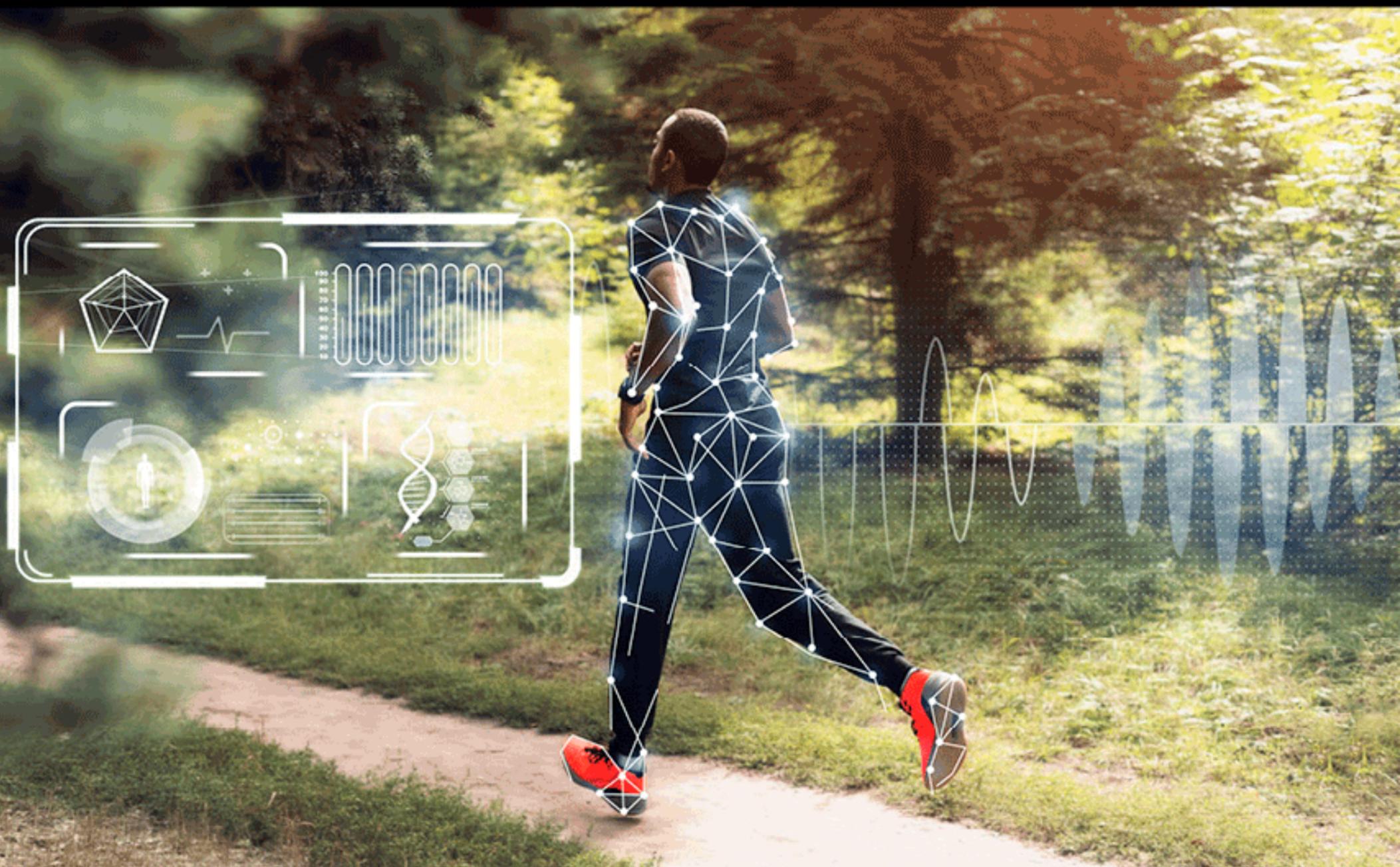


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The times are they a-changing? Evolving attitudes in Australian exercise science students' attitudes towards sports concussion

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ABSTRACT

The issue of concussion in sport continues to be discussed widely in the community as current and retired players reveal personal experiences, and concerns, about the long-term sequelae of their concussive injuries. This is the first study to examine evolving attitudes and beliefs towards concussion in sport by comparing data in an Australian exercise science student cohort between 2015 and 2020. Using a repeated cross-sectional design 1,013 participants (2020 cohort: n = 751; 21.6 ± 7.1 years; 2015 cohort: n = 312; 22.0 ± 5.2 years) responded to statements about concussion, including: personal attitudes, the media's portrayal, elite athletes who continue to play concussed, if participants would continue to play on when concussed, and on completing rehabilitation for concussion. Comparisons revealed statistically significant differences between cohorts across the majority of statements. Specifically, more progressive attitudes were found regarding the media presentation (glorification) of concussed athletes (decreased agreement of 14.7%, p < 0.001), admiration of concussed athletes who continued to play (decreased agreement of 10.5%, p < 0.001), and rehabilitation (increased agreement of 13%, p < 0.001). However, participants still presented attitudes of wishing to continue to train or play if they had a concussion for fear of letting team-mates down, or if the injury was not noticeable. While positive attitudes are evolving, more work is required, particularly as attitudes towards concussion still appear to be situation dependent.

