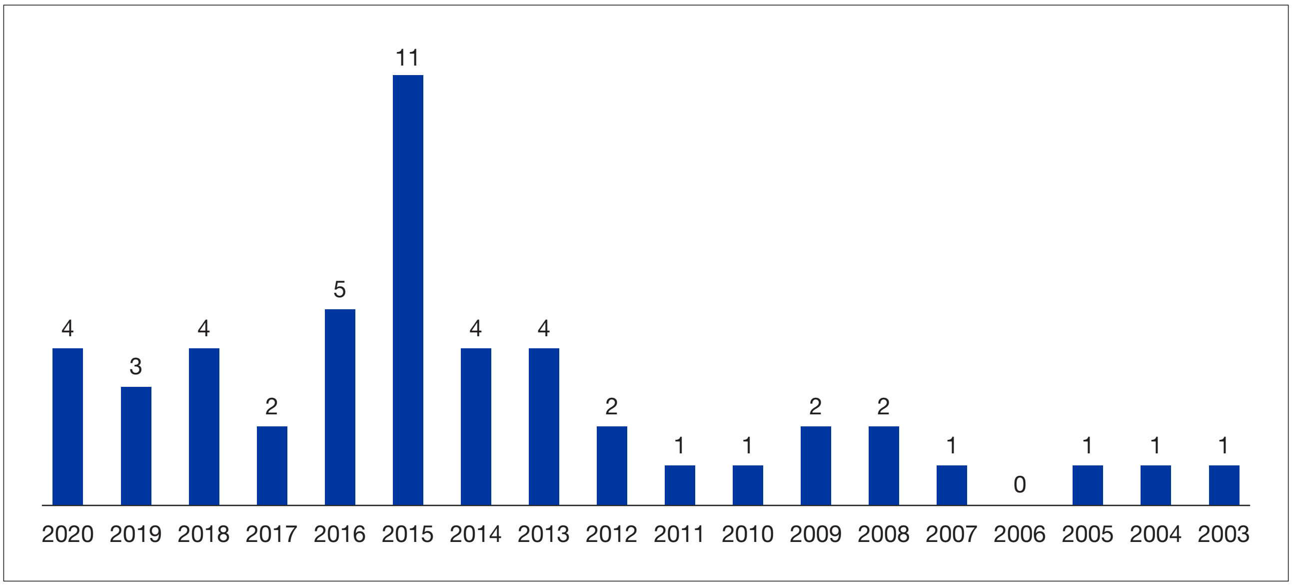

Figure 2
Scientific publications by years. Source: authors using WOS data.

Jakubowska, 2017; MacArthur et al., 2016; 2017) and, for the moment, two publications about Pyongyang 2018 (Oh et al., 2020; Xu et al., 2020). To date, six specific studies about the recent Rio 2016 Summer Games have been published (Dashper, 2018; Litchfield, 2018; Lichfield & Kavanagh, 2019; Villalon & Weiller-Abels, 2018; Xu et al., 2018; Xu et al., 2019), although studies on these Games have also been found in some longitudinal analyses combining a number of Olympic periods (Johnson et al., 2020; Organista et al., 2020).

Types of studies carried out

Being interdisciplinary, women's, media and sport studies have moved forward through several areas in the course of their evolution (Fig. 3). The social sciences and communication are the most prominent domains, although sports science, psychology, history and linguistics also figure prominently, and in some cases records were found in several disciplines at the same time. Thus, the highest percentage was in the social sciences, accounting for 55 % of the total number of publications, particularly papers such as the ones by Xu et al. (2020, 2019, 2018) on the last two Olympic events (the 2016 Summer and 2018 Winter Games), examining the coverage provided by Chinese and Australian television. They found an underrepresentation of women, although particularly a clear difference in the attribution of athletes' success and failure, with women prevailing on account of their skills and men by dint of their experience. In areas such as communication, which accounted for 40 % of the total, research about the print media occupied a significant position, including papers by Delorme and Pressland (2016) and Delorme and Testard (2015), the latter based on photo analysis. Both described significant differences in the quantity and quality of coverage, with gender bias, invisibilisation and underrepresentation of women. Another representative area was sociology, which accounted for 31 %, particularly featuring studies on image restoration and public apologies by women athletes (Litchfield, 2018), notions which were revisited and amended by sport, gender and third-wave feminist studies. This area also includes the research by Amara (2012), in a study about media accounts of the clash of cultures addressing the representation of Muslim sportswomen and the use of the veil at the 2008 Beijing Games. Furthermore, film, radio and television accounted for 12 % of the total, and studies in this discipline largely examined television coverage, finding more airtime and more mentions for men (61.2 %), significant differences in physical and personality descriptions based on gender (Billings, 2007; MacArthur et al., 2017), more pictures of women's body parts and inferior sports status compared to male athletes (Kian et al., 2013), as well as differences in visual production, making women's sport appear to be somewhat less exciting (Greer et al., 2009). Other outstanding areas were psychology, with 10.3%, and sports science (8.6 %), which shared articles with the areas mentioned above. Sports science includes papers by Xu et al., 2019; Litchfield and Kavanagh, 2019; Dashper, 2018 and Litchfield, 2018. The remaining areas, albeit a minority, transferred these studies to history and addressed the historical evolution of women's representation in men's sports such as skiing and its impact on the current rise in women's participation (Hofmann, 2012), public

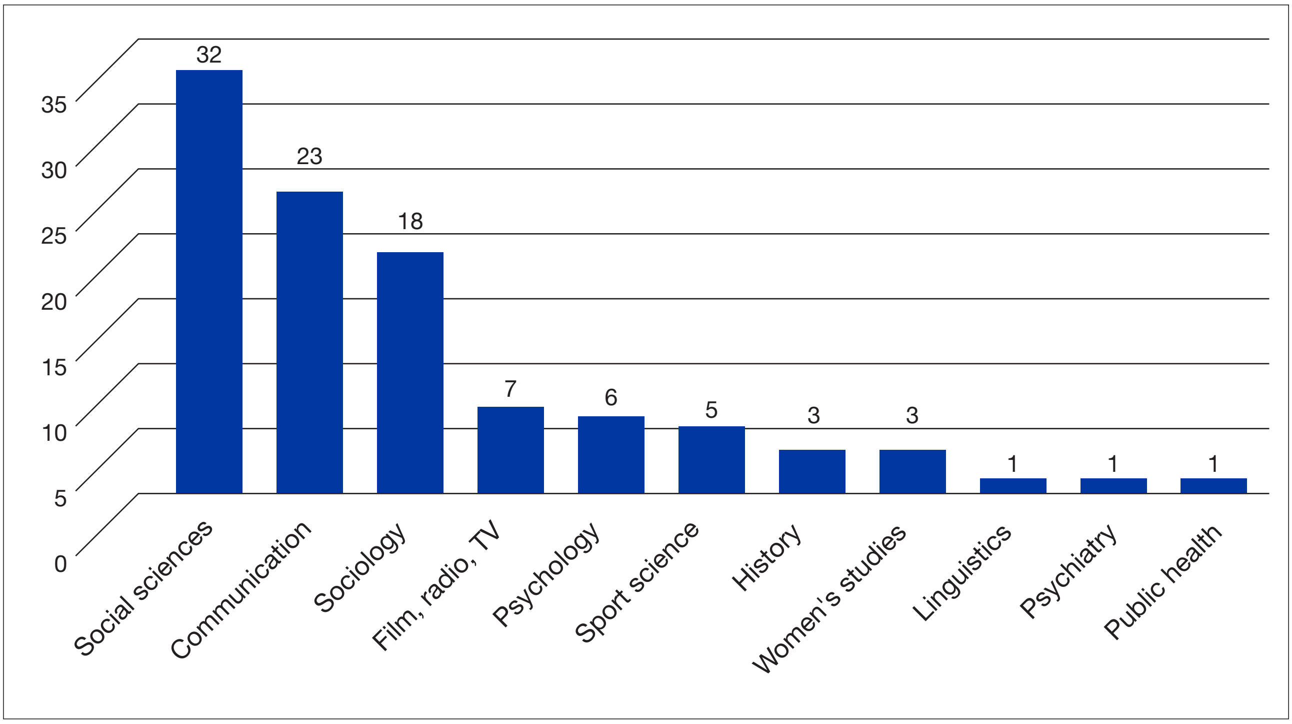

Figure 3
Areas of knowledge of the research. Source: authors using WOS data.

health and psychiatry. Finally, research on linguistics also featured, for instance by Zhang (2015), focusing on gendered language about Chinese gymnasts in Western and Chinese coverage, revealing gender discrimination in both of them. In the former, they were depicted as childlike, passive victims of the severe Chinese training programmes, whereas the latter casts them as submissive, innocent and obedient to the country's norms.

Countries and regions with the longest track record and interest in the coverage of women at the Olympic Games

The studies on women's Olympic sport and the media have expanded over the years to a number of countries and regions, although, as shown in Figure 4, the initial and greatest incidence has been in the United States. Hence, 53% of the output in this field has been produced in the United States and covers everything from the print media (Knight & Giuliano, 2001) and magazines such as *Sport Illustrated* (Dafferner et al., 2019) to the new media and social networks (Johnson et al., 2020), although the TV networks, particularly the NBC (Angelini et al., 2012; Billings, 2007; Billings et al., 2010; Greer et al., 2009; Higgs et al., 2003; MacArthur et al., 2016; Smith, 2016), have warranted the greatest attention.

The United Kingdom holds second place, with 19% of publications, with several studies addressing the representation of women in the British national press, where women athletes are still underrepresented (O'Neill & Mulready, 2015), including bias in photos (Godoy-Pressland & Griggs, 2014) and a low proportion of women sports journalists (Franks & O'Neill, 2016). Additionally, comparative studies between countries were also found, such as those by Delorme and Pressland (2016) on France, Britain and Spain, which identified variations in media discrimination in each country, with Spanish coverage being the fairest. The comparisons also analysed cultural differences, such as the representation of the veil (Amara, 2012) and of Muslim women in general in the Western press, where they were presented as childlike, victims and helpless, and also objectified and constructed from othering and exclusionary essentialism (Samie & Sehlikoglu, 2015).

France accounted for 10.3 % of total scientific output, focusing on the study of female underrepresentation in the French media (Delorme & Testard, 2015). However, comparisons between countries such as Belgium, Denmark, France and Italy (Capranica et al., 2005) were also found, as well as an examination of the US media (Dafferner et al., 2019), evincing significant progress in the coverage of women's achievements, albeit with persisting biases based on the sexualisation and objectification of their bodies. Other countries presenting the highest incidence of studies on women athletes were Australia (Litchield, 2018; Litchfield & Kavanagh, 2019; Xu et al., 2019) and

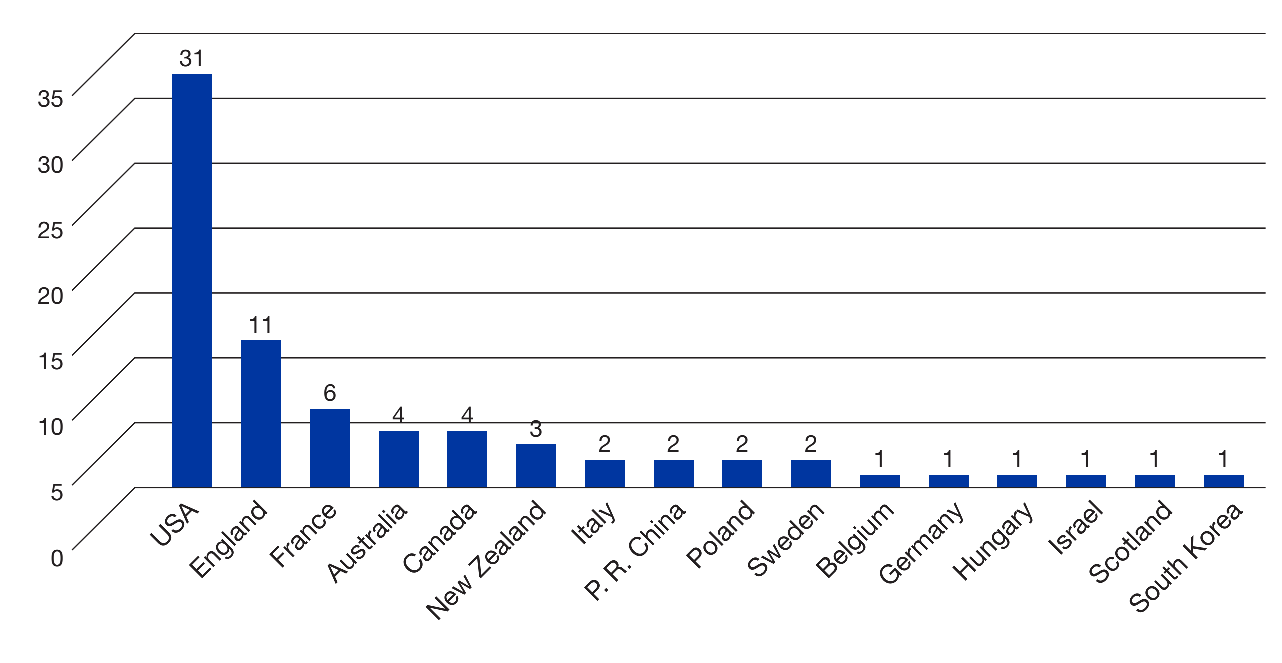

Figure 4
Countries/regions with the highest incidence of research. Source: authors using WOS data.

Canada (Johnson et al., 2020; McGannon et al., 2015), each one with approximately 7 %. Lastly, New Zealand provided 5% (Eagleman, 2015; Eagleman et al., 2014), with token contributions by Italy (Capranica et al., 2008), China (Oh et al., 2020; Xu et al., 2020), Poland (Organista et al., 2020) and Sweden (Hedenborg, 2013; Hellborg & Hedenborg, 2015), with 3.5% each. These percentages refer to the total number of articles analysed (58) and vary due to the fact that some studies were conducted by more than one country.

Citations, authors and main findings

Scientific publications on the media coverage of women at the Games total 763 citations with an average of 13.16 citations per article, 44.8 citations per year for all studies and an h-index of 15. In addition, there has been a major increase in citations since 2011 (15), which peaked in 2017 (totalling 109). This total dipped slightly to 84 the following year, followed by an increase in 2019 (to 106), and totalling 91 this year so far (2020) (Fig. 5).

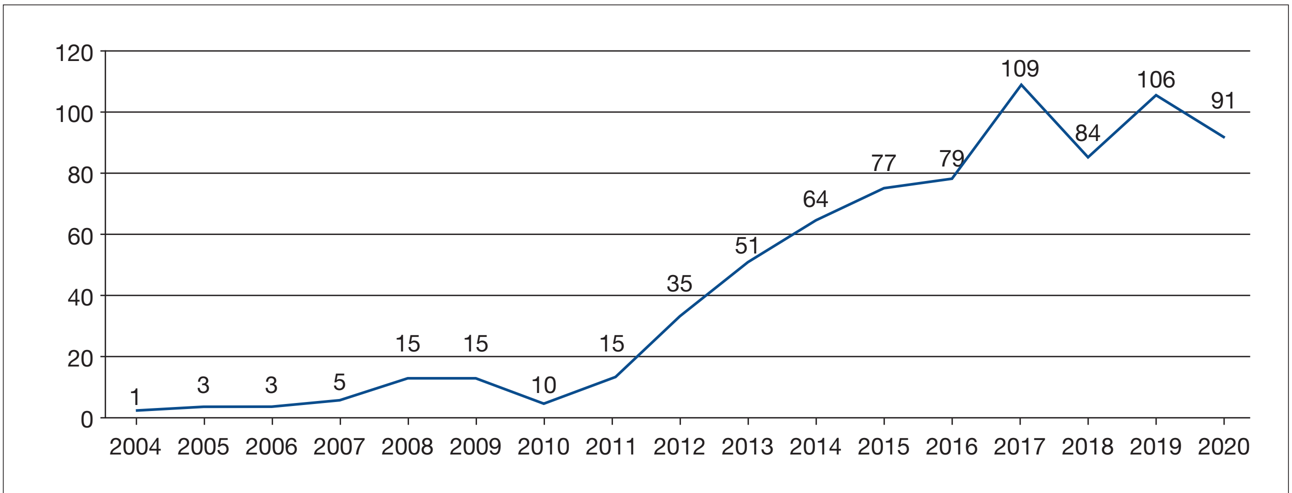

Figure 5
Evolution in citations by years. Source: authors using WOS data.

The following table (Table 1) lists some of the most significant research on the Olympic Games published since the year 2000. The earliest studies examined American television (NBC) in particular, finding, first of all, more male than female coverage across the different editions of the Games (Angelini et al., 2012; Billings, 2007; Billings et al., 2010; Higgs et al., 2003). Subsequent types of studies revealed gender differences rooted in biases according to the sport; for example, winter sports were perceived as more masculine as they tend to be more demanding and involve more physical contact (Billings, 2007). However, the studies also extended to images or pictures, more exciting in the case of male athletes, as seen in the Athens 2004 Games (Greer et al., 2009), or to the use of language, with differences in the descriptions of athletes' personality and physique in the case of Sochi 2014 (MacArthur et al., 2016).

Table 1
Evolution of research on women's coverage.

Author and year	Olympic event	Medium analysed	Main findings
Higgs et al. (2003)	Barcelona 92- Atlanta 96	Television: NBC	More male coverage, sports regarded as appropriate for women, greater criticism of women's mistakes
Capranica et al. (2005)	Sydney 2000	Print media	Nationalism, greater equality in coverage
Billings (2007)	Athens 2004	Television: NBC	Gender-differentiated coverage: subjectivity and bias in the portrayal of women
Greer et al. (2009)	Athens 2004	Television: NBC	Image biases: visually more exciting male coverage, symbolic male authority
Billings et al. (2010)	Beijing 2008	Television: NBC	Less female coverage, gender differences and lack of balance in depictions
Jones (2013)	Beijing 2008	Digital television: ABC, BBC, CBC and TVNZ	Twice as many male stories and pictures and gender stereotypes: sportswomen as emotionally weak or dependent and less committed
Angelini et al. (2012)	Vancouver 2010	Television: NBC	Quantitative imbalance: 3/5 male airtime and 75% of mentions
Kian et al. (2013)	London 2012	Various media	Sports regarded as appropriate for women, sexualisation, infantilisation and secondary status for women
Godoy-Pressland & Griggs (2014)	London 2012	Print media	More male photo coverage, more active and in teams
Eagleman (2015)	London 2012	Print media	Gender-differentiated framing, appropriate sport, infantilised, simplified and female body depictions
Delorme & Testard (2015)	London 2012	Sports media	Underrepresentation of women in photographs, albeit without significant differences in size, position or content
MacArthur et al. (2016)	Sochi 2014	Television: NBC	Less coverage of women (41.7%) Gender differences in depictions of physicality and personality
Litchfield & Kavanagh (2019)	Rio 2016	Twitter pages	Progress in the amount of coverage (47% male and 42% female). Gender-differentiated images and infantilisation of women
Xu et al. (2018)	Rio 2016	China Central Television	No significant differences found. Male figure skaters received more airtime than in Western countries
Organista et al. (2020)	Vancouver 2010, London 2012, Sochi 2014, Rio 2016	Media	Significant underrepresentation of women and differences in the description of rival competitors, nationalism and scant consideration of non-Polish women athletes

Source: authors.

From 2012 onwards, studies began to straddle other media, such as digital television. Of note here is the paper about Beijing 2008 by Jones (2013), who also found quantitative differences in online images and obvious stereotypes such as emotion, dependence and lack of commitment to the sport in the case of women, and additionally in the print media, ranging from female underrepresentation in text and pictures at London 2012 (Delorme & Testard, 2015; Godoy-Pressland & Grigg, 2014) to gender-differentiated framing (Eagleman, 2015) and the prevalence of stereotypes such as female sexualisation and infantilisation (Kian et al., 2013). This contrasted with the study by Xu et al. (2018) that found greater fairness in Chinese television coverage. Analyses of the social media have begun to emerge in recent years, including, for example, the study by Litchfield and Kavanagh (2019) on the Twitter accounts of two institutions at Rio 2016, where they also identified greater levels of fairness, albeit also persistent gender differences with more active male images and infantilisation of women. The latest situation update was provided by Organista et al. (2020) about the Polish press in a longitudinal study covering all the Olympic Games, both winter and summer, staged since 2010, which revealed a significant underrepresentation of women and the maintenance of gender biases which was more understated in its national team due to the distinct nationalist discourse associated with this type of global competition event.