1. Introduction

While the incidence of concussions continues to rise, awareness regarding the signs, symptoms and risks of concussion concurrently grows. Here, the increase in reported concussions might be a result of the increased media attention (White et al., 2020) featuring the premature retirement of elite athletes, as well as the long-term sequelae of older retired athletes. Following growing concerns about the pathophysiological and neuropathological changes in the brains of American Football players (Mez et al., 2017), Association Football (Grinberg et al.,

2016), Rugby (Buckland et al., 2019), and Australian Football players (Pearce et al., 2020), some national sporting organisations have also driven initiatives in education and concussion management. However, education alone has limited effectiveness on attitudinal changes. For example, a recent systematic review reported that knowledge improvements, and associated attitudinal responses, tend to return to baseline as time progresses following educational sessions (Conaghan, Daly, Pearce, King, & Ryan, 2020).

Conversely, public discussion, particularly through media framing of concussion, has the potential to influence public

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perceptions and attitudes over time (White et al., 2020). While previous studies have suggested that ongoing media coverage may trivialize the injury (Kennard, McLellan, & McKinlay, 2018) supporting negative attitudes towards concussion this is not always the case. Recently the media have published articles about retired athletes' mental health relating to their head injuries. The media have also reported scientists calling out media presentation around the language of concussion (i.e., glorification and/or humour to diminish its seriousness), and changes in management of concussion rules to ensure athletes have improved recovery outcomes (see examples by Cherny, 2016; Belson, 2019; and Twomey, 2021). How this shapes attitudes and beliefs over time has yet to be examined.

The aim of this study was to explore changing attitudes towards concussion over time. Studies investigating attitudes towards concussion in 'student-athletes' at high schools, colleges and club athletes at elite and non-elite levels (Kraak, Coetzee, Kruger, Stewart, & van Vuuren, 2019; Register-Mihalik, Guskiewicz, et al., 2013) have traditionally only surveyed participants at a single timepoint. Therefore, it is difficult to know if changes in attitude towards concussion are evolving, particularly in light of the ongoing media discussion. In our previous study, with data collected in 2015 (Pearce, Young, Parrington, & Aimers, 2017) we assessed an exercise science cohort on their beliefs and attitudes towards concussion. Investigating an exercise science student cohort provided us with a sample who are learning and preparing to work with athletes, of all levels, as well as in allied health settings where students will be exposed to individuals who have been concussed. Moreover, exercise science students are generally active in regular competitive sport, so we would anticipate some to have the 'lived experience' of being concussed, which may also shape their attitudes. Finally, having subsequent university cohorts undertaking the same course content, allows us to reprise our questions to determine if any changes in attitudes have occurred towards concussion five years apart. With continuing mainstream media and wider discussion, for example in social media, regarding concussion in sport, we hypothesised that attitudes between the groups would differ; with data collected in a 2020 cohort having more positive progressive attitudes regarding concussion when compared to the 2015 cohort.

2. Methods

The combined sample consisted of 1,013 undergraduate students (2020 cohort: male, $n = 495$; female $n = 256$; mean age 21.6 ± 7.1 years; 2015 cohort: male, $n = 217$; female, $n = 95$; mean age 22.0 ± 5.2 years). All students were enrolled at the same two Australian Universities offering courses under the umbrella of exercise science. Students were invited to participate in the anonymous survey. No incentive was provided to participants. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and was approved by the University Human Research Ethics committees (HRE-16-237).

Replicating previous research (Pearce et al., 2017), the survey consisted of 17 closed questions (see Table 1). Demographic data between both groups are shown in Table 2.

Comparisons of attitudes were made between all participants over time (2020 vs. 2015 cohort). Further analyses were made between comparisons between those previously concussed and those not reporting concussions, over time.

Data was entered an Excel spreadsheet and analysed with SPSS v.26.0.0 (SPSS Inc., USA). A Shapiro-Wilk test for normal distribution was conducted (2015: 0.547-0.913, $p < 0.001$; 2020: 0.426-0.914, $p < 0.001$). Transformation of the data showed that the data was still not normally distributed (2015: 0.605-0.877, $p < 0.001$; 2020: 0.465-0.874, $p < 0.001$). Therefore Mann-Whitney U tests were conducted to evaluate differences between cohorts, except for proportion of participants experiencing a concussion which was assessed using Chi-square. Significance was set at $p < 0.05$.