Future strands

Over time, researchers on women's representation during Olympic events have proposed extending the analysis beyond the legacy media and exploring the coverage of women in new media such as digital platforms in greater depth (Xu et al., 2020). They have also proposed the conduct of more in-depth qualitative studies comparing different Olympic events or different sports, including not only disciplines deemed appropriate for women but also those appropriate for men or neutral (Eagleman, 2015). In addition, continuous media monitoring is proposed to measure the impact of the different gender equality measures implemented by national and international organisations and to ascertain how the daily routine coverage of women in the sports media is progressing outside the major championships (Delorme & Testard, 2015).

Discussion and conclusions

Studies on the coverage of women during the Olympic Games have evolved slowly but steadily since the early 2000s, peaking in 2015 with a total of 11 publications. This has been prompted by the interest in women's successes, particularly since the London 2012 Games, which attracted the attention of a large number of researchers seeking to examine the coverage of women athletes and their achievements, totalling 15 publications exclusively about these Games. Following London, the Rio 2016 Games sustained this high level of attention (six publications), which is not expected to end in the near future.

These studies are highly interdisciplinary, to the extent that they are addressed from fields such as the social sciences (55 %) and communication (40 %), psychology (10.3 %) and sports science (8.6 %). A large part of this research is produced in the United States (53 %), followed by the United Kingdom (19 %) and France (10.3 %) and other countries, making Europe the second-largest source with more than 46 % of total output. This research is also beginning to spread to other countries, including Australia and Canada (6.9 % each).

The impact of this research has also increased substantially from just one citation in 2005 to a maximum of 109 in 2017 and close to 100 in 2020, amounting to a mean of almost 45 citations per year for all authors. In general, the studies cover all media, ranging from television (Billings, 2007; Greer et al., 2009, Xu et al., 2018) to the print media (Capranica et al., 2005, Godoy-Pressland & Griggs, 2014, Eagleman, 2015), the new digital media (Jones, 2013) and the social media (Litchfield & Kavanah, 2019). These papers suggest that although significant progress has been made in terms of the quantity of coverage received by women, which is now fairer and more extensive (Litchfield & Kavanagh, 2019, Xu et al., 2018), biases persists, including underrepresentation in text and pictures (Billings, 2007; Jones, 2013; MacArthur et al., 2016), gender-based differences in depictions of athletes (Billings et al., 2010; Organista et al., 2020), and a greater focus on sports regarded as appropriate for males and females (Eagleman, 2015). Furthermore, sportswomen are still portrayed as emotionally weak or dependent (Jones, 2013) or childlike and passive (Godoy-Pressland & Griggs 2014) with an emphasis on female beauty and sexualisation (Kian et al., 2013).

Accordingly, the researchers recommend extending the study approach to other competitions and sports considered masculine or neutral (Eagleman, 2015) and to explore the coverage provided by the new media such as digital platforms (Xu et al., 2020) further. They also suggest rounding out the research with new studies to ascertain whether the measures put in place by organisations to further gender equality in sport are reflected in these media (Delorme & Testard, 2015).

In summary, despite the evident progress made in the coverage of women's sport, gender and gender norms continue to shape the media coverage of the Olympic Games today, regardless of the medium, the sport or the country in which they are held. Therefore, compiling the papers produced by researchers is intended to help to move forward in new studies which monitor the media to ascertain whether the progress made in the amount of female coverage is eventually consolidated. Ultimately, and above all, the intention is to shift the focus towards qualitative studies to ascertain the story framings imposed by the media on audiences, to find out whether the existing gender differences persist, whether others tailored to the new media emerge and whether progress is being made towards greater equality in the representation of sport in the media.

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Penetrative Passing Patterns: Observational Analysis of Senior UEFA and FIFA Tournaments

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Abstract

This study aimed to identify the most frequent behavioural, structural and interactional variables that induced three types of penetrative passing that generated goal-scoring chances in elite soccer. Following restrict inclusion criteria (each and every type of pass that disrupts the opposition's last defensive line), 134 attacking sequences from UEFA Euro 2016, 2017 FIFA Confederations Cup, and 2018 FIFA World Cup, were sampled. The PePas observational instrument – which integrates previous validated criteria – was used to analyse the penetrative passes. Moreover, the proportion *z*-test was performed to verify whether the proportions of tactical and technical behaviours differed from the others (α = .05). The results showed that ball control and running with the ball were the most frequent behaviours before the short penetrative pass preceded by an individual action, and the short pass was the most frequent behaviour that preceded the short penetrative pass preceded by a collective action. All tactical-technical behaviours occurred in an interactional context of no pressure and mostly in the pitch's central paths. Further, ball control was significantly different from the other categories in the long penetrative pass preceded by an individual action. We suggest that coaches consider replicating scenarios with no pressure of the defence and include activities that encourage tactical-technical behaviours such as running with the ball and quick exchange of passes with one and two touches.

Keywords: assist, attacking phase, match analysis, perturbation, soccer.

Introduction

Soccer is a game with a complex and dynamical nature, characterised by the interaction between two teams in opposing relationship. This relationship constantly and simultaneously prompts order and disorder during a match (Gréhaigne et al., 1997).

Soccer match analysis is considered an essential tool for coaches and players due to the potential insights it often provides for practice (Lames & Hansen, 2001). Accordingly, gathering information from the game regarding the temporal sequence of events might contribute to the design of more representative training activities to simulate typical situations in actual competitive settings (Pfeiffer & Perl, 2006). Moreover, it seems relevant to understand which events are more likely to lead to successful attacking plays, *i.e.*, the behaviours that induce the critical events that characterise an attacking sequence.

Goal-scoring has been largely investigated in sports science literature, and studies have indicated that more scoring opportunities are created when players are inside the box (e.g., González-Ródenas et al., 2020) due to the proximity to the opposing goal. Also, after an assist, more than 60% of the goals were scored in a first-touch shot, *i.e.*, with no contact with the ball before the shot (González-Ródenas et al., 2020). The authors have also emphasised the importance of penetrative passes to create goal-scoring opportunities (González-Ródenas et al., 2020). This critical event can be defined as a perturbation, *i.e.*, an external force that causes a disturbance in the system, forcing it to reorganise itself towards an attractor or moving the system towards a new attractor (Gorman et al., 2017). Robins and Hughes (2015) maintain that perturbations are associated with the destabilisation of the opposing team's dynamic organisation/coordination, and are defined by incidents (e.g., penetrative passing, dribbling, changing of pace) capable of modifying the regular flow of the game, resulting in a clear scoring opportunity.

In this sense, to the best of our knowledge, only one study (Zani et al., 2021) analysed the types of penetrative passes – "here conceived as the last pass of the sequence of play that disrupts the opponent's last defensive line (*i.e.*, a pass played into the space behind the last defensive line), performed by an attacking player and successfully received by a teammate who either performs the last action of the sequence of play in front of the goalkeeper (e.g., first-touch shot), or maintains ball possession until the last action (e.g., ball reception, dribble and shot), which generates a goal-scoring opportunity"). The authors found that the penetrative short pass preceded by an individual action was the most frequent, followed by penetrative long pass preceded by an individual action, and penetrative short pass preceded by a collective play. However, in our perspective, it is relevant to comprehend how the aforementioned penetrative passing leading to goal-scoring opportunities are induced concerning the tactical and technical behaviours, the interactional conditions among players, and the locations where the actions more frequently take place.

Thus, we aim to identify the most frequent behavioural (*i.e.*, tactical-technical behaviours of the attacking and defending teams and players), structural (*i.e.*, pitch locations) and interactional (*i.e.*, the interactions between attacking and defending players) variables that induced each type of penetrative passing that generated goal-scoring chances in soccer.

Methods

Observational Design

The observational design followed the specific taxonomy used (Anguera et al., 2011). The nomothetic criteria were represented by analysing different national teams in the UEFA Euro 2016, 2017 FIFA Confederations Cup, and 2018 FIFA World Cup tournaments (see Table 1). The follow-up criteria were configured through a sequential analysis of the events (starting from the action that preceded the penetrative pass until the end of the offensive phase) using an observational instrument called PePas (Table 2), that includes multiple criteria and responses (multidimensional concept).

Participants

All matches were obtained from the InStat Scout® platform. A search was made and included all the 227 matches played from the group stage to final matches in the UEFA Euro 2016, 2017 FIFA Confederations Cup, and 2018 FIFA World Cup. One hundred and thirty-four attacking sequences with a penetrative pass in behind the opponent's last defensive line were sampled and met the inclusion and analysis criteria. Although the number of sequences may seem limited, the specific nature of the events being studied, as well as the number and significance of the tournaments we analysed, justifies the size of the sample. The number of attacking sequences according to the stage of the competition was as follows: 92 in the group stage; 20 in the round of 16; 4 in the quarter-finals; 11 on the semi-finals; 3 in the finals; and 4 in the third-place matches. Out of 134 attacking sequences, 120 included the three types of penetrative passes analysed in the present work.

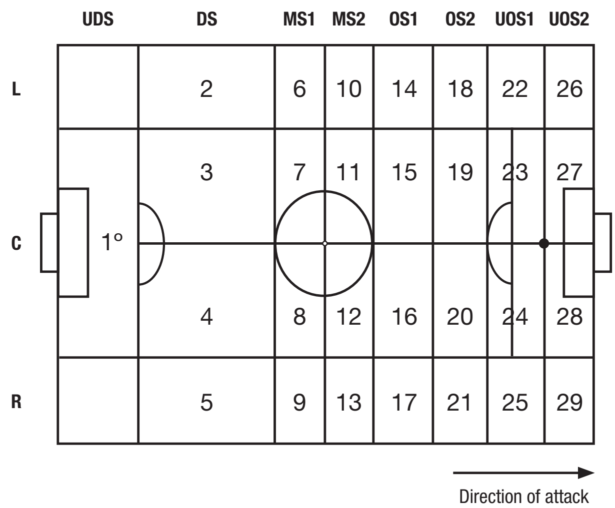
Table 1
National teams that performed penetrative passes during either the 2016 UEFA Euro, and/or the 2017 FIFA Confederations Cup, and/or 2018 FIFA World Cup.

Albania	Czech Republic	Japan	Saudi Arabia
Argentina	Denmark	Korea Republic	Spain
Australia	Egypt	Mexico	Sweden
Austria	England	New Zealand	Switzerland
Belgium	France	Panama	Ukraine
Brazil	Germany	Peru	Uruguay
Cameroon	Hungary	Poland	Wales
Chile	Iceland	Portugal	
Colombia	Ireland	Romania	
Croatia	Italy	Russia	

Table 2
PePas observational instrument criteria and categories.

CRITERIA	SUB-CRITERIA	CATEGORIES	CODE
1. Ball recovery or ball development before the last pass (RDB) (adapted from Barreira et al., 2013)	BY COLLECTIVE ACTION	Short pass Long pass Throw-in Corner Kick	RDBsp RDBlp RDBti RDBck
	BY INDIVIDUAL ACTION	Running with the ball Dribbling (1x1) Ball control Defensive behaviour followed by a pass Opponent's intervention with no success	RDBrb RDBd RDBbc RDBdb RDBns
2. Penetrative pass (PP) (adapted from Melo, 2017)		Short penetrative pass preceded by a collective action Short penetrative pass preceded by an individual action Long penetrative pass preceded by a collective action Long penetrative pass preceded by an individual action Opponent's intervention with no success Short penetrative pass preceded by an opponent's intervention with no success Long penetrative pass preceded by an opponent's intervention with no success	PPspca PPspia PPlpca PPlpia PPns PPspns PPlpns
3. Development of the ball possession after the last pass (DA) (adapted from Barreira et al., 2013)		Running with the ball Dribbling (1x1) Ball control Unsuccessful attempt Shot on goal with one contact	DArb DAd DAbc DAua DAoc
4. First Defender (DD) tactical-technical actions (adapted from Fernandes et al., 2019)	CLOSE MARKING	Player marking Pressure Intervention without success Unsuccessful tackle	DDmh DDcp DDis DDtr
	DEFENSIVE SPACE MANAGEMENT	Close longitudinal spaces Close transversal spaces Zonal cover with player marking Control or balance positioning	DDel DDet DDcz DDpe
	DEFENSIVE RECOVERY	Displacements of recovering Recovery balance	DDdr DDer
	DEFENSIVE VIGILANCE	Defensive coverage Temporisation	DDcb DDct

Table 2 (Continuation)
PePas observational instrument criteria and categories.

CRITERIA	SUB-CRITERIA	CATEGORIES	CODE
5. Second Defender (DI) tactical-technical actions (adapted from Fernandes et al., 2019)	CLOSE MARKING	Player marking Pressure Intervention without success Unsuccessful tackle	DImh DIcp DIis DItr
	DEFENSIVE SPACE MANAGEMENT	Close longitudinal spaces Close transversal spaces Zonal cover with player marking Control or balance positioning	DIel DIet DIcz DIpe
	DEFENSIVE RECOVERY	Displacements of recovering Recovery balance	DIdr DIer
	DEFENSIVE VIGILANCE	Defensive coverage Temporisation	DIcb DIct
6. End of the offensive phase (F) (adapted from Barreira et al., 2013)		Goal conceded Shot on target	Fgl Fst
7. Pitch zones and sectors where the actions took place (adapted from Castañer et al., 2016)		 UDS = Ultra defensive sector; DS = Defensive sector; MS1 = Middle sector 1; MS2 = Middle sector 2; OS1 = Offensive sector 1; OS2 = Offensive sector 2; UOS1 = Ultra offensive sector 1; UOS2 = Ultra offensive sector 2; R = Right; C = Central; L = Left	
8. Centre of the game (CJ) (adapted from Barreira et al., 2013)	WITH PRESSURE (P)	Relative numerical inferiority Absolute numerical inferiority Pressure in numerical equality	Pr Pa Pe
	WITH NO PRESSURE (NP)	No pressure in numerical equality Relative numerical Superiority Absolute numerical Superiority	NPe NPr NPa
9. Spatial pattern of interaction between teams (CEI) (adapted from Barreira et al., 2013)	VERSUS EXTERIOR ZONE	Back line versus exterior zone	BE
	VERSUS OFFENSIVE LINE	Ball in the empty zone (goalkeeper) versus offensive line Back line versus offensive line Mid line versus offensive line	EF BF MF
	VERSUS MID LINE	Back line versus mid line Mid line versus mid line Offensive line versus mid line	BM MM FM
	VERSUS BACK LINE	Mid line versus back line Offensive line versus back line Exterior zone versus back line	MB FB EB
	VERSUS EMPTY ZONE	Offensive line versus empty zone (goalkeeper)	FE

Instruments

Observational instrument

Initially, the researchers screened the video footage of the matches to verify the incidence of penetrative passes (as previously described) in the three international tournaments (2016 UEFA Euro, 2017 FIFA Confederations Cup and 2018 FIFA World Cup) with the purpose of registering the variables that could ascertain the aspects that characterised the period from the action that preceded the penetrative pass up to the conclusion of the sequence of play. Following this procedure, The PePas observational instrument was designed using criteria and/or categories of other previously published tools (Barreira et al., 2013; Fernandes et al., 2019) that integrate teams' offensive and defensive technical and tactical behaviours, thus uncovering the structural, behavioural and interactional contexts of the game (Table 2). This instrument includes 9 criteria and 93 categories, namely four behavioural (attacking team, criteria 1, 2, 3 and 6; defending team, criteria 4 and 5), two interactional (criteria 8 and 9) and one structural (criterion 7) variables. For the present investigation, criteria 1, 2, 4, 5, 7, 8 and 9 were used.

Data Collection Software

The Lince v1.3 software was used to collect data. It allows data encoding, video analysis, data quality estimation, and data exporting from file formats used by other analysis software (Gabin et al., 2012).

Procedures

We performed an analysis of the ball recovery or ball development before the last pass (criterion 1) and their correspondent structural (criterion 7) and interactional (criteria 4, 5, 7, 8 and 9) variables, for each type of the following penetrative passes (criterion 2): (i) penetrative short pass preceded by an individual action (PPspia); (ii) long penetrative pass preceded by an individual action (PPlpia); and (iii) short penetrative pass preceded by a collective action (PPspca).

Data quality

The Lince software comprises systems of analysis that enable the design of observational instruments, inclusion of video files and data collection through notational analysis. In addition, analysis can be saved in, and loaded from specific folders, which can then be compared. Intra-observer reliability was calculated using Cohen's Kappa (*k*) (Cohen, 1960) through the Lince v1.3 software. A 30% (n = 35) of the sample was observed twice by the same observer with an interval of fifteen days. The values of *k* ranged between 0.86 and 1.00. These values are classified as almost perfect (0.81-1.00) by literature (Bakeman & Gottman, 1997).

Data Analysis Software

Orange: Data Mining Toolbox in Python v3.22. (Demšar et al., 2013) was used to explore and visualise data; and RStudio v1.2.1335 (R Core Team, 2019) for statistical analysis.

Statistical analysis

It was made an exploratory analysis through data visualisation and contingency tables. In most of the cells, the expected count was less than the minimum expected (Rothman et al., 2008). Thus, we utilised the sub-criteria (see Table 2) of the following criteria: first defender tactical-technical actions (DD); second defender tactical-technical actions (DI), centre of the game (CJ) and spatial pattern of interaction between teams (CEI). As for the pitch zones, we grouped the central zones of the same sectors (*i.e.*, central zones 3 and 4; 7 and 8; and so on). Subsequently, we applied the proportion *z*-test, specifically to the groups with a sufficiently large number of events, *i.e.*, $n > 5$ (Montgomery & Runger, 2003), to test the hypothesis that the proportion of a group is statistically greater than another one within the same criterion. The significance level was set at $p < .05$.

Results

Behavioural variables of the attacking team

Table 3 shows that ball recovery or ball development before the last pass by reception/control (RDBbc) tended to occur more often in the penetrative short pass preceded by an individual action (PPspia, n = 39) and in long penetrative pass preceded by an individual action (PPlpia, n = 21), although in the PPspia it did not display statistical differences when compared to ball recovery or ball development before the last pass by running with the ball RDBrb (n = 30, p = .09). On the other hand, ball recovery or ball development before the last pass by a short pass (RDBsp) was the most predominant action that preceded the short penetrative pass preceded by a collective action (PPspca, n = 13).

Table 3
Frequency of ball recovery or ball development before the last pass (RDB).

PP	RDB								
	RDBbc	RDBrb	RDBsp	RDBdb	RDBd	RDBlp	RDBck	RDBti	TOTAL
	N	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*
PPspia	39	30	0	4	3	0	0	0	76
PPlpia	21	4	0	2	0	0	0	0	27
PPspca	0	0	13	0	0	2	1	1	17
TOTAL	60	34	13	6	3	2	1	1	120

Note. PP = Penetrative pass; PPspia = Short penetrative pass preceded by and individual action; PPlpia = Long penetrative pass preceded by an individual action; PPspca = Short penetrative pass preceded by a collective action; RDB = Ball recovery or ball development before the penetrative pass; RDBbc = Ball recovery or ball development before the last pass by ball control; RDBrb = Ball recovery or ball development before the last pass by running with the ball; RDBsp = Ball recovery or ball development before the last pass by a short pass; RDBdb = Ball recovery or ball development before the last pass by defensive behaviour followed by a pass; RDBd = Ball recovery or ball development before the last pass by dribbling; Ball recovery or ball development before the last pass by a long pass.