3. Results

A greater proportion of participants in the 2020 cohort (see Table 2) reported experiencing a concussion when compared to the 2015 cohort (42.3% versus 33.7% respectively, $\chi^2 = 7.16$, $p = 0.007$). However, the median number of concussions reported between groups were not different (2.0 and 2.0 concussions respectively).

3.1. Overall comparisons between cohorts

The percentage of participants that responded with agreement (by responding with 'always' or 'often') to the statements are presented in Table 3. The 2020 cohort was found to be less risk adverse with a 12.4% reduction in agreement to the statement regarding it is *safe to play or train with a concussion* ($U = 100296.0$, $p < 0.001$), alongside a 4.7% reduction in agreement to personally *risk playing or training with a concussion if I thought my chances of being selected to compete would be affected* than the 2015 cohort ($U = 96375.0$, $p < 0.001$). Similarly, the 2020 cohort reported increased (16.6%) concerns regarding players who continue to play with a concussion and possible (negative) long-term outcomes ($U = 94204.5$, $p < 0.001$), as well as 13% increase in reporting that players should be fully rehabilitated prior to returning to training and competition ($U = 89320.0$, $p < 0.001$). Conversely, the 2020 cohort showed significantly less (10.5%, $U = 82881.0$, $p < 0.001$) admiration for athletes who continued to play or train when concussed and less cynicism (14.7%, $U = 94673.5$, $p < 0.001$) about the media 'glorifying' athletes who play through a concussion.

Similarly, differences were found in the statements relating to playing with a concussion under different circumstances. For example, compared to the 2015 cohort the 2020 cohort were significantly less in agreement to play or train with a concussion if they didn't feel any symptoms (47.5% vs. 53.5% respectively, $U = 100799.5$, $p = 0.008$), felt symptoms but thought they were okay (24.2% vs. 27.5% respectively, $U = 100847.5$, $p = 0.008$), didn't want to let teammates down (20.5% vs. 26.9% respectively, $U = 97242.5$, $p = 0.001$), or were knocked out but came to (8.3% vs. 12.5% respectively, $U = 90161.0$, $p < 0.001$).

Table 1: Survey questions attitudes and beliefs towards concussion (Pearce et al., 2017).

Please circle the number that best represents what you believe, even if you have never sustained a concussion previously.

	Always	Often	Sometimes	Rarely	Never
I believe that it is safe to play or train with concussion	1	2	3	4	5
I would risk playing or training with a concussion if I thought my chances of being selected to compete would be affected	1	2	3	4	5
Players who continue to play or train with a concussion are likely to suffer problems later in life	1	2	3	4	5
I believe that players should be fully rehabilitated before returning to play or train again after they have suffered a concussion	1	2	3	4	5
I admire elite athletes who continue to play or train when they are concussed	1	2	3	4	5
The media (television, newspapers, radio) glorify elite athletes when they continue to play with a concussion	1	2	3	4	5
<i>I would be willing to play or train with a concussion if:</i>					
I didn't feel any symptoms (i.e., dizzy etc.)	1	2	3	4	5
I felt dizzy but know within myself I'm okay	1	2	3	4	5
I felt dazed but can't let my team mates down	1	2	3	4	5
I was knocked out but came to before the end of the game	1	2	3	4	5

Perceptions of support when/if concussed. Even if you have not received a concussion, circle the number that best represents what you think your coach/ administrators/ teammates would provide if you had sustained a concussion.

	Always	Often	Sometimes	Rarely	Never
My <i>coach</i> supports me to stop playing or training when I am concussed	1	2	3	4	5
The <i>administration</i> of my club supports me to stop playing or training when I am concussed	1	2	3	4	5
My <i>teammates</i> support me to stop playing or training when I am concussed	1	2	3	4	5
My <i>family</i> (parents, siblings, spouse, children) supports me to stop playing or training when I am concussed	1	2	3	4	5

Perceptions of first aid, medical follow up, rehabilitation following concussion. Even if you have not received a concussion, circle the number that you think best represents your club would provide if you had sustained a concussion.

	Always	Often	Sometimes	Rarely	Never
My club provides me with <i>first aid</i> support (e.g., sports trainers) when I am concussed	1	2	3	4	5
My club provides me with <i>follow up medical</i> support (e.g., doctor to examine me after the game and the following week) when I am concussed	1	2	3	4	5
The club assists me with my <i>rehabilitation</i> when I am concussed	1	2	3	4	5

A higher percentage (88.7 vs. 82.7%) of participants felt that their coach would be more supportive when comparing the 2020 with the 2015 participants and this was significant ($U = 101883.0, p = 0.002$) (see Table 3). Similarly, the 2020 cohort believed their teammates ($U = 96799.0, p < 0.001$) and family would be more supportive when compared with the 2015 cohort (94.0% vs. 88.8% respectively, $U = 104338.0, p < 0.001$). However, differences were not identified between cohorts with regards to club/association administration, including first aid (88.3% vs. 89.4% respectively, $U = 111833.5, p = 0.731$), medical follow-up (66.9% vs. 60.2% respectively, $U = 107688.5, p = 0.223$), or rehabilitation support (65.2% vs. 60.3% respectively, $U = 108674.0, p = 0.347$).

3.2. Previously concussed

Attitudes of participants who indicated that they had previously experienced a concussion are presented in Table 4. There were significant improvements were found across a number of statements. For example, there was an 8.9% decrease in the 2020 compared to the 2015 groups in terms of their agreement with the statement that *it is safe to play or train with a concussion* (11.0% vs. 18.1% respectively, $U = 13828.5, p = 0.002$) and an increase of 17.5% in the 2020 group who agreed that players should be *fully rehabilitated before returning to play or training* (86.1% vs. 68.6% respectively, $U = 12938.0, p < 0.001$). Changes were also observed in positive attitudes towards admiration of elite athletes continuing on after a concussion (reduction in agreement of 10.4%, 11.4% vs. 21.8% respectively, $U = 11711.5, p < 0.001$), as well as media glorification of concussion (reduction in agreement of 17.4%, 28.3% vs. 45.7% respectively, $U = 13193.0, p < 0.002$).

When asked if participants were willing to play on or train with a concussion, there were significant changes in attitudes

between 2020 and 2015 cohorts as indicated by decreases in agreement for playing/training on if *I didn't feel any symptoms* (8.7%, 53.0% vs. 61.7% respectively, $U = 14127.0, p = 0.023$), *I felt symptoms but know within myself I'm okay* (4.6%, 30.6% vs. 35.2% respectively, $U = 14582.5, p = 0.037$), *I felt symptoms but can't let my teammates down* (6.7%, 25.7% vs. 32.4% respectively, $U = 13864.5, p = 0.016$), as well as *I was knocked out but came to before the end of the game* (7.4%, 9.9% vs. 17.3% respectively, $U = 13695.0, p = 0.006$). No other significant changes were found.

3.3. No previous concussion

Those who denoted they had not experienced a concussion were compared between cohorts (see Table 5). In all but three statements (club/association first aid support, club/association follow-up medical support, club/association rehabilitation support), significant differences were found in attitudes between 2020 and 2015 groups. Here, the largest positive changes in attitudes were found in agreement with players who continue to play or train with concussion are likely to suffer problems later in life (21.1%, 64.5% vs 43.4% respectively, $U = 33124.0, p < 0.001$), and players should be fully rehabilitated before returning to playing or training (11.2%, 90.4% vs 79.2% respectively, $U = 33038.5, p < 0.001$). Similarly, positive changes in attitudes, as shown by significant reduction in agreement with statements were observed with it being safe to play or train with a concussion (7.3%, 3.3% vs 10.6% respectively, $U = 38358.5, p < 0.001$), admiration for elite athletes who continue to play or train with a concussion (10.1%, 9.7% vs 19.8% respectively, $U = 31649.0, p < 0.001$), as well as the media glorifying elite athletes when they continue to play with a concussion (13.2%, 29.5% vs 42.7% respectively, $U = 36809.5, p < 0.001$).

Table 2: Demographic data for 2020 and 2015 cohorts.

Characteristic (# reporting)	Frequency (%) ^a	
	2020 (n = 751)	2015 ^b (n = 312)
Gender		
Male	495 (66.0)	217 (69.6)
Female	256 (34.0)	95 (30.4)
Primary sport played		
Team sport – contact	200 (26.6)	164 (52.6)
Team sport – non-contact	246 (32.8)	81 (26.0)
Individual sport – contact	28 (3.7)	8 (2.6)
Individual sport – non-contact	161 (21.4)	41 (13.1)
No competitive sport (e.g., weights, recreational running/cycling/swimming)	116 (15.5)	18 (5.8)
Participation type of sport played		
Competitive (all levels)	635 (84.6)	136 (43.6)
Recreational non-competitive ^c /No competitive sport/physical activity	116 (15.4)	176 (56.4)
Self-reporting concussion		
Yes	318 (42.3)	105 (33.7)
No	432 (57.7)	207 (66.3)
Mean (±SD)/median number of reported concussions	2.4 (± 2.3)/2.0	2.5 (± 1.9)/2.0

Note: ^a Some percentages are rounded. ^b Cohort from Pearce et al. (2017). ^c Recreational non-competitive may include participation in club sport during the day/evening, but not in a league or pennant competition.

Table 3: Percentages of agreement towards attitudinal and perception statements between 2020 (n = 751) and 2015 (n = 312) cohorts.