Behavioural variables of the defending team

As Table 4 shows, the ball recovery or ball development before the last pass by ball control (RDBbc) in the PPspia showed that the most frequent actions of the first defender (DD) were defensive recovery ($n = 20$), as their occurrence was significantly higher than defensive vigilance ($n = 11$, $p = .04$) and defensive space management ($n = 6$, $p = .001$). As for the second defender (DI), the defensive space management ($n = 21$) occurred significantly more often than defensive recovery ($n = 5$, $p < .05$) and defensive vigilance ($n = 7$, $p = .002$).

Following the tendency of ball development before the last pass by ball control (RDBbc), the results of ball development before the last pass by running with the ball (RDBrb) also revealed that defensive recoveries ($n = 16$) were the most frequent actions. However, in this case, no significant differences were found in the comparison with defensive vigilance ($n = 13$, $p = .31$). The second defender's (DI) most frequent actions were defensive space management ($n = 17$), which were significantly more frequent than defensive recovery ($n = 5$, $p = .002$) and defensive vigilance ($n = 7$, $p = .01$).

As for the long penetrative pass preceded by an individual action (PPlpia), Table 3 shows that the DD's most frequent actions were defensive space management ($n = 11$), although no significant differences were found in comparison with defensive recovery ($n = 9$; $p = .378$). Similarly, the DI concentrated most actions on the defensive space management cluster ($n = 14$), and their frequency was significantly higher than defensive recovery ($n = 5$; $p = .006$).

Regarding the PPspca, defensive space management was the most common action in both DD and DI ($n = 6$). With respect to the centre of the game (CJ), the results showed that the context of no pressure ($n = 12$) occurred more often than the context of pressure ($n = 1$).

Interactional variables

In the short penetrative pass preceded by an individual action (PPspia), the centre of the game (CJ) revealed that, for both RDBbc and RDBrb, a context with no pressure ($n = 37$ and 28, respectively) was more frequent than the context of pressure ($n = 2$ in both cases). With respect to the spatial patterns of interaction between teams (CEI), it was observed that the RDBbc was significantly more frequent in the rapport of forces against the back line ($n = 21$) when compared to the mid line ($n = 9$, $p = .01$).

On the other hand, when running with the ball (RDBrb), the rapport of forces versus the mid line ($n = 21$) occurred more often than the one against the back line ($n = 18$), although this difference was not statistically significant ($p = .31$).

Regarding the long penetrative pass preceded by an individual action (PPlpia), the results of CJ revealed that the context with no pressure occurred in 100% of the cases ($n = 21$). As for the CEI, the most frequent rapport of forces occurred versus the middle line ($n = 13$), and it occurred significantly more often in comparison with the offensive line ($n = 6$; $p = .03$).

As for the short penetrative pass preceded by a collective action (PPspca), the spatial pattern of interaction between teams (CEI) displayed more rapports of forces versus the back line of the opposing team ($n = 7$), despite the absence of significant differences, when compared to the mid line ($n = 6$; $p = .5$).

Table 4
Behavioural and interactional variables according to the type of ball recovery or ball development before the last pass (RDB) for each type of penetrative pass.

	PPspia		PPlpia	PPspca
	RDBbc	RDBrb	RDBbc	RDBsp
First Defender (DD)				
Close marking	2	1	0	2
Defensive space management	6 a	0	11	6
Defensive recovery	20 b	16	9	3
Defensive vigilance	11 c	13	1	2
Second Defender (DI)				
Close marking	7 e	1	3	1
Defensive space management	21 d	17 f	14 h	6
Defensive recovery	5 e	5 g	5 i	3
Defensive vigilance	6 e	7 g	0	3
Centre of the Game (CJ)				
With pressure	2	2	0	1
With no pressure	37	28	21	12
Spatial Pattern of Interaction Between Teams (CEI)				
Versus offensive live	0	0	6m	0
Versus mid line	9k	21	13 l	6
Versus back line	21 j	18	2	7

Note. PPspia = Short penetrative pass preceded by and individual action; PPlpia = Long penetrative pass preceded by an individual action; PPspca = Short penetrative pass preceded by a collective action; RDB = Ball recovery or ball development before the penetrative last pass; RDBbc = Ball recovery or ball development before the last pass by ball control; RDBrb = Ball recovery or ball development before the last pass by running with the ball; RDBsp = Ball recovery or ball development before the last pass by a short pass. Frequencies with different subscripts at each column and criterion differ at p = .05, one-tailed z-test.

Structural variables

As shown in Figure 1, RDBbc that preceded the PPspia occurred predominantly in three central sectors of the pitch, which were central offensive sector 1 (COS1, n = 9), central offensive sector 2 (COS2, n = 9) and central ultra-offensive sector 1 (CUOS1, n = 9). Altogether, the central offensive sectors (COS1 and COS2, n = 18) displayed statistically higher proportion when compared to ultra-offensive sectors (CUOS1 and CUOS, n = 10), p = .049.

As for the RDBrb, as with the RDBbc, it was observed that the central offensive sectors were predominant (COS1 and COS2, n = 15) for this type of action, and it displayed significant differences in comparison with ultra-offensive sectors (CUOS1 and CUOS 2, n = 7, p = .03). The central offensive sector 2 (COS2, n = 9) was the most predominant, although differences to COS1 and CUOS1 (both n = 6) were not significant (p = .27).

According to Figure 1, before the PPlpia, both the central defensive sector (CDS, n = 7) and central midfield sector 1 (CMS1, n = 7) displayed the highest number of ball control (RDBbc), followed by the central offensive sector 1 (COS1, n = 4).

Regarding the RDBsp in the PPspca, COS2 had the highest frequency (n = 3) of RDBsp. The central sectors presented, altogether, nine occurrences, whereas this behaviour was observed three times in the right-wing, and only one in the left-wing.

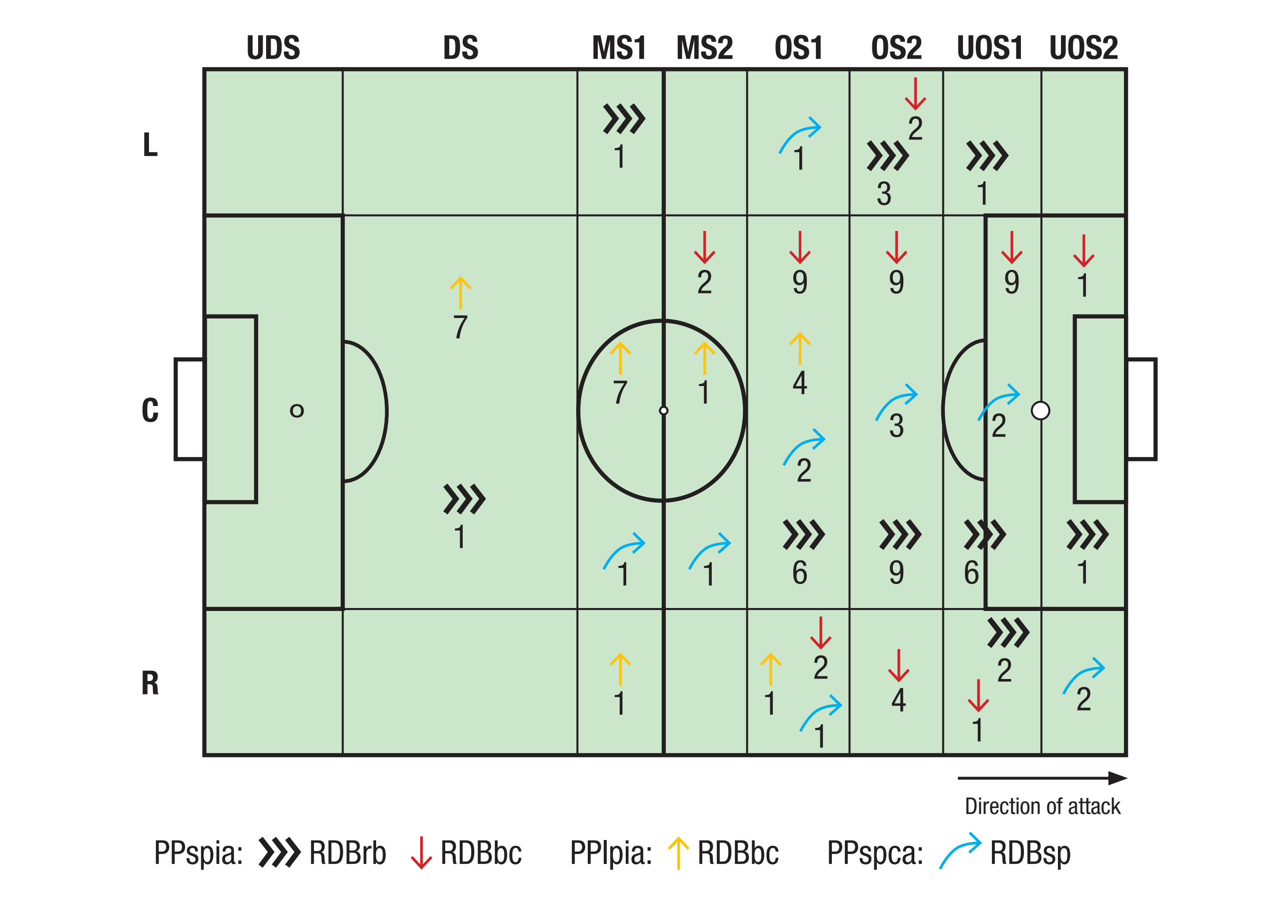


Figure 1
Frequencies of ball recovery or ball development before the penetrative last passes (RDB) according to the pitch sectors.
Note. RDBbc = Ball recovery or ball development before the last pass by ball control; RDBrb = Ball recovery or ball development before the last pass by running with the ball; RDBsp = Ball recovery or ball development before the last pass by a short pass; L = Left; C = Central; R = Right; UDS = Ultra defensive sector; DS = Defensive sector; MS1 = Middle sector 1; MS2 = Middle sector 2; OS1 = Offensive sector 1; OS2 = Offensive sector 2; UOS1 = Ultra offensive sector 1; UOS2 = Ultra offensive sector 2. PPspia = Short penetrative pass preceded by and individual action; PPlpia = Long penetrative pass preceded by an individual action; PPspca = Short penetrative pass preceded by a collective action.

Discussion

The present research aimed to identify the most frequent behavioural, structural and interactional variables that induced three types of penetrative passes (PPspia, PPlpia and PPspca), which generated goal-scoring chances in soccer. Ball control and running with the ball were the most frequent actions, and they occurred in a context of no pressure. Some published works (e.g., González-Ródenas et al., 2020) identified the types of assists, but none of them identified the action that preceded the assist action, which precludes comparison with the results of the present study.

Our findings showed that the PPspia was characterised by two types of ball recovery or ball development before the penetrative last passes which were significantly more frequent than the others: (i) ball control; and (ii) running with the ball. Barreira et al. (2014) reported that attacking patterns have changed over the years, shifting from individual actions such as running with the ball and dribbling in the central corridors of the pitch, to collective actions along the lateral paths. In addition, the density of players near the ball has similarly increased. The explanation for the fact that the results of the present work differ from those of the aforementioned study could be related to the style of play or strategy adopted by the teams to use penetrative actions to explore critical spaces of the opposing team, such as the central corridors of the pitch near the goal. In this sense, the type of play is likely to influence the attacking phase, as indicated by González-Ródenas et al. (2020), who identified that counterattack is an effective way to produce scoring opportunities, probably because the attacking team often exploits an imbalanced defence. The lack of defensive organisation in certain moments of the game might explain the results regarding the RDBbc and RDBrb in risky locations of the pitch, especially the central offensive sectors, in a context of no pressure ($p < .05$). According to Silva et al. (2005), running with the ball appears to be an essential action to turn less favourable attacking scenarios into contexts more susceptible to afford scoring opportunities and disrupt the defensive organisation.

Also, Tenga et al. (2017) suggested that when resorting to penetrative actions, either by a pass or running with the ball, exploiting vulnerable spaces within and behind the last defensive line is an important indicator of success in the attacking phase. In that perspective, our results showed that for both RDBbc and RDBrb, the most frequent tactical-technical actions of the DD were defensive recovery – which means that the player in possession had enough time and space – and defensive vigilance; while the second defender (DI) performed defensive space management in most of the observed sequences. In 1v1 sub-phases, at critical values of interpersonal distance, the attacker-defender dyad can be destabilised by the attackers if they change the difference between the defender's speed and their own, which can modify the structural organisation of the system (Duarte et al., 2010).

With respect to the CEI, the rapport of forces in the RDBbc was significantly higher ($p < .05$) against the back line. Regarding the RDBrb, no significative difference was observed between the rapport of forces against the mid line and back line. As for the RDBbc sequences, it is relevant to hypothesise the occurrence of a quick change of passes until the final action, due to the proximity to the goal.

As reported throughout this study, RDBbc preceded the PPspia in considerably favourable conditions in most analysed sequences, either by behavioural or interactional variables. These results corroborate with the findings of Castañer et al. (2017), which indicated that expert players, such as those participating in the elite competitions analysed in the present study, are able to frequently create conditions, in time and space, to play in no-pressure contexts. According to Amatria et al. (2019), in order to reduce opponents' density in the central zones of the pitch, the Spanish team strategically favoured breadth over depth in the attacking phase, as a means to achieve offensive success.

Although our findings also reinforce that short penetrative passes lead to more scoring opportunities, long penetrative passes also proved to be important actions to disrupt the defensive organisation. The most frequent action that preceded the PPlpia was RDBbc, having most frequently occurred in the central defensive sector and the central middle sector 1, in a context of no pressure. Also, the rapport of forces against the mid line was significantly higher ($p < .05$) than the others, suggesting that the opposing team could apply pressure high up or in the middle of the field, which opens space between the goalkeeper and the last defensive line. It could be a strategic opportunity to exploit it, especially because both defenders' tactical-technical actions were defensive space management, which indicates that the defenders could be reducing space between the lines (either transversal or longitudinal) controlling their position or performing a zonal covering.

As for the RDB in the PPspca, short passes were more frequent than long passes, and occurred in the central sectors of the pitch more often than in the wings. In addition, the most common rapport of forces was against mid line and back line.

Conclusion

In conclusion, three types of RDB preceded the three types of PP: ball control, running with the ball and short pass. Most of the actions occurred in the central sectors of the pitch, especially in both the central offensive sectors. The rapport of forces mostly occurred against back line and mid line, and when defenders were not pressing the attackers. The present study provides relevant insights to soccer coaches, as there seems to be a limitation in the literature regarding the actions that precede a final pass. The use of this information in training sessions could help improve the quality of behaviours and the team's attacking effectiveness.

Despite the relevant contributions, this paper has limitations. Some groups did not achieve the expected numbers of events, which prevented the comparison with others. Future studies could benefit from the analysis of the entire offensive sequence, in order to identify more relevant aspects that are likely to influence the execution of penetrative passes (e.g., type of attack, playing style, ball recovery). Thus, it would be important to gather detailed information to support the design of training activities to encourage players to perform penetrative passes in the attacking phase or to avoid them during the defensive phase.

As for the practical implications, our findings showed the importance of taking advantage of the moments when the opposing team is performing low pressure (by quickly moving the ball away from pressure zones and creating an imbalance for the opponent's defence), and when actions are more likely to occur before a penetrative pass in behind the last defensive line. Therefore, coaches could design activities that replicate scenarios of no pressure from the defence, especially in the central sectors of the pitch, while the attacking players should coordinate their movements to create space to the player in possession and for the other teammates to receive the penetrative pass. Activities that encourage running with the ball and quick exchange of passes (either with one touch or two) could also deliver effective results.

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Effects of Light-Emitting Diode Therapy on Recovery of Adult Male Futsal Players

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Abstract

The aim of this study was to investigate the effects of light-emitting diode (LED) therapy on markers of physical performance, muscle damage, inflammation, and oxidative stress up to 24h post the Futsal-Specific Intermittent Shuttle Protocol (FISP). Ten adult futsal players performed the FISP seven days apart. Participants were randomized into two groups that received LED (630 nm; 300 mW; 4.6 J/cm^2, 6 J per point, 120 J on each thigh) or Placebo. Heart rate (HR) and blood lactate concentration [Lac] were collected during the FISPs. Blood samples were collected for analysis of creatine kinase (CK), interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF-α), and advanced oxidation protein products (AOPP), and countermovement jump (CMJ) and perceived muscle soreness were assessed pre, post, and 24h post FISP. LED and Placebo groups presented similar mean HR (p = .58) and [Lac] (p = .86) during the FISPs. Interaction (p < .01) and time effects (p < .01) were observed for CK, with both Placebo (p < .01) and LED (p < .01) increasing CK at the post moment compared to pre. A time effect was found for CMJ (p < .01) and IL-6 (p < .01), showing that CMJ presented lower values at post (p < .01) and 24h post (p = .01) compared to the pre moment, and IL-6 increased at post compared to pre (p < .01) and returned to pre values 24h post FISP. Interaction, time, and group effects were not reported for muscle soreness, TNF-α, or AOPP (p > .05). In conclusion, LED therapy altered CK behavior post FISP, but did not change markers of physical performance, muscle soreness, inflammation, or oxidative stress of futsal players up to 24h post FISP.

Keywords: muscle damage, photobiomodulation, phototherapy, team sports.

Introduction

Futsal is a team sport, in which players cover 15% of total distance (~3000-4000 m) at high-intensity velocities (*i.e.* > 18.3 km h−1) (De Oliveira Bueno et al., 2014) and present heart rate (HR) values close to 86-90% of maximal HR (HRmax) during a match (Barbero-Alvarez et al., 2008; Castagna et al., 2009). Furthermore, constant sprints, abrupt stops, accelerations, changes of direction, and finalizations occur during matches (Naser et al., 2017). As a consequence of high-intensity physical and physiological demands, previous studies have reported decrements in physical performance during matches, as demonstrated by a lower distance covered at high intensity in the second half compared to the first (Barbero-Alvarez et al., 2008; De Oliveira Bueno et al., 2014; Milioni et al., 2016) and impaired knee flexor and extensor torque and lower-limb muscle power (inferred by countermovement jump test – CMJ) immediately (Dal Pupo et al., 2014) and up to 24h post-match (De Freitas et al., 2017). When consecutive matches are played, the same phenomenon is also observed on the following days (Freitas et al., 2014).

Exercise-induced muscle damage (EIMD) is frequently related to impaired performance immediately post and for some days after a futsal match (De Marchi et al., 2019; et al., 2012; Freitas et al., 2014). Previous studies have reported an increase in muscle damage, inflammation, and oxidative stress, indicated by increases in serum creatine kinase (CK) and lactate dehydrogenase (LDH) activities (De Marchi et al., 2019; De Moura et al., 2012), in interleukin 6 (IL-6) and C-reactive protein (CRP) (De Moura et al., 2012), and in carbonylated protein (CP) (De Marchi et al., 2019) levels immediately post and 48h post a futsal match. In this sense, strategies that accelerate the recovery of EIMD and physical performance are useful in assisting futsal players to reduce fatigue symptoms, leading to prompt availability of athletes for training sessions or competitions on days following matches.

Recently, the use of phototherapy has been suggested in sport with the main objective of promoting ergogenic effects, increasing physical performance during exercise, and as a recovery method after high intensity exercises, reducing EIMD in athletes of team and individual sports (Leal-Junior et al., 2015; Leal-Junior et al., 2019; Vanin et al., 2018). Phototherapy consists of applying light from red to near-infrared wavelengths emitted by low-density laser (Laser) or light-emitting diodes (LED) (Leal-Junior et al., 2019). Phototherapy stimulates cell photoreceptors in the mitochondrial respiratory chain of skeletal muscle, especially the enzyme cytochrome c oxidase (Hayworth et al., 2010). As a consequence, improvement in electron transference at the internal inner mitochondrial membrane can be seen, reducing the increased formation of reactive oxygen species (ROS), and enlarging the resultant intracellular adenosine triphosphate (ATP) pool (Hayworth et al., 2010). Improvement in the yield of total ATP production in skeletal muscle provides more available energy for muscle function, attenuating EIMD. A previous study suggested that phototherapy performed before futsal matches promoted a muscle protective effect, reducing muscle damage (*i.e.*, CK and LDH) and oxidative stress (thiobarbituric acid reactive substances – TBARS and CP) markers of futsal players post and 48h post matches (De Marchi et al., 2019). However, it has not yet been reported whether phototherapy applied post-matches could be effective for accelerating recovery of futsal players. Furthermore, up to now, the effects of phototherapy on recovery markers of futsal players, including physical performance, up to 24h-post matches are still unknown. This information could assist coaches mainly in short tournaments, where the interval between matches is approximately 24h (Freitas et al., 2014).