Attitude statement	Agreement with item		<i>U</i>	<i>p</i>	<i>M</i> _{rank}	
	2020	2015			2020	2015
I believe that it is safe to play or train with a concussion	0.7%	13.1%	100296.0	<0.001	550.4	477.9
I would risk playing or training with a concussion if I thought my chances of being selected to compete would be affected	17.1%	21.8%	96375.0	<0.001	552.6	465.9
Players who continue to play or train with a concussion are likely to suffer problems later in life	62.4%	45.8%	94204.5	<0.001	498.8	591.6
I believe that players should be fully rehabilitated before returning to play or train again after they have suffered a concussion	88.6%	75.6%	89320.0	<0.001	492.2	613.2
I admire elite athletes who continue to play or train when they are concussed	10.3%	20.8%	82881.0	<0.001	572.5	460.4
The media glorify elite athletes when they continue to play with a concussion	28.9%	43.6%	94673.5	<0.001	550.2	460.4
<i>I am willing to play or train with a concussion if:</i>						
I didn't feel any symptoms	47.5%	53.5%	100799.5	0.008	536.9	484.1
I felt symptoms but know within myself I'm okay	24.2%	27.5%	100847.5	0.008	536.5	483.6
I felt symptoms but can't let my team mates down	20.5%	26.9%	97242.5	0.001	540.7	471.8
I was knocked out but came to before the end of the game	8.3%	12.5%	90161.0	<0.001	549.0	449.6
My <i>coach</i> supports me to stop playing or training when I am concussed	88.7%	82.7%	101883.0	0.002	504.8	557.4
The <i>administration</i> of my club supports me to stop playing or training when I am concussed	89.8%	86.2%	107276.5	0.110	511.9	539.1
My <i>teammates</i> support me to stop playing or training when I am concussed	81.7%	73.1%	96799.0	<0.001	498.1	576.3
My <i>family</i> (parents, siblings, spouse/partner, children) supports me to stop playing or training when I am concussed	94.0%	88.8%	104338.0	0.001	508.7	553.1
My club/association provides me with <i>first aid</i> support (e.g., sports trainers) when I am concussed	88.3%	89.4%	111833.5	0.731	521.6	516.3
My club/association provides me with <i>follow up medical</i> support (e.g., doctor to examine me after the game and the following week) when I am concussed	66.9%	60.2%	107688.5	0.223	512.4	536.1
My club/association assists me with my <i>rehabilitation</i> when I am concussed	65.2%	60.3%	108674.0	0.347	513.5	531.9

Table 4: Percentages of agreement towards attitudinal and perception statements in participants reporting a concussion between 2020 (n = 318) and 2015 (n = 105)

Attitude statement	Agreement with item				M _{rank}	
	2020	2015	U	p	2020	2015
I believe that it is safe to play or train with a concussion	11.0%	18.1%	13828.5	0.002	221.0	184.7
I would risk playing or training with a concussion if I thought my chances of being selected to compete would be affected	21.7%	25.7%	14978.0	0.114	216.7	195.6
Players who continue to play or train with a concussion are likely to suffer problems later in life	59.4%	52.5%	15231.5	0.250	207.4	222.1
I believe that players should be fully rehabilitated before returning to play or train again after they have suffered a concussion	86.1%	68.6%	12938.0	<0.001	199.7	246.8
I admire elite athletes who continue to play or train when they are concussed	11.4%	21.8%	11711.5	<0.001	227.1	164.5
The media glorify elite athletes when they continue to play with a concussion	28.3%	45.7%	13193.0	0.002	281.1	187.8
<i>I am willing to play or train with a concussion if:</i>						
I didn't feel any symptoms	53.0%	61.7%	14127.0	0.023	218.1	187.8
I felt symptoms but know within myself I'm okay	30.6%	35.2%	14582.5	0.037	216.4	189.9
I felt symptoms but can't let my team mates down	25.7%	32.4%	13864.5	0.016	217.1	185.0
I was knocked out but came to before the end of the game	9.9%	17.3%	13695.0	0.006	217.9	184.2
<hr/>						
My <i>coach</i> supports me to stop playing or training when I am concussed	86.7%	89.5%	16131.5	0.919	207.8	206.6
The <i>administration</i> of my club supports me to stop playing or training when I am concussed	89.3%	93.4%	15281.0	0.284	210.5	198.5
My <i>teammates</i> support me to stop playing or training when I am concussed	75.9%	67.7%	14463.5	0.058	202.5	226.2
My <i>family</i> (parents, siblings, spouse/partner, children) supports me to stop playing or training when I am concussed	93.6%	91.4%	15585.0	0.319	205.8	214.6
My club/association provides me with <i>first aid</i> support (e.g., sports trainers) when I am concussed	87.0%	91.4%	15804.5	0.623	208.8	203.5
My club/association provides me with <i>follow up medical</i> support (e.g., doctor to examine me after the game and the following week) when I am concussed	62.4%	54.3%	14930.0	0.200	203.3	219.8
My club/association assists me with my <i>rehabilitation</i> when I am concussed	59.9%	54.3%	15738.5	0.635	205.9	212.1

Table 5: Percentages of agreement towards attitudinal and perception statements in participants not reporting a concussion between 2020 (n = 426) and 2015 (n = 207).