The aim of this study was to investigate the effects of LED therapy on markers of physical performance, muscle damage, inflammation, and oxidative stress up to 24h post an exercise protocol that simulates the physical demands of futsal match-play. To justify the aim, we hypothesized that the exercise protocol performed could negatively affect EIMD associated markers of futsal players, similar to those reported post futsal (De Marchi et al., 2019; et al., 2012), and that LED may attenuate these negative effects.

Methods

Participants

Ten outfield players (age 23.5 ± 7.8 years, height 174.3 ± 6.1 cm, and weight 69.1 ± 3.8 kg), from an adult futsal team participated in the present study. This team was ranked in the second position from the access division (to the first division) of a State Futsal Championship. The sample was selected by convenience due to the limited number of players in a futsal team and the difficulty in finding different teams with the same training routine and schedule, with availability. The inclusion criteria were: playing for the team included in the present study; having trained in futsal for at least four years. All players were healthy, free of injury, and reported not having consumed ergogenic substances or anti-inflammatory drugs at the time of the experiment. In addition, all volunteer players were instructed not to consume alcohol or foods containing caffeine for at least 24h before performing the experimental procedures. The dietary intake was not guided by a nutritionist and no dietary recall was performed, however, players were instructed to eat regularly and hydrate frequently, voluntarily, and freely. Experimental procedures were conducted in the middle of the competitive season, in a moment of pause in the competitive calendar. The

Ethics Committee on Research involving humans of the State University of Londrina (CAAE: 39519414.4.0000.5231; code granted: 930.218) approved the study, respecting the regulatory standards established by the National Health Council and according to the Declaration of Helsinki.

Procedures

To simulate the physical demands of futsal match-play, players performed the Futsal-Specific Intermittent Shuttle Protocol (FISP) (De Freitas et al., 2017). The FISP is a valid exercise protocol, allowing players to be homogeneously submitted to the physical demands of futsal matches. On the first experimental day, players arrived at the club at 9:00 a.m., without exercising for approximately 48h, for sample characterization (anthropometric measures: weight and height). Futsal players performed the FISP (De Freitas et al., 2017) seven days apart, at 2:00 p.m., on an official futsal court. Participants were randomized by a simple draw into two groups that performed LED or Placebo in a cross-over design (5 players underwent LED and 5 Placebo on the first day, being inverted on the second day). Although similar recovery effects are reported when using both LED and laser (Vanin et al., 2018), in the present study LED (non-coherent light source) was preferred due to the larger spot area, covering large skin areas at each point of light application. LED or Placebo conditions were applied approximately ~1-35 minutes after players completed the FISP and data collection. HR was monitored continuously and blood samples were collected from the earlobe after each block of FISP to analyze blood lactate concentration [Lac]. In addition, blood samples were collected before (pre), immediately post (post), and 24h post (24h) FISP to analyze the plasma concentration of CK, IL-6, tumor necrosis factor-alpha (TNF-α), and advanced oxidation protein products (AOPP). Pre and 24h post FISP, blood was collected before the warm-up. Pre and 24h post FISP, after the warm-up, and immediately post, the countermovement jump test (CMJ) was applied and perceived muscle soreness was monitored. The warm-up consisted of performing the FISP for 5 min with sprints at ~90% of maximal speed. This warm-up was also used to familiarize players with the FISP. To verify the maximal heart rate (HR), players performed the YO-YO intermittent recovery test level 1 ($\text{YO-YO}_{\text{IR1}}$) (Bangsbo et al., 2008) one week prior to the first FISP, under exercise deprivation for approximately 48h. Experimental procedures were conducted in the middle of the competitive season, in a moment of pause in the competitive calendar.

Light-emitting diode therapy (LED) or Placebo

Light-emitting diode therapy (LED) or Placebo, were performed using commercial equipment (Table 1). The equipment was positioned on the quadriceps and hamstring muscles in contact with the skin, in accordance with Figure 1. At each point, 6 J of energy (20 s of application) were irradiated, totaling 120 J of energy applied on each thigh. The Placebo procedure was performed with the device switched off, without the players' knowledge, as both groups (LED and Placebo) wore a blindfold when submitted to the protocol application. LED and Placebo were performed at the same anatomical sites and for a similar duration. LED wavelength and irradiated energy were performed in accordance with previous systematic reviews (Leal-Junior et al., 2015; Vanin et al., 2018). Before the experimental procedures, players of both groups (LED and Placebo) received an explanation about the effect of LED application, aiming to convince them that LED is effective to accelerate recovery.

Table 1
LED application parameters.

Apparatus - Biostherapy II; BIOS®, São José dos Campos, Brazil
Wavelength - 630 nm
Output frequency - continuous
Power - 300 mW
Beam size - 1.32 cm²
Time of application per point - 20 s
Number of irradiated sites - 20 on each thigh: 5 on the vastus lateralis, 3 on the vastus medialis, 4 on the femoral rectus, 4 on the femoral biceps, and 4 on the semitendinosus
Density of power at each point - 227.3 mW / cm²
Energy density at each point - 4.5 J / cm²
Total energy density to each thigh - 90.8 J / cm²

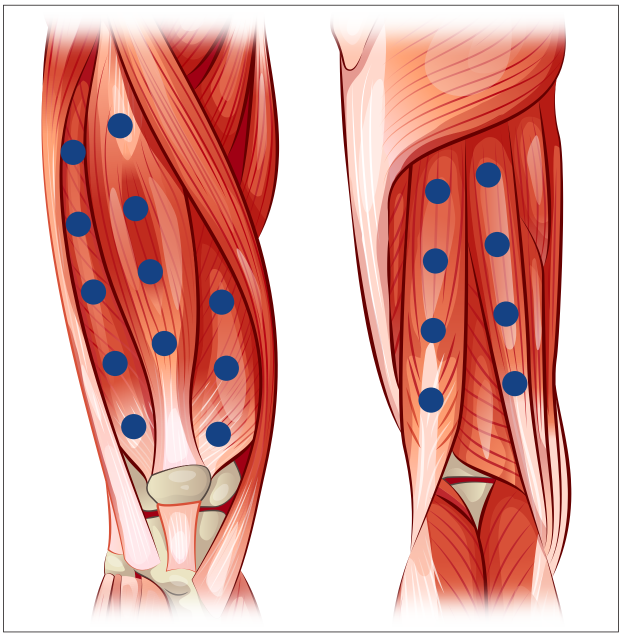

Figure 1
Map of LED application.

Futsal-specific intermittent shuttle protocol (FISP)

The FISP consists of four blocks with a duration of 6 minutes per block, and five-minute intervals between blocks (totaling 39 min). The total distance covered during the FISP is 3600 meters and each exercise block is structured with 6 sequences of 10 displacements of 15 meters, in which players run at different intensities dictated by a beep and voice command. The sequence of displacements is: walking - 5.4 km/h; 2 x low-intensity running - 9 km/h; sprinting – maximal velocity; 2 x low-intensity running - 9 km/h; 2 x medium-intensity running – 13.5 km/h; high-intensity running - 18 km/h; walking - 5.4 km/h. The values of HR, changes in CMJ, perceived muscle soreness, and recovery markers of inflammation and oxidative stress in the FISP have been demonstrated to be similar to a simulated match (De Freitas et al., 2017).

Heart rate (HR)

HR was monitored at 1-s intervals using telemetric monitors (Polar®, RS800, Polar Electro, Finland). Mean HR was computed for the entire 4 blocks of the FISP (24 min = 4 x 6 min blocks). Furthermore, HR was measured in the $\text{YO-YO}_{\text{IR1}}$, with the HR at the end of the test considered as maximal HR (HRmax). The percentage of HR monitored in the FISP, corresponding to HRmax (%HRmax), was also calculated.

Countermovement jump test (CMJ)

CMJ was performed using a contact mat (Smart Jump®, Fusion Sport, Australia). Players started the test in a standing position and performed a squat (~90º knee flexion) followed by a jump with hands placed on the hips. Players performed 3 maximal CMJ attempts with a 60s rest interval between attempts and the highest jump height was considered for analyses. The CMJ test presented an intra-class correlation coefficient (ICC) of 0.97 (Sattler et al., 2012).

Perceived muscle soreness

Muscle soreness was evaluated using a categorical scale (0-10) of pain (Cook et al., 1998). Players performed a ~90° knee flexion squat before reporting perceived muscle soreness on a scale, with 0 representing “no pain at all” and 10 “extremely intense pain, almost unbearable”. It is important to note that this variable was recorded by the same evaluator, one player at a time, in an isolated place without influence of other players.

Blood markers

5 ml blood samples were collected from an antecubital vein into heparinized tubes (Becton Dickinson, Franklin Lakes, USA). Samples were centrifuged (1370 g for 10 min at 4 °C) and the plasma collected was aliquoted and stored at −20 °C. Levels of IL-6 and TNF-α were determined through enzyme-linked immunosorbent assay (ELISA) using commercial kits, according to the manufacturer’s instructions (IL-6; BD OptEIA Human IL6 ELISA set, cat. n. 555220; TNF-α; BD OptEIA Human TNF ELISA set, cat. n. 555212, Becton & Dickinson, Franklin Lakes, USA). The AOPP was estimated by plasma levels of chloramines, which are end-products derived from protein oxidation by HOCl, the main product of neutrophil activity during inflammation, through its reaction with KI. The final reaction produces a colored compound, spectrophotometrically detected at 340 nm (Witko-Sarsat et al., 1996). Plasma concentrations of CK were determined using an automated biochemical system (Dimension EXLTM Chemistry System, Siemens, Munich, Germany).

Blood lactate concentration [Lac]

Samples of approximately 25 µl of blood were collected from the earlobe for analysis of [Lac]. Briefly, the earlobe was sanitized with alcohol 70%, and a disposable metal lancet used for puncture. Blood collection was performed using heparinized glass capillaries and the blood immediately transferred to polyethylene 1.5 ml microcentrifuge tubes containing 50 µl of sodium fluoride 1%. The tubes were stored in a container with ice, and then frozen in a freezer at −20 °C. Analysis of the [Lac] was performed using an electrochemical analyzer (YSI 2300 STAT PLUS; Copyright © Yellow Springs, Ohio, USA), with a measurement error of ± 2 %.

Data analysis

No outliers were identified using the *z*-score (z = (sample-mean) / standard deviation; outliers = $z > 3$). The Shapiro-Wilk test was used to verify data normality. Paired Student´s t tests were used to compare mean HR, %HRmax, and [Lac] between the LED and Placebo conditions. The results at pre and post moments are presented as mean ± standard deviation. A two-factor (time and group) generalized estimating equation technique (GEE) was performed for between, within, and interaction comparisons. When effects were found, a pairwise comparison with Bonferroni adjustment was performed. The ICC was used to verify the reproducibility of the HR and [Lac] measured at the first

Table 2

Means of Heart rate (HR), percentage of maximal heart rate (%HRmax), and Lactate concentration [Lac] of four blocks/stages of FISP on first and second performance days and in LED and Placebo conditions.

	HR ($b.min^{-1}$)	%HRmax	[Lac] (mmol/L)
FISP day 1	179.05 ± 4.55	92.84 ± 3.33	6.16 ± 3.26
FISP day 2	177.24 ± 7.39	91.88 ± 4.06	6.41 ± 2.81
LED	178.95 ± 5.05	92.79 ± 3.75	6.13 ± 2.99
Placebo	177.33 ± 7.09	91.92 ± 3.69	6.43 ± 3.09

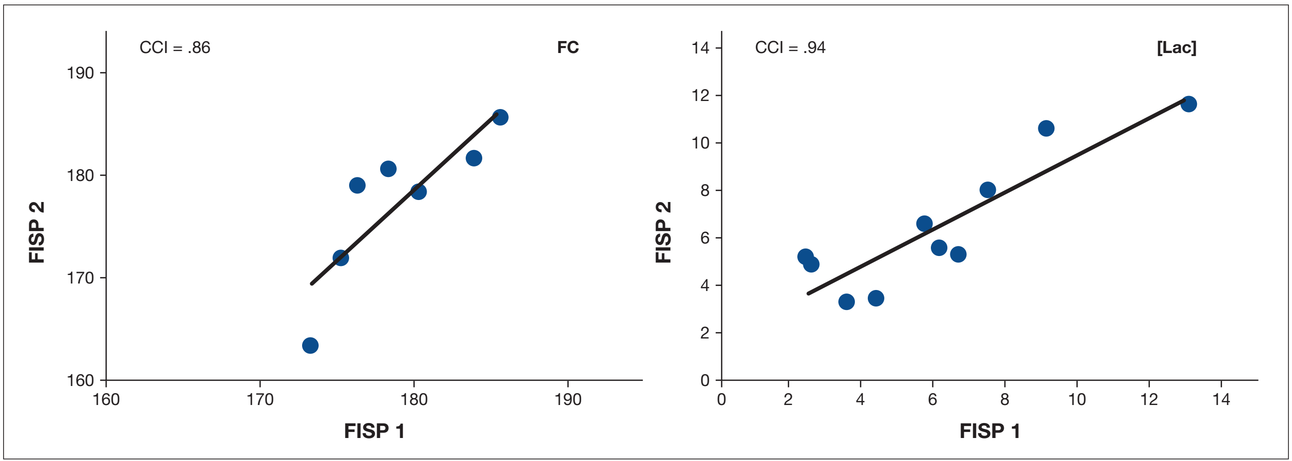

Figure 2

Intraclass correlation coefficient (ICC) of heart rate (HR) and lactate concentration [Lac] of FISP performed on first (FISP 1) and second days (FISP 2).

and second execution of the FISP. The ICC was interpreted using the following thresholds: .1 to .29 small, .30 to .49 moderate, .50 to .69 large, .70 to .89 very large, and .90 to 1, nearly perfect (Hopkins, 2002). All analyses were performed using IBM® SPSS® for windows version 20.0. The significance level adopted was $p < .05$.

Results

Players presented an HRmax of 194 ± 5 b.min-1 in the YO-YOIR1 test. Mean HR and %HRmax ($n = 7$; Table 2) were similar in both FISPs, analyzed independent of treatment performed ($p = .31$; $p = .30$ respectively), and when LED and Placebo were compared ($p = .58$; $p = .61$ respectively). Three participants were not included in the HR analyses due to technical errors associated with the HR recording. Mean [Lac] obtained in the FISP (Table 2) was similar in the first and second bouts, analyzed independent of treatment performed ($p = .61$), and when LED and Placebo were compared ($p = .86$). The ICC of HR was very large and of [Lac] nearly perfect (Figure 2).

For CMJ and IL-6, the GEE did not demonstrate interaction or group effects ($p > .05$), but did show an effect for time ($p < .01$; Table 3). The pairwise comparisons showed that CMJ presented lower values at post ($p < .01$) and 24h post ($p = .01$) compared to the pre moment and that the values at post were not different to 24h ($p = 1$). IL-6 blood concentration increased at post compared to pre ($p < .01$) and the value of IL-6 at 24h was lower than at post ($p = .04$) but not different from pre ($p = 1$), suggesting that IL-6 returned to pre values 24h post FISP. For CK, the GEE showed interaction and time effects, but did not demonstrate an effect for group (Table 3). The pairwise comparisons showed that CK increased in both Placebo ($p < .01$) and LED ($p < .01$) at the post moment compared to pre. However, no differences were found in either group when 24h was compared with pre and post moments ($p > .05$). For Muscle soreness, TNF-α, and AOPP, the GEE did not demonstrate interaction, time, or group effects ($p > .05$; Table 3).

Discussion

The hypothesis raised in the present study was that LED therapy could attenuate the worsening in markers of physical performance, muscle damage, inflammation, and oxidative stress of futsal players up to 24h post FISP. It is important to highlight that in contrast to what was expected, only CMJ worsened 24h post FISP. The principal results found were that LED therapy was effective for changing the CK behavior post FISP. However, no other positive effects were observed.

Table 3

Values and between, within, and interaction comparisons of countermovement jump (CMJ), perceived muscle soreness, creatine kinase (CK), interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF-α), and advanced oxidation protein products (AOPP) of Placebo and LED groups at pre, post, and 24h.

		Pre	Post	24h						
	Groups	mean ± SD	mean ± SD	mean ± SD	Mean difference post – pre (95%CI)	Mean difference 24h – pre (95%CI	Mean difference 24h – post (95%CI)	*p* Group	*p* Time	*p* Inter.
CMJ	Placebo	41.80 ± 3.90	39.46 ± 3.22*	39.70 ± 3.52**	–2.34 (–3.58; –1.10)	–2.10 (–4.43; 0.23)	0.24 (–2.01; 2.49)	.97	< .01	.86
	LED	41.63 ± 3.00	39.61 ± 3.45*	39.87 ± 4.20**	–2.01 (–3.12; –0.90)	–1.76 (–3.89; 0.37)	0.26 (–2.65; 3.16)			
Soreness	Placebo	0.80 ± 1.23	1.00 ± 1.33	0.20 ± 0.63	0.41 (–0.23; 1.06)	–0.02 (–1.74; 1.69)	–0.44 (–1.72; 0.85)	.26	.06	.83
	LED	0.40 ± 0.70	0.95 ± 1.07	0.70 ± 1.03	0.63 (–0.65; 1.92)	0.15 (–1.38; 1.67)	–0.49 (–1.54; 0.56)			
CK	Placebo	98.30 ± 33.03	135.30 ± 48.81$^{\Psi}$	170.30 ± 139.44	37.00 (17.66; 56.34)	72.00 (–22.06; 166.06)	35.00 (–43.42; 113.42)	.82	< .01	< .01
	LED	95.90 ± 33.66	144.40 ± 57.47$^{\Psi}$	143.70 ± 89.79	48.50 (27.89; 69.11)	47.80 (–2.67; 98.27)	–0.70 (–35.66; 34.26)			
IL-6	Placebo	18.79 ± 6.81	20.59 ± 7.26*	19.49 ± 7.49$^{\#}$	1.80 (0.09; 3.50)	0.70 (–1.85; 3.25)	–1.10 (–3.39; 1.20)	.87	< .01	.55
	LED	20.01 ± 9.85	21.30 ± 9.40*	19.31 ± 8.49$^{\#}$	1.29 (–0.49; 3.06)	–0.70 (–2.55; 1.15)	–1.99 (–3.84; –0.14)			
TNF-α	Placebo	23.82 ± 3.93	23.80 ± 4.18	23.15 ± 4.44	–0.03 (–1.98; 1.93)	–0.68 (–2.28; 0.93)	–0.65 (–3.00; 1.69)	.92	.65	.85
	LED	23.91 ± 8.43	23.91 ± 7.47	23.75 ± 8.04	0.01 (–1.16; 1.17)	–0.16 (–1.72; 1.39)	–0.17 (–1.61; 1.27)			
AOPP	Placebo	2.34 ± 0.71	2.35 ± 1.02	2.03 ± 0.80	0.00 (–0.89; 0.90)	0.31 (–1.06; 0.44)	–0.32 (–1.38; 0.75)	.25	.71	.57
	LED	2.06 ± 0.80	1.79 ± 0.67	2.03 ± 0.71	–0.27 (–0.93; 0.39)	–0.03 (–0.81; 0.75)	0.24 (–0.42; 0.89)			

Note. Significantly different from pre with time effect (* $p < .01$; ** $p < .05$).
Significantly different from post with time effect ($^{\#}$ $p < .05$).
Significantly different from pre within the same group (Ψ $p < .01$).

Attenuation of the increase in CK blood activity is one of the most likely positive effects of phototherapy reported in the literature (Nampo et al., 2016). In the present study, LED therapy changed the behavior of CK post FISP, corroborating with a previous study that showed attenuation of the increase in CK blood activity post and 48h post futsal matches (De Marchi et al., 2019). Although the pairwise comparisons did not show effects at 24h compared to pre or post, it is possible to note that values of CK remained increased after the Placebo, while this behavior was not shown after LED, possibly contributing to the interaction effect found. The mechanism related to the capacity of LED to reduce CK is still not clear (Nampo et al., 2016). However, it is possible that LED attenuates the ROS generated post exercise (that did not reflect in changes in AOPP) and increases the muscular ATP pool (Hayworth et al., 2010), attenuating EIMD. It is important to highlight that the increase in CK reported in the present study was lower than the elevation reported for athletes at 24-72h post-exercise (~400%) (Brancaccio et al., 2010). It is possible that the metabolic and physical demands of the FISP were not sufficient to promote elevated levels of muscle damage in well trained futsal players (De Freitas et al., 2017). In addition, there could be a limit to the intensity which the muscle tissue can stand, and this limit could be lower in poorly trained compared to well-trained subjects (Brancaccio et al., 2010). Therefore, for futsal players, the physical demands of FISP and, consequently, of futsal matches do not promote large EIMD. Another possibility could be that 24h was not sufficient time for the peak of CK release into the bloodstream (Brancaccio et al., 2010). However, some studies have shown that the peak of CK release was 24h post soccer matches (Magalhaes et al., 2010; Russell et al., 2015), suggesting that the time of data collection in the present study was sufficient to detect signs of muscle damage. Although the lack of measurements at 48 and 72h may be a limitation of this study, in practical use this is difficult due to the weekly training routines of athletes. Therefore, future studies are encouraged to test the effect of phototherapy on CK blood activity up to 72h post exercise with elevated physical and metabolic demands. Up to now, beneficial effects of phototherapy have been reported for reducing the elevation in CK in the blood of futsal players, even if only a slight increase in this variable is shown.

To our knowledge, this is the first study to investigate the effects of LED on CMJ performance of futsal players who performed simulated match efforts. Despite the effect of LED on CK, the results found did not suggest a positive effect of LED on performance in CMJ. It is important to note that a ~4-5% reduction in CMJ post and 24h post FISP, reported in the present study, was in accordance with previously reported results (De Freitas et al., 2017; Freitas et al., 2014). In contrast to the results found, a previous study reported a small beneficial effect of photobiomodulation on the CMJ performance of amateur soccer players (Dornelles et al., 2019). However, the present study was performed with professional futsal players, and it is possible that mechanisms other than the low level of muscle damage, such as central fatigue (Milioni et al., 2016), for example, could be responsible for the impaired performance observed in well-trained futsal players submitted to a common effort such as a futsal match.

Borges et al. (Borges et al., 2014) observed a positive effect of LED after exercise to attenuate the isometric muscular strength decrement in subjects submitted to an eccentric exercise protocol. In this study, the eccentric exercise protocol negatively modified markers of EIMD (*i.e.*, perceived muscle soreness and range of motion) that were also attenuated by LED (Borges et al., 2014). In agreement, as previously reported (De Freitas et al., 2017), the FISP increased plasma concentration of CK, but did not change perceived muscle soreness, inflammation, or oxidative stress markers. These results suggest that if the FISP promotes EIMD, the level of damage is not sufficient to alter pain or the inflammatory and oxidative stress systemic markers analyzed in the present study. In other team sports, such as soccer, increases in muscle damage, and inflammatory and oxidative stress markers were observed 24h post matches (Magalhaes et al., 2010). However, the distance covered in soccer matches is higher than the distance covered in futsal matches (De Oliveira Bueno et al., 2014; Stolen et al., 2005), suggesting higher metabolic demands in soccer than futsal. Therefore, we encourage future studies investigating the effect of LED in subjects performing exercises with high metabolic demand, implicating in high levels of EIMD. Furthermore, although the invasive characteristic makes it difficult to perform frequent blood sample collections in professional athletes, this may be interesting in future studies since some markers, inflammatory and oxidative stress for example, present different times for release and removal from the blood (Brancaccio et al., 2010).

The use of FISP to test recovery methods may be advantageous since it imposes a similar effort on all subjects. In the present study, HR and %HRmax values monitored during the FISP in the LED and Placebo groups were similar. The values of these variables (HR, ~177-179 b.min-1; %HRmax, ~91-92%) were similar to those reported in previous studies during simulated and official futsal matches (Barbero-Alvarez et al., 2008; Castagna et al., 2009; De Freitas et al., 2017). These results were in accordance with [Lac], which did not present different values when LED and Placebo were compared, and the values reported in the present study (~6-6.5 mmol/L) were close to values reported previously (Castagna et al., 2009).

Furthermore, HR, %HRmax, and [Lac] values were similar when the two times of execution of FISP were compared (independent of intervention methods), and the ICCs of HR and [Lac] were very large and nearly perfect respectively. These results may confirm that players were submitted to similar physical efforts during the two FISPs and that this was similar to the physical effort of official futsal matches.

The dose of treatment applied in the present study was in accordance with previous systematic reviews, which suggested a positive effect of phototherapy (Leal-Junior et al., 2015; Vanin et al., 2018). However, an update on the therapeutic window for large muscle groups, suggesting a large recommended dose, was published after the data collection in the present study (Leal-Junior et al., 2019). Therefore, the dose response dependence of the LED effect (Leal-Junior et al., 2015) could be a possible explanation for the limited effect found for this treatment. On the other hand, in the present study LED therapy promoted an effect on CK, suggesting that for this variable, the dose applied was effective. Whether high doses of LED are necessary to change physical performance, muscle soreness, and inflammatory and oxidative markers, should be investigated in future studies. We believe that the principal results found were a consequence of the low level of muscle damage induced by the FISP in well trained futsal players.

The number of participants could be a possible limiting factor for the results found in the present study. Unfortunately, the number of players in a futsal team is limited, and it is difficult to recruit players from different teams because of the training routines and schedules of each team. It is important to highlight that a lower sample size was used previously to show the muscle protective effect of phototherapy performed before futsal matches (De Marchi et al., 2019). However, we assume that for better understanding of the results found in the present study a large sample size may be necessary, and, thus, the sample size should be defined in future investigations. Some other points were controlled to reduce the risk of bias in the present study, such as randomization of the participants into the two groups, blinding of the participants, the presence of the Placebo, and the cross-over design of the study, factors that should be considered in the interpretation of the results found.

Conclusion

In conclusion, LED therapy applied in the present study was effective for changing CK behavior, but did not change markers of physical performance, muscle soreness, inflammation, or oxidative stress of futsal players up to 24h post FISP. It seems that the use of LED as a recovery method in well-trained futsal players post-match presented limited effects, since, apparently, for these players, a futsal effort does not promote important increases in markers associated with EIMD. In view of the positive effects reported previously, the effect of phototherapy could be more pronounced with a different dose, different sample, different level of trainability, different measurement moments, and in matches performed on consecutive days, which should be tested in future studies.

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Contextual Variables and Weekly External Load in a Semi-professional Football Team

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Abstract

The objective of this study was to compare the external load of microcycle training sessions in a semi-professional football team based on player role during competition and match location. Eighteen football players competing in the Spanish third division were monitored by global positioning systems in the course of seven microcycles consisting of five sessions categorised by their position on match day (MD). The data were analysed according to whether the player was a starter or substitute and also whether the team played at home or away. The external load variables used were total distance (DREL), sprint distance (SPD), high (HSD), medium (MSD) and low (LSD) speed distance expressed as a function of session time, and the number of accelerations per minute (ACC n/10). External load was higher in MD+1 ($p < .01$) for substitutes (SPD, HSD and ACC) and in MD-1 ($p < .05$ and ($p < .01$) for starters (DREL, SPD and HSD). Similarly, in the microcycle's middle sessions, load (MD-4: DREL, SPD and HSD; MD-3: DREL, SPD and MSD; MD-2: DREL, MSD and LSD) was higher ($p < .05$ and $p < .01$) when the team played at home than when it played away. The findings of this research are relevant for planning the training process and post-competition recovery strategies.

Keywords: football, GPS, monitoring, performance, periodisation.

Introduction

Load is the physical and psychological stress generated in an athlete by training and competition (Foster et al., 2001). In these activities, stress on an athlete has traditionally been defined by internal load, which is related to physiological response (e.g. heart rate, perceived exertion, etc.), and by external load, which reports the effort made by the athlete (e.g. distance covered, number of sprints, etc.) (Wallace et al., 2014). In recent years, researchers and coaches (Akenhead & Nassis, 2016) have taken an increasingly greater interest in monitoring these variables, as this can help to optimise the training process and plan injury prevention strategies (Jaspers et al., 2017).

Technological progress has made it possible to improve load control processes and has also made it easier for coaches and players to familiarise themselves with training and competition monitoring tools (Rago et al., 2019). More specifically, portable microsensors using global positioning systems (GPS), approved by the International Federation of Association Football (FIFA) (FIFA, 2015), can easily quantify the volume of activity carried out by players during sports by recording variables such as distance travelled, high-speed movements and the number of accelerations and decelerations (Buchheit & Simpson, 2017). Although these instruments have certain limitations when it comes to monitoring high-speed effort, accelerations and decelerations (Buchheit et al., 2014), they are used by many teams for assessing the training process and footballers (Akenhead & Nassis, 2016).

Monitoring primary external load variables has made it possible to describe the training microcycle in professional (Malone et al., 2015; Owen et al., 2017), amateur (Sanchez-Sanchez et al., 2019) and youth (Wrigley et al., 2012) teams. However, the approach used on most occasions might be considered reductionist (Paul et al., 2015), as the microcycle load monitoring was conducted without taking the factors coaches have used to schedule their training sessions into consideration (Rago et al., 2019). Variables such as match location, the result of the competition, the number of matches included in the microcycle, the length of the training week, the upcoming opponent relative ranking and the role of the actual players during the match need to be studied and factored into the interpretation of the load associated with each training cycle (Brito et al., 2016). A recent study conducted with young football players from five teams (Curtis et al., 2020) found differences in weekly training load depending on the season phase (*i.e.*, preseason, regular season and postseason), days between matches (*i.e.*, < 4, 4-5 and > 5 days) and match result (*i.e.*, win, draw and loss). In a similar line, albeit using a sample of professional players from teams competing in the Spanish league, training volume was found to increase and intensity decrease in the week before and after matches against a higher-ranking opponent (Rago et al., 2019). Furthermore, the authors reported that volume rose in the week following a defeat while load intensity increased after home matches.

Monitoring the physical demand associated with the training microcycle without considering aspects such as player role during competition, match location or the relative ranking of the opposing team means ignoring the complexity associated with workload in football (Curtis et al., 2020). Although the number of studies in this area has increased in recent years, further research is needed to clarify the potential cause-effect relationship between certain contextual variables and weekly training load (Rago et al., 2019). Consequently, the main objective of this paper was to compare the external load of microcycle training sessions in a semi-professional football team based on player role during competition and match location.

Methodology

Participants

The study involved 18 semi-professional football players (26.2 ± 3.9 years old; 177.7 ± 5.3 cm height; 73.9 ± 6.4 kg body mass) competing in the Spanish third division. The players trained five times a week and played one official match at the weekend. The study monitored seven consecutive competition microcycles in the first section of the season. The inclusion criteria for choosing the study sample were: i) being an outfield player; ii) taking part in 85 % of the training sessions; iii) completing at least 50 % of the regular matches; iv) not having sustained any injury in the four months prior to data collection (Sánchez et al., 2019). The circumstances intrinsic to the training process meant that 601 of the 630 total records were ultimately used for the study, divided according to the different variables shown in Table 1.

The participating club's coaching staff approved the research and the players signed an informed consent form describing the procedures, risks and benefits associated with taking part in the study. The experimental design fulfilled the requirements of the Declaration of Helsinki.

Table 1
Number of records analysed for each variable under study.

Sessions	Location		Role	
	Home	Away	Starter	Substitute
MD+1	64	50	65	49
MD-4	69	54	70	53
MD-3	68	53	69	52
MD-2	68	53	69	52
MD-1	69	53	70	52

Note. MD+1: first training session of the microcycle; MD-4: second training session of the microcycle; MD-3: third training session of the microcycle; MD-2: fourth training session of the microcycle; MD-1: last training session of the microcycle.

Instruments

The external load measurement during the training sessions was obtained using a GPS unit (K-GPS 10 Hz, K-Sport®, Motelabbate, PU, Italy) with acceptable reliability demonstrated in previous studies (Fernandes-da-Silva et al., 2016). The device was fitted to the player's upper back inside the pocket of a purpose-built vest worn under the training shirt. All the GPS units were switched on at the same time, *i.e*., 10 minutes before the start of the external load recording. The start and end of each measurement session was noted in order to extract only the gross training time data. The data collected were analysed using the K-Fitness software (K-Sport®, Motelabbate, PU, Italy). A spreadsheet designed for the study was used to tabulate the data.

Procedure

To assess the differences between player roles during competition, the footballers were classified as starters, if they had begun the match in the starting eleven, and as substitutes, when i) they had participated in the match once it had started, ii) they had been called up but had not played any minutes, iii) they had not been called up to the squad for that match. To test for the effect of match location, home status, *i.e.*, when the team played at its own ground, and away status, when the team played at the opposing team's ground, was recorded (Table 1). The training sessions were also classified chronologically depending on what the next competition was (Sánchez-Sánchez, et al., 2019). In the first training session of the week (post-match day [MD+1]), the starters in the previous match did recovery work (*i.e.*, low-intensity aerobic and mobility exercises) while the substitutes and non-called-up players performed supplementary work (*i.e.*, specific circuits with high neuromuscular demand). In the second training session (*i.e.*, MD-4), specific work was carried out in the form of small-sided games with high neuromuscular demand (50 m^2 per player) together with preventive work (mobility, eccentric and core strength) for all the squad players. In the third training session of the week (*i.e.*, MD-3), small-sided games (100 m^2 per player) were combined with 11 *vs.* 11 matches with a defensive tactical orientation for all players. In the fourth training session of the week (*i.e.*, MD-2), all the players took part in situations geared towards speed optimisation and 11 *vs.*11 contests with an offensive tactical orientation. In the last training session, held on match day (*i.e.*, MD-1), all the players did activation drills and set pieces. In all the microcycles analysed, the rest day for the players was the day after the MD+1 session.

Measurements

All the variables were expressed in relative values (m·min-1) as a function of each player's participation time during the training session. The external load variables were selected on the basis of previous studies (Sánchez-Sánchez et al., 2019): i) total distance (DREL; m·min-1), ii) sprint distance (SPD; > 19.8, m·min^{-1}), iii) high-speed distance (HSD; 14.4-19.8 km·h-1, m·min^{-1}), iv) medium-speed distance (MSD; 7-14.4 km·h^{-1}, m·min^{-1}), v) low-speed distance (LSD; 0-7 km·h^{-1}, m·min^{-1}) and vi) number of accelerations (ACC; >3.0 m·s^{-2}, n/10·min^{-1}). The external load of each variable analysed was the mean value of the sessions with the same orientation that comprised each one of the seven microcycles analysed. The ACC value was stated in base-10 for better expression of the result.

Statistical analysis

Data were presented as mean ± standard deviation. The normality of the data was verified with the Shapiro-Wilk test ($p > .05$). The Student's t-test for independent samples was used to determine differences in external load, factoring in match location and player role during competition. Significant differences were considered when $p < .05$. Additionally, the effect size (ES) was assessed using Cohen's d-test (Cohen, 1988). The *d* value was interpreted using the following scale: trivial < 0.2, low = 0.2 - 0.5, moderate = 0.5 - 0.8 and high > 0.8 (Hopkins et al., 2009). The Statistical Package for the Social Sciences was used (SPSS, version 25.0, SPSS Inc., Chicago, IL, USA).

Table 2
External load values (mean ± SD) in each training session factoring in the player role during competition.

Variable	MD+1		MD-4		MD-3		MD-2		MD-1	
	Starter	Substitute	Starter	Substitute	Starter	Substitute	Starter	Substitute	Starter	Substitute
DREL (m·min^{-1})	74.42 ± 12.97	77.19 ± 14.56	75.50 ± 13.85	76.62 ± 15.05	74.06 ± 14.13	73.89 ± 17.87	70.40 ± 6.78	70.42 ± 7.29	49.95 ± 4.00**	46.85 ± 4.60
SPD (m·min^{-1})	0.64 ± 0.95**	1.28 ± 1.08	1.03 ± 0.66	0.95 ± 0.67	2.29 ± 1.65	2.09 ± 1.72	2.41 ± 1.04	2.67 ± 1.25	0.50 ± 0.40*	0.22 ± 0.24
HSD (m·min^{-1})	1.36 ± 1.98**	2.80 ± 2.24	8.97 ± 7.91	9.50 ± 10.88	7.73 ± 3.94	7.71 ± 5.72	6.90 ± 2.03	6.71 ± 1.97	1.91 ± 1.13**	1.23 ± 0.85
MSD (m·min^{-1})	46.06 ± 11.43	43.25 ± 11.53	32.43 ± 8.78	33.27 ± 7.55	31.34 ± 9.37	32.05 ± 13.06	28.60 ± 5.58	28.22 ± 5.58	17.37 ± 1.82	16.54 ± 2.21
LSD (m·min^{-1})	25.22 ± 5.01	28.15 ± 5.09	32.03 ± 2.89	31.75 ± 3.08	31.61 ± 3.28	31.00 ± 3.56	31.47 ± 2.94	31.75 ± 2.84	28.76 ± 2.50	27.43 ± 2.74
ACC (n/10·min^{-1})	3.87 ± 4.22**	7.53 ± 4.93	9.94 ± 2.44	10.33 ± 2.70	9.87 ± 6.45	9.26 ± 2.06	8.80 ± 1.57	9.01 ± 1.76	6.03 ± 2.11	6.00 ± 1.95

MD+1: first training session of the microcycle; MD-4: second training session of the microcycle; MD-3: third training session of the microcycle; MD-2: fourth training session of the microcycle; MD-1: last training session of the microcycle ; DREL: total distance; SPD: sprint distance (>19.8 km·h^{-1}); HSD: high-speed distance (14.4-19.8 km·h^{-1}); MSD: medium-speed distance (7-14.4 km·h^{-1}); LSD: low-speed distance (0-7 km·h^{-1}); ACC: number of accelerations (>3.0 m·s^{-2}).* Shows starter *vs.* substitute difference, *p < .05 y **p < .01.

Table 3
External load values (mean ± SD) in each training session controlling for match location.

Variable	MD+1		MD-4		MD-3		MD-2		MD-1	
	Home	Away	Home	Away	Home	Away	Home	Away	Home	Away
DREL (m/min)	74.74 ± 16.56	76.87 ± 8.58	79.60 ± 17.24**	71.20 ± 6.82	79.63 ± 17.43*	66.46 ± 9.12	72.70 ± 7.74**	67.41 ± 4.33	48.51 ± 4.56	48.57 ± 4.53
SPD (m/min)	0.91 ± 1.06	0.95 ± 1.07	1.25 ± 0.71**	0.66 ± 0.40	2.62 ± 1.97**	1.65 ± 0.95	2.41 ± 1.16	2.67 ± 1.10	0.37 ± 0.37	0.38 ± 0.37
HSD (m/min)	1.88 ± 2.12	2.16 ± 2.33	12.58 ± 11.13**	4.70 ± 1.57	9.51 ± 5.50**	5.33 ± 1.86	7.13 ± 2.17	6.41 ± 1.68	2.11 ± 0.96	2.90 ± 0.95
MSD (m/min)	44.81 ± 12.73	44.83 ± 9.77	33.28 ± 9.86	32.17 ± 5.39	35.35 ± 12.56**	26.74 ± 6.10	29.65 ± 6.26**	26.83 ± 3.99	17.42 ± 1.97	17.45 ± 1.97
LSD (m/min)	25.93 ± 5.15	27.31 ± 5.29	31.39 ± 3.11	32.59 ± 2.63	31.19 ± 4.03	31.54 ± 2.36	32.37 ± 2.99**	30.57 ± 2.42	28.61 ± 2.61	28.63 ± 2.60
ACC (n/10·min^{-1})	5.33 ± 4.67	5.26 ± 5.18	10.08 ± 2.34	10.15 ± 2.83	9.20 ± 6.54	9.57 ± 2.06	8.81 ± 2.07	8.83 ± 1.47	6.02 ± 2.05	6.02 ± 2.03

MD+1: first training session of the microcycle; MD-4: second training session of the microcycle; MD-3: third training session of the microcycle; MD-2: fourth training session of the microcycle; MD-1: last training session of the microcycle; DREL: total distance; SPD: sprint distance (>19.8 km·h^{-1}); HSD: high-speed distance (14.4-19.8 km·h^{-1}); MSD: medium-speed distance (7-14.4 km·h^{-1}); LSD: low-speed distance (0-7 km·h^{-1}); ACC: number of accelerations (>3.0 m·s^{-2}).* Shows home vs. away difference, *p < .05 and **p < .01.