Attitude statement	Agreement with item				M _{rank}	
	2020	2015	<i>U</i>	<i>p</i>	2020	2015
I believe that it is safe to play or train with a concussion	3.3%	10.6%	38358.5	<0.001	331.2	289.3
I would risk playing or training with a concussion if I thought my chances of being selected to compete would be affected	13.1%	19.9%	33653.0	<0.001	339.8	266.9
Players who continue to play or train with a concussion are likely to suffer problems later in life	64.5%	43.4%	33124.0	<0.001	290.9	366.4
I believe that players should be fully rehabilitated before returning to play or train again after they have suffered a concussion	90.4%	79.2%	33038.5	<0.001	291.1	370.4
I admire elite athletes who continue to play or train when they are concussed	9.7%	19.8%	31649.0	<0.001	346.2	256.9
The media glorify elite athletes when they continue to play with a concussion	29.5%	42.7%	36809.5	<0.001	331.7	282.2
<i>I am willing to play or train with a concussion if:</i>						
I didn't feel any symptoms	43.5%	51.3%	38210.5	0.026	320.7	282.0
I felt symptoms but know within myself I'm okay	18.3%	24.5%	37461.5	0.017	323.4	287.8
I felt symptoms but can't let my team mates down	16.8%	25.0%	36502.0	0.004	325.7	283.0
I was knocked out but came to before the end of the game	7.1%	10.5%	32968.5	<0.001	332.4	265.7
My <i>coach</i> supports me to stop playing or training when I am concussed	90.0%	79.6%	36281.5	<0.001	296.9	347.4
The <i>administration</i> of my club supports me to stop playing or training when I am concussed	90.2%	83.0%	38308.0	0.006	301.4	336.5
My <i>teammates</i> support me to stop playing or training when I am concussed	85.9%	75.8%	35505.0	<0.001	294.7	351.5
My <i>family</i> (parents, siblings, spouse/partner, children) supports me to stop playing or training when I am concussed	94.3%	87.4%	38949.5	0.002	303.5	336.5
My club/association provides me with <i>first aid</i> support (e.g., sports trainers) when I am concussed	89.2%	89.2%	42871.0	0.911	312.8	313.9
My club/association provides me with <i>follow up medical</i> support (e.g., doctor to examine me after the game and the following week) when I am concussed	70.2%	63.9%	42871.0	0.433	308.7	320.2
My club/association assists me with my <i>rehabilitation</i> when I am concussed	69.1%	64.4%	40492.5	0.241	306.4	323.5

4. Discussion

This is the first study to compare cohorts of undergraduate students studying exercise science and related courses, across two time points, separated by five years. Data between the two cohorts shows a meaningful and positive shift in attitudes, accompanied by a reduction in risk-adverse attitudes towards playing with a concussion. At the same time, there was an increased acknowledgement of the possible long-term consequences of concussions, reflecting a continued positive evolution of attitudes towards sports concussion. While this study did not explicitly investigate why attitudes changed, we speculate that the continuing publicity from regular media articles discussing older athletes revealing their on-going concerns as well as younger players retiring early, may have had an effect (White et al., 2020). Indeed, with increasing evidence of long-term impairments and neurodegenerative disease associated with repeated brain trauma in contact sports the opinion of many sports medicine practitioners is that concussion is now considered the number one problem in international sport (Brukner, 2020). However, this existential concern is not only due to clinical outcomes of athletes suffering from multiple concussions (Alosco et al., 2020) but due to wider sociological concerns regarding the effects of concussions on athlete welfare (Liston, McDowell, Malcolm, Scott-Bell, & Waddington, 2018; White et al., 2020).

In recent years there have been increased exploration of the presentation of concussion in the media regarding concussion in sport (Ahmed & Hall, 2017; Cassilo & Sanderson, 2018). In Australia, this has been illustrated by major news articles reporting post-mortem analyses of neurodegenerative disease in deceased football players, as well as increasing number of media articles that have highlighted older retired athletes speaking out on their multiple concussions and concerns about their long-term brain and mental health. There has also been increasing attention on recently retired younger athletes discussing their decisions to retire prematurely due to too many concussions, alongside the effects it has on their quality-of-life post career. These examples support the assertion that media attention of athlete health and safety in sport is growing (Cassilo & Sanderson, 2018). Specifically, the media is likely to have influenced this study's participant responses about no longer glorifying or trivialising concussion, participants expressing less admiration for elite athletes who play on with a concussion, as well as agreeing that players who continue to play on with a concussion are at-risk of experiencing neurological concerns later in life (see Table 3).