Results

Table 2 shows that in the MD+1 session, the SPD (d = 0.63), HSD (d = 0.69) and ACC (d = 0.68) demands were significantly lower (p < .001, p < .000, p < .002 and p < .000, respectively) for starters than for substitutes. The results showed no significant differences in the external load obtained between starters and substitutes in the middle sessions of the microcycle (*i .e.*, MD-4, MD-3 and MD-2). However, the values found in DP-1 indicated that the external load for the starting players was significantly higher than for substitutes (DREL: p < .01, d = -0.73; DE: p < .05, d = -0.83; DAV: p < .01, d = -0.51

With regard to match location (Table 3), in MD-4 the DREL (d = -0.61), SPD (d = -0.99) and HSD (d = -0.93) values were significantly higher (p < .001, p < .000 and p < <.000) when the team trained to play at home than when it played away. In MD-3, the results showed that DREL (d = -0.91), SPD (d = -0.6) and HSD (d = -0.96) were significantly higher (p < .000, p < .001 and p < .000, respectively) when the team played at home than when it played away. Similarly, the DREL (d = -0.81), MSD (d = -0.52) and LSD (d = -0.65) values found in MD-2 were significantly higher (p < <.000, p < .005 and p < .000, respectively) when the team played at home as opposed to away.

Discussion

The main purpose of this paper was to compare the external load of microcycle training sessions in a semi-professional football team based on player role during competition and match location. To our knowledge, most studies have examined weekly training load in terms of contextual variables, although few have investigated the effect of these factors in the microcycle sessions. The most outstanding results of this study indicated a higher external load in the MD+1 session for substitutes and in the MD-1 session for starters. Similarly, training load was higher in the MD-4, MD-3 and MD-2 sessions when the team was playing at home than when they played away.

There were no differences between starters and substitutes in external load in the middle sessions of the microcycle (*i.e,.* MD-4, MD-3 and MD-2). Previous studies reported similar results when analysing weekly training load as a function of player role in competition (Curtis et al., 2020). Due to the short time interval between competitions, during regular training weeks (*i.e.*, 5-7 days between matches), coaches tend to concentrate training load days in the middle part of the microcycle (Rago et al., 2019). This allows starters and substitutes to receive sufficient training stimulus to maintain their level of fitness without compromising their readiness for imminent competition (Martín-García et al., 2018). Although player fitness depends largely on the training done during the week, competition load also influences the footballer's preparation (Morgans et al., 2018). Based on this result, it transpired that substitute players, whose yearly match/game time only amounts to 20% may have less-developed aerobic fitness than starters (Curtis et al., 2020). Therefore, in these players, the load of the middle microcycle sessions should be supplemented by training to offset the lack of game time (Anderson et al., 2016). On most occasions, the post-match session (*i.e.*, MD+1) was used to replicate competition load for players who had had less game time (Martín-García et al., 2018).

Our results show higher load values for substitutes in MD+1 (*i.e.*, SPD, HSD and ACC) and for starters in MD-1 (*i.e.*, DREL, SPD and HSD). The differences found in MD+1 are consistent with the results of previous studies (Martín-García et al., 2018). In these sessions, the training load is diversified to meet the needs of the players depending on their role in competition. More specifically, the load differences found in the MD+1 session are due to the fact that the starters do recovery training based on aerobic load, whereas the substitutes engage in tasks to make up for their lack of game time (Stevens et al., 2017). Given that it is hard for a training session to replicate match demands (Sánchez-Sánchez et al., 2019), the MD+1 session usually includes high neuromuscular demand and little by way of high speed (Martín-García et al., 2018), as it usually involves few players and small areas (Owen et al., 2011). However, as high speed appears to be a skill that is increasingly more associated with success in football (Faude et al., 2012) and with the prevention of hamstring injuries (Malone et al., 2018), coaches should include activities that encourage this type of drills in substitutes during the MD+1 session.

When the external load of the sessions was analysed in terms of match location, the MD-4, MD-3 and MD-2 sessions in general presented higher load values when the team was playing at home. These results are consistent with those of other studies conducted with elite youth football players (Brito et al., 2016). It may be that neuromuscular load is lower in the microcycles used to prepare for away matches to offset the fatigue associated with these weeks caused by travel and disrupted sleep routines (Rago et al., 2019). To cope with this problem, coaches regulate session loads and the actual players adapt their weekly training rhythm to keep fatigue within acceptable limits that allow them to compete successfully at the weekend (Brito et al., 2016).

Studies investigating the effect of the contextual variables related to training load in football should use a full training period, multiple teams and several seasons for the analysis (Rago et al., 2019). However, our study was conducted at a specific point in the season using a small sample of semi-professional players. In addition, given that football players may respond differently to training load (Brito et al., 2016), the load control process should take each player's individual characteristics into consideration. To this end, it would seem advisable to use individual speed thresholds to monitor external load (Abt & Lovell, 2009). Nevertheless, our study was based on general references for speed ranges.

Conclusion

The most salient results of our study indicated a higher external load in the MD+1 session for substitutes and in the MD-1 session for starters, with no other differences for this player role in the other sessions. Our findings are relevant for training planning processes and recovery strategies for football players taking part in a sport with a match-intensive competition period. Consequently, when coaches plan their sessions, they should consider the interaction between the variables analysed in this study and others included in previous research in order to understand player response to the training stimulus. In a highly complex sport, training load needs to be tailored to all the aspects that may impact the adaptation process during a prolonged and competition-intensive period.

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PHYSICAL PREPARATION

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Preventive Training of Anterior Cruciate Ligament Injuries in Female Handball Players: a Systematic Review

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Abstract

Handball is a sport which involves the repetition of high-intensity movements and actions, such as single-leg landing and one-on-one actions, which are conducive to anterior cruciate ligament injury mechanism. Preventive training can modify the neuromuscular risk factors associated with the danger of this injury in women athletes. Determining their characteristics (duration, frequency, type of exercise, etc.) and components (strength, plyometrics, balance, etc.) is critical when designing specific and individualised training for players. The objectives of this study were to identify and categorise the common components of preventive training programmes for anterior cruciate ligament injury in women handball players and to describe and classify the exercises involved in each category. A systematic review was conducted following the guidelines of the PRISMA Statement in the Web of Science, Sport Discus, PubMed, Scopus, Cochrane and ScienceDirect databases. The inclusion criteria were: (a) participants were female handball players of any age, (b) there was a preventive training intervention, and (c) injury incidence was reported with the number of ACL injuries. Six studies were included and their methodological quality was assessed using the ROB 2.0 tool. The results show that most interventions included more than one training component with a median duration of 15 minutes and that the exercises which varied most across the programmes were plyometrics.

Keywords: anterior cruciate ligament, prevention, training, women's handball.

Introduction

Handball is one of the sports with the highest number of non-contact anterior cruciate ligament (ACL) injuries (De Loës et al., 2000; Myklebust et al., 1997). In 90% of cases, the injury is associated with cutting or single-leg landing from a jump (Olsen et al., 2004; Takahashi et al., 2019). These types of actions typically involve the valgus position of the knee in flexion and internal rotation of the tibia relative to the femur, which is the main mechanism of ACL injury (Koga, H., 2010). It is one of the most serious injuries, both because of the prolonged period required to return to competition and the long-term consequences (Lai et al., 2018).

The ACL injury rate in women handball players is 0.7-2.8 injuries per 1,000 hours of exposure (Myklebust et al., 1998), with an incidence two to five times greater than in their male counterparts (Montalvo et al., 2019). This difference is also found between the ages of 12 and 16, and women players are at greatest risk of sustaining this injury during adolescence (LaBella et al., 2014; Reckling et al., 2003).

Intrinsic and non-modifiable anatomical and hormonal risk factors, coupled with modifiable risk factors associated with neuromuscular control, are the most important aetiological contributions to ACL injury in women athletes (Griffin et al., 2006; Shultz et al., 2015). Since the injury is multifactorial in origin, the first prevention strategy should be to identify the modifiable risk factors (Fort-Vanmeerhaeghe & Romero, 2013).

Women athletes tend to present less knee and hip flexion (Bencke et al., 2018) and increased knee valgus (Hewett et al., 2005) in landing and cutting actions. The relative strength deficit in the lower limbs, particularly in the hamstrings (DiStefano et al., 2015) and a lower activation of the latter relative to the quadriceps in this type of action, increases anterior tibial traction forces and consequently generates greater stress on the ACL (Ahmad et al., 2006).

Preventive training recommends that consideration be given to the risk factors described (Gómez et al., 2019), mainly targeting abnormal biomechanical movement patterns and neuromuscular alterations and adapting to the training principles (Fort-Vanmeerhaeghe & Romero, 2013; Taylor et al., 2015). A lower risk of ACL injury has been demonstrated in women athletes following multifactorial and general preventive training (Myer et al., 2013; Petushek et al., 2019; Soomro et al., 2016; Sugimoto et al., 2016).

The objectives of this review were to identify and categorise the common components of preventive training programmes for anterior cruciate ligament injury in women handball players and to describe and classify the exercises comprising each category.

Method

The study followed the guidelines of the PRISMA Statement for systematic reviews to guarantee an appropriate structure and performance (Urrutia & Bonfill, 2010).

A literature search was conducted in the Web of Science (WOS), Sport Discus, PubMed, Scopus, Cochrane and ScienceDirect databases combining the following keywords: "*female*" or "*woman*" or "*girl*", "*handball*", "*exercise*" or "*training*" or "*prevention*" or "*intervention*" and "*ACL injury*" or "*anterior cruciate ligament injury*" or "*lower limb injury*" or "*knee injury*" (Table 1). All scientific articles published in Catalan, Spanish and English were considered using the following inclusion criteria: (a) the participants were female handball players of any age, (b) there was a sports training intervention, and (c) injury incidence was reported with the number of ACL injuries. Articles for which the full text was not available or were reviews were excluded.

The country where the study was conducted, participant age, the sample analysed, the frequency of weekly sessions and session duration were recorded for data extraction purposes. The description of all the exercises performed in each one of the preventive training sessions in the studies was also recorded and classified in five categories:

1) Agility: exercises designed to foster a full-body movement with change of velocity or direction in response to a stimulus (Sheppard & Young, 2006).
2) Running: exercises intended to develop motor-locomotor pattern based on movement and technique (Jeffreys, I., 2019).
3) Balance: exercises that involved maintaining a single- or two-legged position specifically designed to challenge stability and improve proprioceptive awareness (Crossley et al., 2020).
4) Strength: exercises designed to improve muscle capacity by using body weight, free weights, resistance bands or resistance machines (Crossley et al., 2020).
5) Plyometric: exercises that included powerful dynamic movements such as jumping, landing or bouncing (Crossley et al., 2020). The plyometric exercises were classified into three levels based on the movement's intensity (increase in horizontal velocity or vertical height) and complexity.

Each exercise could only be classified in one category, although a training programme might consist of one or more categories.

Table 1
Search strategy and key.

Database	Equation
Web of Science (WOS)	#1 TS=(female* OR women OR girl*) #2 TS=(handball) #3 TS=(exercise* OR training OR prevent* OR intervention) #5 TS=(ACL injury* OR anterior cruciate ligament injury* OR lower limb injury* OR knee injury*) #1 AND #2 AND #3 AND #5
Sport Discus	(female* OR women OR girl*) AND handball AND (exercise* OR training OR prevent* OR intervention) AND (ACL injury* OR anterior cruciate ligament injury* OR lower limb injury* OR knee injury*)
PubMed	((((female*[Title/Abstract] OR women[Title/Abstract] OR girl*[Title/Abstract]) AND (handball[Title/Abstract])) AND (exercise*[Title/Abstract] OR training[Title/Abstract] OR prevent*[Title/Abstract] OR intervention[Title/Abstract])) AND (ACL injur*[Title/Abstract] OR anterior cruciate ligament injur*[Title/Abstract] OR lower limb injury*[Title/Abstract] OR knee injury*[Title/Abstract])
Scopus	(TITLE-ABS-KEY (female* OR women OR girl*) AND TITLE-ABS-KEY (handball) AND TITLE-ABS-KEY (exercis* OR training OR prevent* OR intervention) AND TITLE-ABS-KEY (acl AND injury* OR anterior AND cruciate AND ligament AND injury* OR lower AND limb AND injury* OR knee AND injury*))
Cochrane	(female* OR women OR girl*) in Title Abstract Keyword AND handball in Title Abstract Keyword AND (exercis* OR training OR prevent* OR intervention) in Title Abstract Keyword AND (ACL injur* OR anterior cruciate ligament injury* OR lower limb injury* OR knee injury*) in Title Abstract Keyword
ScienceDirect	(females OR women OR girls) AND (ACL injury OR anterior cruciate ligament injury) AND (exercise OR training OR prevention) AND handball

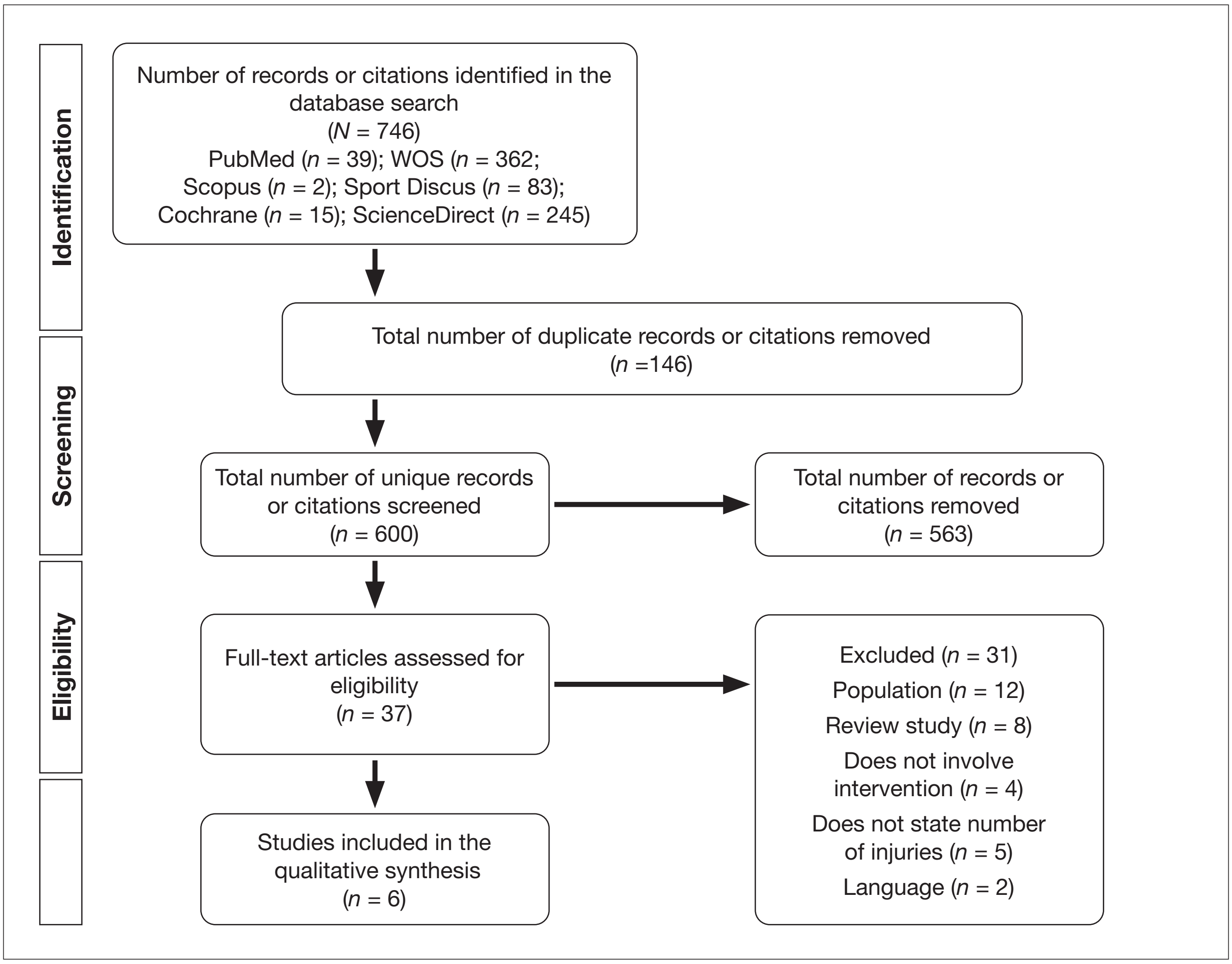

Figure 1
Study selection flowchart.

Table 2
Scores of the studies reviewed with ROB 2.0.

Study	D1	D2	D3	D4	D5	General
Achenbach et al. (2018)	+	+	+	+	+	+
Myklebust et al. (2003)	-	+	+	+	+	-
Olsen et al. (2005)	+	+	+	+	+	+
Petersen et al. (2005)	-	+	+	+	+	-
Wedderkopp et al. (1999)	+	+	+	+	+	+
Zebis et al. (2016)	+	+	+	+	+	+

Note. D1 = randomisation process; D2 = deviations from scheduled interventions; D3 = outcome data; D4 = outcome measurement; D5 = result reporting

Risk of bias assessment

Two reviewers (MC and SM) independently assessed the methodological quality of the articles included using the ROB 2.0 tool, which consists of five domains and an overall criterion. The five domains are: (a) bias arising from the randomisation process, (b) bias due to deviations from intended interventions, (c) bias due to missing outcome data, (d) bias in measurement of the outcome, and (e) bias in reporting results (Sterne et al., 2019).

Results

Selection of studies

The initial yield of articles for this review was 746 original papers. After duplicates (*n* = 146) had been discarded and following screening by title and abstract (*n* = 563) and the application of the inclusion criteria *n* = 31) (Figure 1), three studies which did not fully meet the inclusion criteria (the participants were male and female and the sample was handball and football) were included as they fitted the objective of the review. Finally, six studies were included for analysis (Urrutia & Bonfill, 2010).

The overall methodological quality of the six studies included is summarised in Table 2.

To facilitate understanding, the results of the data extracted were grouped by the characteristics of the population analysed (country, age and sample) and by the components, duration and exercises of the training programmes.

Study characteristics

In most of the studies included (4/6 = 66 %) the participants were adolescent (under 18 years of age) women handball players. In the study by Zebis et al. (2016), participants could be handball or football players, whereas the studies by Achenbach et al. (2018) and Olsen et al. (2005) included both male and female participants (Table 3).

The study by Zebis et al. (2016) used the same training programme as Olsen et al. (2005). The study by Wedderkopp et al. (1999) did not say what exercises were used in the training programme.

Training programme components

Balance was included in all the training programmes, followed by plyometrics (5/6 = 83 %), while half of the studies analysed (3/6 = 50 %) worked on agility and strength. Combining components in preventive training was most common in the studies reviewed (5/6 = 83 %). Only Wedderkopp et al. (1999) used balance as the sole programme component (Table 3).

Table 3
Study characteristics.