While we are encouraged by the positive shift in attitudes between the cohorts, it is still nevertheless disquieting to observe that five years on, while less than 1% of the 2020 cohort agreed with the statement that it was *safe to play or train with a concussion*, nearly a quarter (24.2%) agreed that they would play on with concussive symptoms; with a fifth saying that they would play on to not let teammates down (20.5%). Although this is lower than 2015 data (27.5% and 26.9% respectively) such findings are still concerning. This should not be surprising, however. Indeed, studies over a similar time period to ours have reported that despite a doctor's assessment athletes themselves believe they should make the final decision on continuing to play (Lee, Resch, JSES | <https://doi.org/10.36905/jses.2021.04.02>

Han, Miles, & Ferrara, 2016; Salmon et al., 2020), highlighting a general lack of awareness that concussion is a brain injury. Moreover, this disparity may indicate an engrained culture of either playing with pain and symptoms, including concussion and mild head injury (Chrisman, Quitiquit, & Rivara, 2013; Conway et al., 2020; Kaut, DePompei, Kerr, & Congeni, 2003), concerns about a loss of athletic standing in a team, or interpersonal pressure to not let team mates down (Conway et al., 2020; Longworth, McDonald, Cunningham, Khan, & Fitzpatrick, 2021; Register-Mihalik, Linnan, et al., 2013), as well as a high internal motivation to continue playing in the belief that they are making a contribution to their team (Longworth et al., 2021; Salmon et al., 2020).

While overall positive improvements across the years were seen in participants with a history of concussion or no injury (see table 4), greater positive attitudinal changes were seen in the non-concussed participants (see table 5). This is illustrated specifically in the lack of statistical significance in differences across years in the concussed group for their beliefs with regards to *playing or training with a concussion if I thought my chances of being selected would be affected*, and that *players who continue to play or train with a concussion are likely to suffer problems later in life*. Here, it is well known that previous experiences can influence current attitudes (known as planned behaviour) first argued by Ajzen (1991) and more recently by Kroshus, Baugh, Daneshvar, and Viswanath (2014). As such, we suggest that those who have previously been concussed may view the injury as 'less serious' than those who have never experienced a concussion. Accordingly, the attitudes in those with a previous experience of concussion(s) have not changed over time irrespective of the wider public discussion. Similarly, the lack of change in attitudes across both cohorts from those previously concussed towards support from coaches, administrators and clubs (table 4) reflects the lived experience that when concussed there was no assistance. Thus, the 'subjective norms' within this sporting culture may downplay the severity of concussion and/or athletes who have a suspected concussion may feel little 'perceived behavioural control' with regards to reporting concussive symptoms. This highlights the need for not only content specific education regarding concussion for club administrators and coaching staff, but also the development of awareness and sociocultural change towards the injury from a holistic perspective. An example of this would be to develop a cultural change that coaching and administration staff will take seriously athletes who speak up that they are concussed, or team-mates who notice a concussion to notify club trainers and coaching staff.

Although a novel aspect of our study was to quantify changing attitudes, a limitation of our study was that it was not possible to explore the motivations, from a qualitative perspective, for changes that were observed across the cohorts. Other limitations included not asking the students about their knowledge regarding concussion injury to ascertain if changes in attitudes were due to improved general or specific knowledge about concussion.

Given the continuing discussion and resulting increasing awareness regarding concussion in sport, future research should continue in tracking changes in attitudes and beliefs towards this injury. Moreover, in contextualizing changes in attitudes, not only

a mixed-methods approach should be employed, but further research could expand questions with regards to participants' understanding of how various factors, such as leadership behaviour and psychological safety, may play a role in influencing and shaping attitudes towards concussion and concussion reporting intentions and behaviours (Light Shields, Gardner, Light Bredemeier, & Bostro, 1997).

In conclusion, this is the first study to directly examine attitudes towards concussion across comparable student cohorts, five years apart. The positive shift in attitudes found in this study may reflect an evolving cultural narrative influenced by altered media framing, such as highlighting long-term sequelae in former players. Nevertheless, there remained a contradiction in the 2020 cohort regarding attitudes towards concussion safety, such as playing on with a concussion. These findings suggest that, while attitudes towards concussion are changing, shifts in sociocultural attitudes are slow. Similar to other health-related change behaviours, concussion awareness may require a multi-faceted strategy to address this important public health issue; including published guidelines by national sporting organizations; ongoing media attention of individuals that have had adverse concussion experiences (e.g., persistent post-concussion symptoms), as well as a united approach by the sporting community (administrators, coaches, education institutions, medical and allied health professionals, and politicians).