Study	Population			Training programme							
	Country	Age (years)	Sample analysed	Frequency[a]	Duration (min)	No. of exercises	Components				
							R	B	S	A	P
Achenbach et al. (2018)	Germany	IG: 14,9 ± 0,9[b] CG:: 15,1±1,0[b]	*N* = 174 IG: *n* = 98 CG: *n* = 76	PRE: 2/3 SEAS: 1	15	5	✗	✓	✓	✗	✓
Myklebust et al. (2003)	Norway	21 - 22	Season 1: *n* = 855 (58 teams) Season 2: *n* = 850 (52 teams)	PRE: 3 SEAS: 1	15	3	✗	✓	✗	✓	✓
Olsen et al. (2005)	Norway	IG: 16,3± 0,6[b] CG:: 16,2± 0,6[b]	*N* = 1586 IG: *n* = 808 CG: *n* = 778	PRE: 3 SEAS: 1	15 - 20	4	✓	✓	✓	✓	✓
Petersen et al. (2005)	Germany	IG: 19,8 CG:: 19,4	*N* = 276 IG: *n* = 134 (10 teams) CG: *n* = 142 (10 teams)	PRE: 3 SEAS: 1	10	4	✗	✓	✗	✗	✓
Wedderkopp et al. (1999)	Denmark	16 - 18	*N* = 237 IG: *n* = 111 CG: *n* = 126	SEAS: all	10 - 15	3	✗	✓	✗	✗	✗
Zebis et al. (2016)	Denmark	IG: 15,9 ± 0,4[c] CG::15,6± 0,5[c]	*N* = 40 IG: *n* = 20 CG: *n* = 20	PRE: 3 (12 weeks)	15	3	✓	✓	✓	✓	✓

Note. R: running; B: balance; S: strength; A: agility; P: plyometric; IG: intervention group; CG: control group; PRE: preseason; SEAS: season.
[a]In sessions per week. [b]The study included men and women. [c]The study included football and handball.

Table 4
Training programme exercises.

Running	Agility	Strength	
Running forward[c, f]	Plant and cut[c, f]	Lower body	Nordic hamstring[a, c, f]
Running backwards[c, f]	Run and plant[b]	Lower body	Squat to 80° knee flexion[c, f]
Running with knees up and heel kicks[c, f]	Run and plant with ball[b]	Trunk	Plank[a]
Sideways crossing legs (carioca)[c, f]		Trunk	Side plank[a]
Sideways running with arms up (parade)[c, f]			
Running forward with trunk rotations[c, f]			
Running forward with intermittent stops[c, f]			
Running speed[c, f]			

Balance		Plyometric	
Stable surface	Single leg, eyes closed and perturbation[a]	Static landing	Two-legged landing after hop[b]
Stable surface	Single leg and ball use (throw, pass-reception or bounce)[d]	Static landing	Two-legged landing after hop and throw[c, f]
Unstable surface (balance mat, wobble board, BOSU balance trainer, etc.)	Both legs[b]	Static landing	Two-legged landing after throw from a 30-40 cm box[b]
	Both legs and squat[b, c, f]	Static landing	Landing on one leg from a 30-40 cm box[b]
	Both legs and perturbation[b, c, d, f]	Controlled landing then subsequent action	Jumps (forward-backward, side-to-side, 180° turn)[b, d]
	Both legs and ball use (throw, pass-reception or bounce)[b, c, d, f]		Repetitive jumps5.7 with perturbation[b]
	Both legs and ball use (reception with jump)[b]		Forward jump from box to a mat and forward jump from mat to box[d]
	Single leg and squat[b, c, f]		Jump from floor to mat with throwing exercises, then side-to-side jumps[d]
	Single leg and perturbation[b, c, f]		Jump from box to mat with throwing exercises, then side-to-side jumps[d]
	Single leg and ball use (throw, pass-reception or bounce)[b, c, d, f]		Jump from box to mat with eyes closed, then side-to-side jumps[d]
	Single leg, ball use (throw, pass-reception or bounce) and perturbation[b]		Lateral jumps (skater)[a]
	Single leg, ball use (throw, pass-reception or bounce) and eyes closed[b, d]	Reducing ground contact time	Front lunges[a, c, f]
	Single leg, ball use (throw, pass-reception or bounce), eyes closed and precision target[d]	Reducing ground contact time	Multi-directional hops[a]
		Reducing ground contact time	Forward hops[c, f]

[a]Achenbach et al. (2018). [b]Myklebust et al. (2003). [c]Olsen et al. (2005). [d] Petersen et al. (2005). [e]Wedderkopp et al. (1999). [f]Zebis et al. (2016).

Training programme duration

The duration of the workouts varied between 10 and 20 minutes (Table 3). If a programme had a time interval, the maximum value of the range was recorded. Most of the programmes analysed lasted 15 minutes (4/6 = 66 %).

Training programme exercises

The training programmes included three to five exercises in each session.

The agility exercises did not specify how they were performed, although they did include plant and cut movements combined with throwing actions.

Running exercises were part of the warm-up and were intended to improve running technique.

The most commonly used balance exercises were on unstable surfaces (wobble board, balance mat, BOSU balance trainer, etc.) with single- or two-leg support and using a ball for throwing, passing, catching or bouncing (Table 4).

All the balance exercises were conducted progressively: different internal perturbations (player's limbs in motion) and external perturbations (handling a ball to perform technical actions related to throwing or unbalancing the partner) were included and sensory afferents were reduced to restrict vision.

Nordic Hamstring was the only exercise common to the training programmes that included strength as a component.

Finally, the exercises classified as plyometric were the most varied, as they included jumping across different planes and axes with perturbations and landings, on one and both legs and also from different heights (Table 4).

The most common work time for each exercise was 30 seconds.

Discussion

Five of the six interventions included more than one training component (Achenbach et al., 2018; Myklebust et al., 2003; Olsen et al., 2005; Petersen et al., 2005; Zebis et al., 2016), while balance was the sole component in one study (Wedderkopp et al., 1999).

It also transpired that the average duration of the training sessions was 15 minutes, which included between three and five exercises per session, and the exercises that varied most across the programmes were plyometrics.

Training programme components

The most frequent combination was balance training with plyometric training (5/6 = 83 %). This was not consistent with the reviews by Petushek et al. (2019), Yoo et al. (2010) and Taylor et al. (2015), who conclude that strength training combined with plyometric training is the best combination for lowering the risk of ACL injury in adolescent girls.

Strength training was under-represented in the studies reviewed (3/6 = 50 %). Myer et al. (2004) and Lloyd and Oliver (2012) emphasised the priority of developing this capacity in growth stages, especially in girls, to offset the anthropometric and hormonal changes that take place during peak height velocity (PHV). Fort-Vanmeerhaeghe et al. (2016) argue that the aim is to create a stable structure prior to plyometric or more sport-specific work to reduce the neuromuscular risk factors described above since, unlike in boys, no correlations have been demonstrated between height, weight and neuromuscular performance in the maturation phase in girls (Hewett et al., 2016).

Balance work was used in all the studies in the review (Table 3) and in most cases (5/6 = 83 %) it was combined with another component. This is consistent with the results of the reviews by Yoo et al. (2010) and Sugimoto et al. (2015) in women athletes, which showed that balance work does not yield results by itself but does do so in combination with other components.

Landing stabilisation exercises geared towards optimising muscle activation to ensure proper jump technique and alignment (soft landing and aligned knees) had been included by definition in the plyometric component. Other studies, such as those by Brunner et al. (2019) and Petushek et al. (2019), classified them as technical exercises. Brunner et al. (2019) attached less importance to them because the sports they reviewed (football and floorball) did not include jumping as a common action. By contrast, in handball, jumping and jump receptions, particularly on one leg, are one of the specific actions which, together with one-on-one actions, most trigger a set of mechanisms that can result in ACL injury (Myklebust et al., 1997; Olsen et al., 2004; Takahashi et al., 2019). For this reason, the progression of plyometric work should focus on landing technique to gradually step up intensity and variability, for example by involving various planes and axes, including perturbations with external stimuli or a mobile one, combining expected and unexpected actions to improve feedforward capacity, increasing the intensity of the muscle stretching and shortening cycle, combining elastic and reactive actions and progressively introducing a fatigued state (Bedoya et al., 2015; Ford et al., 2011; Fort-Vanmeerhaeghe et al., 2016).

Training programme duration

Most of the studies lasted approximately 15 minutes (Table 3). The results of the review by Taylor et al. (2015) did not reveal any clear trend which would make it possible to recommend duration parameters for training programmes. By contrast, Padua et al. (2018) showed that ACL injury rates diminished in training programmes lasting approximately 15 minutes or longer.

Training programme exercises

Only the reviews by Padua et al. (2018) and Arundale et al. (2018) provide a detailed description of the exercises included in the ACL injury prevention programmes.

Nordic Hamstring is the exercise proposed by the three studies that include strength in their training programme. It is essential to perform strength work and activation of the hamstring musculature in positions close to maximum knee extension, as this helps to prevent anterior translation of the tibia and protects the ACL (Sugimoto et al., 2015).

The planks recommended by Achenbach et al. (2018) in their training programme are designed to enhance neuromuscular control of this area, as strength deficits and poor trunk control in exercises involving rapid changes of position during cutting, planting and landing movements compromise dynamic stability and lead to increased knee abduction load (Zazulak et al., 2007). The non-contact ACL injury mechanism in women athletes has been shown to involve lateral trunk lean with the body moving on one leg and will therefore be one of the patterns to be corrected when agility tasks are performed (Hewett et al., 2009; Olsen et al., 2004).

Altering the state of balance through the perturbations proposed in the training programmes is designed to improve awareness of the position, movement and muscular regulation of the knee joint in response to a stimulus, i.e. to stimulate the proprioceptive receptors to promote muscular coactivation and improve activation time (Padua et al., 2018).

Even so, Fort-Vanmeerhaeghe et al. (2016) suggest that balance exercises should target specificity and dynamism in sports movements, since when players sustain the ACL injury they are usually in motion, for example, cutting or landing after a jump.

Learning to land is probably more important than learning to jump, since a player may have to absorb a load of between 5.7 and 8.9 times her body weight depending on flight trajectory and time and jump speed (Mothersole et al., 2014). Achenbach et al. (2018), Myklebust et al. (2003) and Petersen et al. (2005) include drills that combine landing skills with other movements. Exercises aimed at reducing ground contact time should be performed once the previous levels have been achieved, while guaranteeing quality of movement.

Most of the plyometric exercise proposals are general, meaning that greater specificity is needed to enable the player to recognise the movement patterns that may be conducive to the ACL injury mechanism (Fort-Vanmeerhaeghe et al., 2016).

Based on the available evidence, it is recommended that multi-component training programmes aimed at reducing the risk of ACL injury should include feedback on technique and movement quality and also include agility, balance, strength and plyometric exercises.

Conclusions

Training programmes for preventing ACL injury in women handball players are performed two to three times a week for approximately 15 minutes. They are categorised into five components: running, agility, strength, balance and plyometrics. The same programme may consist of one or more components. The most frequent combination was plyometric training with balance training, and balance training was the common component in all the training programmes.

Exercises in the running category are designed to improve running technique; agility exercises include planting and cutting combined with movement actions; strength exercises focus on the lower limbs and trunk; balance exercises are on stable and unstable surfaces, with single- or two-leg support and using a ball; finally, plyometric exercises are performed on various planes and axes with perturbations and landings on one or two legs and also from different heights.

Limitations

One of the main problems was the small number of studies, high variability in terms of components and their combination and the lack of individualisation of the contents of the training programmes based on player characteristics.

Only outcomes in women handball players were analysed in all the articles, except the papers by Achenbach et al. (2018) and Olsen et al. (2005) which also included male participants. The women players analysed in the study by Zebis et al. (2016) played either football or handball.

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Lifeguard's Swimming: Front-crawl's and Up-head Front Crawl's Energetics

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Abstract

Lifeguards use, as part of aquatic rescue, the front crawl and up-head front crawl. Studies on energy expenditure and complementary physiological variables obtained during aquatic rescue strategies are rare. The aim of this study was to compare the front-crawl's and up-head front crawl's energetics and performance as carried out by lifeguards. Twenty-one military lifeguards voluntarily participated in this study. Two tests were performed at maximum intensity: 100-meters in both front crawl and up-head front crawl. From each test, physiological data (direct measurement of oxygen uptake, lactacidemia, and heart rate), rate of perceived exertion, and mean swimming speed (two-dimensional video-analysis) were identified. Each energetic source contribution and energy cost were calculated. Descriptive and inferential statistics were used for $\alpha < .05$. The performance was better in the front-crawl, the physiological results were similar between front-crawl and up-head front crawl, and higher energy cost in up-head front crawl (1.90 ± 0.33 kJ·m^{-1}) compared to the front-crawl (1.51 ± 0.33 kJ·m^{-1}). In conclusion, the up-head front crawl is less economical when compared to the front-crawl.

Keywords: physical exertion, physical functional performance, rescue work.

Introduction

Aquatic rescue by lifeguards is part of the strategies to reduce the number of deaths (Gámez de la Hoz & Padilla Fortes, 2017; Szpilman et al., 2016; Wallis et al., 2015). The possibility of successful rescue increases in regulated swimming environments, such as swimming pools and open water with trained lifeguards (Chan et al., 2018; Idris et al., 2017; Jeong et al., 2016). Swimming is the most common form of rescue to reach and remove the victim from the water. Lifeguards carry out the front crawl stroke (FC) with the head in the water as the fastest and more economical way of human locomotion in water (Barbosa, Fernandes, et al., 2006). However, the rescuer's first option is the up-head front crawl (UH), which consists of the front crawl with the head above water and facing forward to allow a constant visualization of someone at possible risk of drowning.

FC and UH as forms of locomotion in the aquatic environment seem to require different energy costs and total metabolic energy expenditures, depending on swimming speed and drag due to body position (Barbosa, Lima, et al., 2006; Figueiredo et al., 2013; Gonjo et al., 2018; Zamparo et al., 1996). Physiological and biomechanical parameters can provide useful information for lifeguard training, but such studies are very scarce in the literature.

In swimming, the more the body is horizontal in relation to the water surface, the lower the drag and the better the performance (Zamparo et al., 2009). The main technical difference between FC and UH is the head-up position. Head elevation causes the hips and legs to sink, increasing the body's contact area with the water due to an increase of the angle formed between hip and shoulder in relation to the water surface, consequently increasing drag (Toussaint & Hollander, 1994; Zamparo et al., 2009). Both drag and swimming speed influence energy cost in the aquatic environment (Pendergast et al., 2006; Toussaint & Hollander, 1994). Energy cost can be expressed as the quotient between total metabolic energy expenditure (sum of energies from the three energy pathways of aerobic, anaerobic alactic and lactic) and the mean swimming speed at a given distance (Figueiredo et al., 2012). For the same swimming speed, the FC presents the lowest energy cost compared to other swimming strokes (Pendergast et al., 2015).

Studies that seek to analyze and support the activity of lifeguard training are of extreme relevance, although scarce. In this way, with studies focusing the UH energetic and energy cost, training could be more specific. The main outcome ought is a reduction in death rates by drowning and a better clinical condition of saved victims, reducing the possible physiological and psychological sequelae (Schwebel et al., 2007; Wallis et al., 2015). Studies on the performance of lifeguards can inform society work, helping to improve lifeguard fitness (the better prepared lifeguards are, the greater the chance of work success). By analyzing in depth the swimming techniques used by lifeguards, we hope to obtain a body of knowledge that will serve to improve the training and orientation processes at the time of rescue. Thus, the objective of this study was to compare the FC and UH energetics and performance carried out by lifeguards. We hypothesized that: (a) performance (swimming speed and test duration) will be better in FC than in UH; (b) oxygen uptake, heart rate, blood lactate concentration and rate of perceived exertion will be higher in UH than in FC; and (c) total metabolic energy expenditures and energy cost will be higher in UH than in FC.

Methods

Participants

Twenty-one trained military lifeguards, all male with at least three years of rescue experience (age: 32.4 ± 3.1 years; body mass 79.2 ± 8.0 kg; height: 177.0 ± 7.2 cm; upper arm span: 183.3 ± 8.1 cm), participated in this study. This study was approved (nº 2.316.201) by the research ethics committee of the Federal University of Rio Grande do Sul, respecting the guidelines of the Helsinki Declaration. All participants gave written consent to participate in the research. Participants were asked to abstain from intense physical effort and/or training for 24 hours before each test.

Design/Experimental procedure

Each participant performed two test sessions in a 25-meter indoor pool (1.90 m deep, water temperature at ≈ 28 ºC). Participants warmed up with a 400-meter FC but with open turns, followed by a 100-meter FC with a regular snorkel. The warm-up was used to make the participants feel even more comfortable with the AquaTrainer® snorkel (Cosmed, Italy) equipment and the pool during the tests. The tests were (i) 100-meter FC and (ii) 100-meter up-UH, performed 24 hours apart and in maximal intensity, with an in-water start and open turns. All lifeguards were previously familiarized with the use of the AquaTrainer® snorkel for six sessions. The setup of the data collection is pictured in Figure 1.

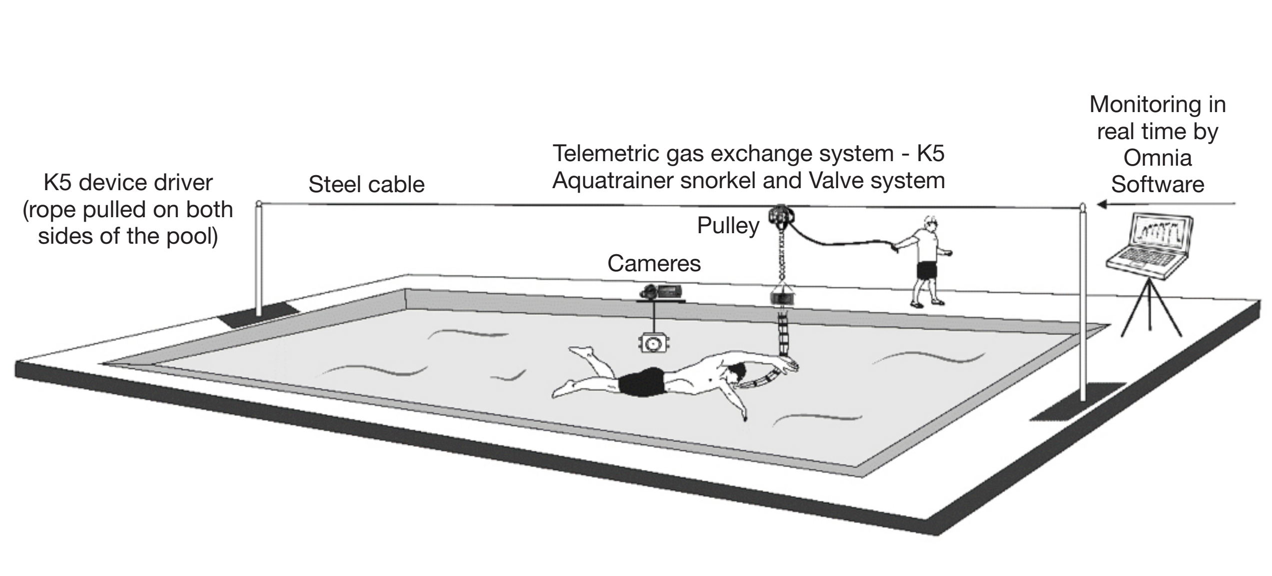

Figure 1
Physiological and performance data collection set-up over the 100-meter front crawl and 100-meter up-head front protocols.

Data collection

Before the swimming test, body mass (SECA® 813 digital scale, resolution of 0.1 kg, Germany), height (SANNY stadiometer, Personal Caprice, resolution of 0.1 cm, Brazil), and arm span (SANNY stadiometer, Personal Caprice, resolution of 0.1 cm, Brazil) were measured. The lifeguards received circular markers (black paste dermatologically tested) on the (bi-laterally) lateral malleolus, greater trochanter of the femur, and acromial process.

Performance in each test was timed by two researchers (CR20 chronometers, Kikos, Brazil). The mean swimming speed (m·s^{-1}) was measured by viogrammetry with support for the Ariel Performance Analysis System (APAS®, Ariel Dynamics Inc., USA) from two sections: 25-50 and 75-100 m (two stroke cycles in each section). The mean swimming speed was obtained by the quotient between hip displacement and time over a complete stroke cycle. A stroke cycle comprised the entry and re-entry of the same hand into the water (Barbosa et al., 2008).

The images for swimming speed identification were recorded with the support of two fixed cameras (Sony Hdr cx260, 60 Hz, United States) one positioned 0.3 m below the water surface line inside a waterproof case (Sony SPK-HCH, United States), and another 0.3 m out of the water (Figure 1). The cameras were halfway through the pool and 7.5 m away from the participant's sagittal plane of displacement. A device with light-emitting diodes arranged above and below the water was used to synchronize the camera images taken, in accordance with studies by de Jesus et al., 2015. The images were recorded by the cameras within a previously calibrated space (calibration structure with x = 4.5 m [horizontal axis]; y = 1 m [medial-lateral axis]; and z = 1.5 m [vertical axis] dimensions). The root mean square error for the x, y, and z-axes were, respectively, 1.92, 0.29, and 1.34 mm (10 real and 10 control points for underwater and external cameras).

Oxygen uptake (VO_2) in both tests was directly measured breath-by-breath using a telemetric portable gas analyzer (K5, Cosmed, Italy) connected to a snorkel and valve system (AquaTrainer®, Cosmed, Italy), suspended at ≈ 2 m over the water surface in a steel cable. The telemetric portable gas analyzer was calibrated before each testing session using reference gases (16% O_2 and 5% CO_2), and the turbine volume transducer was calibrated with a 3 l syringe. For data treatment, errant breaths (swallowing, coughing, and/or signal interruptions) were withdrawn from the VO_2 analysis by only including those within mean ± 4 SD (Ozyener et al., 2001). The data was then smoothed using a 5-breath moving window (de Jesus et al., 2014). Peak oxygen uptake (VO_{2peak}) was considered as the highest value of the curve of both tests (Laffite et al., 2004). VO_2 and lactate concentration in rest (respectively, VO_{2rest} and La_{rest}) were measured prior to each test, after 10 minutes in rest. After rest, VO_{2rest} was the mean of VO_2 in which the respiratory exchange ratio stabilized at approximately 0.8.

Blood was sampled from the fingertip to determine lactate concentration. It was measured at rest and after exercise (1, 3, 5, and 7 minutes after the test) to identify the peak lactate value (Lapeak). Blood lactate was identified by means of a portable lactometer (Accutrend, Roche, Germany).

Both heart rate (HR) and rate of perceived exertion (RPE) were identified at rest and immediately after each test. To verify the HR, a transmitter was allocated in the xiphoid appendix region of the participants during the tests (Garmin, 920XT, USA). The 15 points Borg-scale (6 - 20) was presented to the participants who indicated the RPE according to their visualization (Borg, 1998).

Energetic Contribution and Cost

The proportions of aerobic and anaerobic metabolism during each test (Equation 1) were calculated by the total energy expenditure equation (Capelli et al., 1998; di Prampero, 1986; Figueiredo et al., 2011):

$$E_{tot} = VO_2 + \beta La_b + PCr(1 - e^{-t/r}) \quad (1)$$

where E_{tot} is the total energy consumption over the test; VO_2 was calculated from the time-integral of the net value between VO_{2peak} and VO_{2rest} as the aerobic contribution (Aer, kJ); βLa_b is the difference between La_{peak} and La_{rest} multiplied by 2.7 ml·O_2·mM^{-1} kg^{-1} and then by the total body mass (kg) as the lactic anaerobic contribution (AnLa, kJ); and PCr (phosphocreatine) is the alactic anaerobic contribution (AnAla, kJ), whereas this energy source corresponds in time constant to 23.4 s (Binzoni et al., 1992). The AnAla was estimated by the concentration of phosphocreatine decreased by 18.55 mM·kg^{-1} (net weight at maximum activation muscle, assuming 50% of muscle mass activated) (Capelli et al., 1998; Zamparo et al., 2011). Aer and AnLa were expressed in kJ assuming an energetic equivalent of 20.9 kJ lO_2^{-1} and as a % of the total metabolic energy expenditure. Lastly, energy cost (Equation 2) was calculated by the ratio between the total metabolic energy expenditure and mean swimming speed (di Prampero, 1986):

$$C = E_{tot} \times v^{-1} \quad (2)$$

where C is energy cost; E_{tot} is the total energy consumption over the test; and v is swimming speed.

Statistical Analyzes

The G*Power 3.1 software (Düsseldorf, Germany) was used to determine the minimum sample size required (statistical power of .80, $\alpha = .05$ for the analysis, 95% confidence interval, 5% sampling error, and an assumed effect size of 0.50). All data were checked for distribution normality with the Shapiro-Wilk test. The data were described as the mean ± standard deviation (SD) and 95% confidence interval of the mean [CI]. Comparisons were performed with dependent samples t-test followed by effect size calculation (Rosenthal, 1996): (when d: 0 < insignificant effect size < 0.19; small effect $0.20 \leq d \leq 0.49$; medium effect size $0.50 \leq d \leq 0.79$; large effect size $0.80 \leq d \leq 1.29$; and very large effect size $d \geq 1.30$). Significance level was established at 5%.

Results

The results were expressed as the mean, SD, CI, and Cohen's d for the mean of lifeguards for performance and swimming speed, physiological parameters (VO_{2peak}, La_{peak}, HR and RPE), total metabolic energy contribution, and energy cost (Table 1). The effect size was very large ($d > 1.30$) for performance (83.2 ± 8.2 s in FC and 100.5 ± 11.8 s for UH) and large ($0.80 \leq d \leq 1.29$) for swimming speed (1.09 ± 0.13 m·s^{-1} in FC and 0.96 ± 0.17 m·s^{-1} for UH) (Table 1). The effect size was medium ($0.50 \leq d \leq 0.79$) for Aer (880.2 ± 15.6 kJ in FC and 89.4 ± 18.0 kJ in UH) and small ($0.20 \leq d \leq 0.49$) for AnaerLa (53.4 ± 15.5 kJ in FC and 60.0 ± 15.2 kJ in UH) (Table 1). The effect size was large ($0.80 \leq d \leq 1.29$) for total metabolic energy expenditure (166.4 ± 16.5 kJ in FC and 182.5 ± 23.1 kJ in UH) and very large ($d > 1.30$) for energy cost (1.51 ± 0.24 kJ·m^{-1} in FC and 1.90 ± 0.33 kJ·m^{-1} in UH) (Table 1). At rest, no differences were identified for VO_2, LA, HR and RPE for FC and UP, respectively: 6.6 ± 1.4 and 6.8 ± 2.3 ml·kg·min^{-1}; 2.3 ± 0.8 and 2.0 ± 0.7 mmol·l^{-1}; 73.5 ± 13.6 and 75.9 ± 14.0 bpm; and 7.3 ± 1.5 and 7.5 ± 1.9 points.

The mean and standard deviation of swim speed (image A) energy cost (image B), performance (image C), and aerobic and anaerobic energy contribution (image D) of lifeguards over the 100-meter up-head front crawl and 100-meter front crawl tests, $N = 21$, are shown in Figure 2. The results of the FC test were better than the results obtained in the UH test on variable performance (shorter duration in seconds in the 100-meter test) and swimming speed (Figure 2). The aerobic and anaerobic energy contributions were higher in the UH than in the FC (Figure 2). Total metabolic energy expenditure and energy cost were also higher in the UH than in the FC (Table 1, Figure 1).

Discussion

This study assessed and compared performance, oxygen uptake, and complementary physiological variables (peak lactate, heart rate), rate of perceived exertion, total metabolic energy contribution, and energy cost of the FC and the UH carried out by lifeguards. In general, performance was better in the FC than UH. The VO_2 and complementary physiological variables (Lapeak, HR) and RPE were not different between FC and UH. The total

Table 1
Overall mean, standard deviation, confidence interval, and Cohen's d for the performance and SS, physiological parameters, the total metabolic energy contribution, and the energy cost for the lifeguards, N = *21.*

Variable	FC	UH	*p* (Cohens' *d*)
Performance (s)	83.2 ± 8.2 [79.5, 87.0]	100.5 ± 11.8 [95.2,105.9]	< .001* (1.54)
v (m·s^{-1})	1.09 ± 0.13 [1.02, 1.16]	0.96 ± 0.17 [0.87, 1.05]	< .001* (0.85)
VO_{2peak} (ml·kg·min^{-1})	45.0 ± 8.0 [40.7, 49.3]	44.8 ± 8.8 [40.1, 49.5]	.70 (0.02)
LA_{peak} (ml·l^{-1})	14.6 ± 3.3 [12.9, 16.4]	15.6 ± 4.0 [13.5, 17.8]	.43 (0.13)
HR (bpm)	159 ±13 [152, 167]	160 ± 11 [154, 66]	.83 (0.03)
RPE (points)	17.7 ± 1.4 [16.9, 18.5]	17.8 ± 1.7 [16.9, 18.7]	.75 (0.06)
Aer (kJ)	80.2 ±15.6 [73.0, 87.5]	89.4 ± 18.0 [81.2, 97.6]	.034* (0.54)
AnaerLa (kJ)	53.4 ±15.5 [46.3, 60.5]	60.0 ± 15.2 [53.1, 60.9]	.045* (0.42)
AnaerAla (kJ)	32.9 ± 3.1 [31.4, 34.4]	33.0 ± 3.2 [31.5, 34.5]	.32 (0.03)
E_{tot} (kJ)	166.4 ±16.5[158.9,173.9]	182.5 ± 23.1 [172.0,193.0]	< .001 (0.96)*
% Aer	48.3 ± 7.9 [44.6, 51.8]	49.0 ± 6.0 [46.1, 51.6]	.72 (0.08)
% AnaerLa	31.8 ± 7.7 [28.2, 35.3]	32.8 ± 6.5 [29.8, 35.8]	.54 (0.14)
% AnaerAla	19.9 ± 2.3 [18.0, 21.0]	18.2 ± 2.0 [17.3, 19.1]	< .001* (0.78)
% Anaer	51.7 ± 7.9 [48.1, 55.3]	51.2 ± 6.0 [40.3, 53.8]	.71 (0.07)
Energy cost (kJ·m^{-1})	1.51 ± 0.24 [1.40, 1.62]	1.90 ± 0.33 [1.74, 2.05]	< .001* (1.35)

Note. v = swimming speed; VO_{2peak} = peak oxygen uptake; LA_{peak} = peak lactate value; HR = heart rate; RPE = rate of perceived exertion; E_{tot} = total metabolic energy expenditure; % Aer = % aerobic energy contribution; % AnaerLa = % anaerobic lactic energy contribution; % AnaerAla = % anaerobic alactic energy contribution.

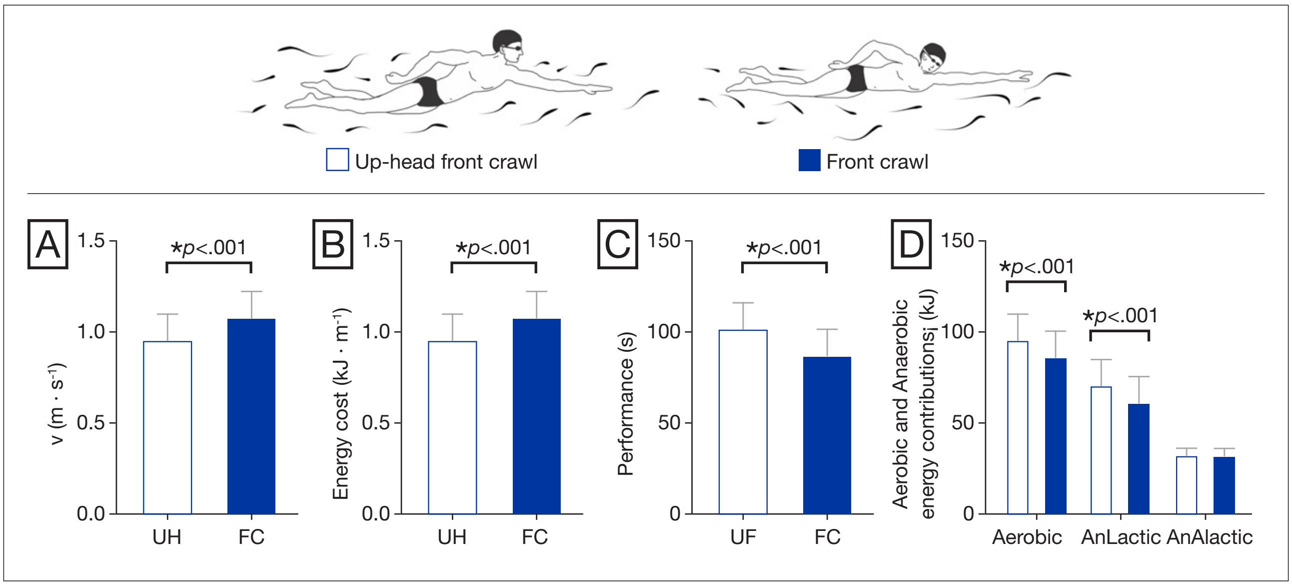

Figure 2
*Mean and standard deviation of swim speed (v) (image A) energy cost (image B), performance (image C), and aerobic and anaerobic energy contributions (AnLactic = anaerobic lactic and AnAlactic = anaerobic alactic) (image D) of lifeguards over 100-meter up-head front crawl and 100-meter front crawl tests. Overall results (*N = *21):* t-test: p *<.001.*

metabolic energy expenditure and the energy cost were higher in UH than in HR.

Lifeguards can benefit from FC compared to UH due to higher swimming speed and, consequently, have better performance (shorter test duration in seconds). Water rescues demand a sustained visual contact with the victim by the lifeguard (Vignac et al., 2017) and therefore choose to swim in UH first. Rescue in swimming pools or in open water that allows good visibility seems to favor strategies with greater use of FC compared to UH at greater distances from the rescuer's starting point to the victim. Body contact with the drowning victim requires different technical procedures that go beyond the objective of this study, e.g., techniques of approach in the last meters near the victim and possible actions of disengagement. In any case, lifeguards can substitute the use of FC at higher swimming speed in exchange for UH at distances that ensure the safety of both lifeguards and the victim.

The swimmers' body inclination, when raising the head, favors an increase in drag (Zamparo et al., 2009). Because of this, the body produces a greater drag during UH as compared to FC. In the current study, the total metabolic energy expenditure was higher for the lifeguards during UH than FC. The energy contribution of the aerobic and anaerobic pathways was higher for UH than for FC. When compared, the three energetic metabolic pathways for FC between lifeguard and well-trained male swimmers were not similar. At least for well-trained male swimmers, it was observed that, for the distance of 100-meters at extreme intensity, 43% of the energy comes from aerobic sources, 33.1% from anaerobic lactic, and 23.5% from anaerobic alactic, values that are smaller for aerobic pathway and higher for anaerobic alactic pathway (Ribeiro et al., 2015).

The energy cost values were higher for UH than for FC. The energy cost for FC and UH were, respectively, 1.51 ± 0.24 kJ·m^{-1} and 1.90 ± 0.33 kJ·m^{-1} ($p < .001$), with higher values for UH. The longer test (lower swimming speed) and the swim with worse horizontal alignment justify the higher values of energy cost in UH. In high performance swimmers in 100-meter FC tests, energy cost values of 1.16 ± 0.10 kJ·m^{-1} were found (Ribeiro et al., 2015), lower values than were found in the present study, even with similar values of VO_{2peak}. It should be noted that energy cost is a variable for a global evaluation of swimming, as it incorporates physiological (total energy) and biomechanical data (swimming speed) (Barbosa, Fernandes, et al., 2006). Thus, a swimmer with a lower energy cost uses less energy than a swimmer with a higher energy cost to travel the same distance. Such an outcome is of utmost importance when seeking a faster and more efficient rescue in the context of lifeguard-executed swimming.

Additionally, our results of RPE (14.6 ± 3.3 points for FC and 15.6 ± 4.0 points for UH) and LA (17.7 ± 1.4ml·l^{-1} for FC and 17.8 ± 1.7 ml·l^{-1} for UH) obtained after the 100 m pool test were different from those reported in tests with rescuers ($N = 23$, male $n = 21$ and female $n = 2$) performed in calm sea with waves smaller than 0.5 m after water rescue without floating rescue equipment (1.01 ± 2.06 ml·l^{-1} and RPE 8 ± 0.77 Borg 10-point scale) (Barcala-Furelos et al., 2016). It was also found a study ($N = 40$, male 28 and female 12) that reported RPE of 7.4 ± 1.4 on Borg's 10-point scale for rescue without floating rescue equipment (but using 12 and 38 cm fins) before rescue with 100 m distance in the sea (Aranda-Garcia & Herrera-Pedroviejo, 2020). Possibly, these differences are due to the constraints of different factors (Newell, 1986): means (density and water movement in pool and sea); organism (distinct samples with one of the groups with females); and task (without rescue and with rescue of an individual). It is worth noting that the support of any equipment (e.g., fins, rescue tube and rescue board) during rescues is better than no equipment (Aranda-Garcia & Herrera-Pedroviejo, 2020; Barcala-Furelos et al., 2016; Serrano Ramón & Ferriz Valero, 2018).

The results obtained from the variables studied can be used to support the lifesaving training planning and execution teams, and allow better performance in the water and visualization of the victim, reducing the energy cost for the performance of the activity. Even if it is not possible to set the swim distances at the time of each rescue, and that in aquatic rescues maximum efforts are not usually applied but submaximal efforts (Aranda-Garcia & Herrera-Pedroviejo, 2020; Barcala-Furelos et al., 2016), the results suggest that the lifeguards must present good aerobic capacity to be able to perform rescue activity. Regarding energy cost, the lifeguards presented higher values during UH than FC, and this can lead to early fatigue if performed over long distances to reach the drowning victim. In relation to energy cost, it can also be observed that lifeguards presented higher values during UH than FC, and this can lead to early fatigue if performed over long distances to reach the drowning victim.

It is also known that some lifeguards do not have a good breathing technique during swimming and always choose to swim with their heads out of the water, preventing them from being faster and more economical. It would thus be appropriate for the lifeguards to be trained to improve their swimming technique for both FC and UH. Regarding UH, it has been shown that water polo players who perform it very often during their training and games develop a great specialty which allows them to maintain swimming speed, stroke length, and stroke rate values in UH similarly to FC (Zamparo et al., 2009). Thus, we believe that if lifeguard training gives more importance to UH, lifeguards will also be able to sustain better values in the variables analyzed, resulting in a smaller energy cost during the performance of their activities.

Limitations

The main limitations of this study were: (a) the methodological infeasibility that does not allow the tests to be performed in the same conditions and environments in which the aquatic rescue activities are performed by the lifeguards; (b) No fins were used during swim tests. Some lifeguards use fins during their aquatic rescues (Barcala-Furelos et al., 2016). Possibly, future studies could provide more information on the use of fins in swimming tests, aquatic rescues and their respective energy costs; (c) the use of a snorkel for respiratory gas collection that allowed the lifeguards to breathe with their faces closer to the water line than if they were performing the approach technique without the snorkel, and which may have influenced the results of the UH. Such data from the current study can help in training planning, whether technical or physiological, in order to improve the planning of the lifeguard's physical activities, as well as in swimming technique related to the drowning approach. We know that it will always be difficult to control all the existing variables in studies of this nature, especially since it is an activity that does not allow the prediction of the effort that will be required to perform each rescue. A greater number of studies related to this issue will make it possible to understand even more about the capabilities that should be improved in the training of lifeguards.

Conclusion

The lifeguards achieved higher swimming speed and consequently better performance in FC than in UH in a 100-meter test at maximum intensity. VO_{2peak}, LA_{peak}, HR, and RPE were similar between FC and UH in the 100-meter test at maximum intensity. In general, lifeguards could alternate the FC strokes with one or two UH strokes, leaving the UH for when they are closest to the victim, in order to establish the most appropriate approach. This approach technique results in higher energy costs compared to FC. Alternatively, the improvement of the UH technique is suggested so that it approaches the physiological and biomechanical characteristics of FC.

Declarations of interest

None. No funding. The study was approved by the local ethics committee (nº 2.316.201) and was performed in accordance with the Declaration of Helsinki.

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