Conflict of Interest

No specific funding was provided for this manuscript. AJP currently receives partial research salary funding from Sports Health Check charity and the Erasmus+ strategic partnerships program (2019-1-IE01-KA202-051555). AJP has previously received partial research funding from the Australian Football League, Impact Technologies Inc., and Samsung Corporation. AJW and NH currently receive partial research funding from the Erasmus+ strategic partnerships program (2019-1-IE01-KA202-051555). The remaining authors declare no conflicts of interests.

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The use of lower-body compression garments during high-intensity exercise performance in basketball athletes

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ABSTRACT

This study examined the effects of lower-body compression garments worn during anaerobic and repeated-effort performance in basketball athletes. In a randomised, crossover design, 20 trained, male basketball athletes (mean \pm SD age: 22 \pm 5 years) performed a control (CON, loose-fitting clothing) and experimental trial (COMP, lower-body compression garments) where they completed dynamic, intense exercise, including a Margaria-Kalamen stair climb test (SCT) and countermovement jumps pre and post a basketball exercise simulation test (BEST). There were no significant condition (CON v COMP) \times time (pre and post BEST) interactions for any measures ($p > 0.05$). There was a small ($d = 0.21 - 0.34$) difference in SCT power both pre and post BEST, in favour of COMP over CON. During the BEST, there was a significant ($p = 0.03$), small ($d = -0.37$) difference between trials in average repeated-sprint time in favour of COMP, but no differences for any other measures. Compression garments were associated with small improvements in lower-body power during a stair-climb task and faster 6-m sprint times during a basketball-specific exercise circuit but did not benefit other performance measures or allow for maintenance of performance in trained basketball athletes.

1. Introduction

Originating from the medical setting to treat various circulatory and lymphatic insufficiencies (Amaragiri & Lees, 2000), the use of compression garments has become common place in the sport and exercise setting over the past decade, both during exercise and for subsequent recovery from exercise (Atkins et al., 2020; Driller & Brophy-Williams, 2016; Gill et al., 2006). While it seems that the use of compression garments as a recovery strategy is generally favourable in the research literature (Brown et al., 2017), the use of compression garments during exercise is less clear (Beliard et al., 2015). In addition to improved blood flow, potential mechanisms that may influence exercise performance when wearing compression garments appear to be related to a myriad of variables. Some of these potential ergogenic factors include enhanced proprioception (Ghai et al., 2016), improved

oxygen delivery and perfusion (Bochmann et al., 2005), and reduced muscle oscillation during exercise (Kraemer et al., 1998). There is some evidence to suggest that wearing compression garments during exercise may also aid in subsequent physical performance (Brophy-Williams et al., 2019) while decreasing subsequent muscle soreness (Ali et al., 2007).

In review articles by MacRae et al. (2011) and Beliard et al. (2015) the authors assessed studies investigating the effects of wearing compression garments either during exercise or following exercise, as a recovery tool. Related to wearing the garments during exercise, both review articles reported few ergogenic effects, but concluded that they may aid aspects of vertical jump performance in some situations. There was also some indication for physical and physiological responses, including attenuation of muscle oscillation, improved joint awareness, perfusion augmentation and altered oxygen usage at

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sub-maximal intensities. Both review articles suggested that one of the possible reasons for inconsistencies in the findings on compression garments during exercise could be varying methodologies (e.g., different modes of exercise, range of participants used, reliability of tests implemented) and lack of information describing the applied pressures of the garments. Indeed, the applied pressure of the garments has been shown to be highly variable with changes in garment sizing and posture of the participants (Brophy-Williams et al., 2015). Furthermore, the optimal pressure of compression garments is yet to be established, however, previous research has suggested that levels $>18\text{mmHg}$ are required to instigate improved haemodynamics (Liu et al., 2008).

The majority of research on compression garment use during exercise seems to be focused on endurance or aerobic-based activities such as cycling (Driller & Halson, 2013) and running (Ali et al., 2007; Ali et al., 2010). Less research has focused on anaerobic and intermittent team-sport types of activities where dynamic movements such as jumping, bounding and sprinting are interspersed with jogging and walking. Basketball is one of these team sports that has received little attention in the compression literature when it comes to wearing the garments during exercise. Basketball is a sport predicated on repeated power-driven movements (Wen et al., 2018), with athletes performing various high-intensity movements such as multi-directional acceleration, deceleration, and jumping manoeuvres (Stojanović et al., 2018), interspersed with short recovery periods of either total rest, jogging or walking. Recent research has shown that upper-body and full-body compression garments may aid kinematic movement mechanics via decreased range of motion (ROM) and improved proprioception during basketball shooting tasks, with $\sim 5\%$ increases in accuracy compared to a control (Wong et al., 2020).

While not in basketball, a study by Higgins et al. (2009) investigated compression garments using Global Positioning System (GPS) tracking to examine the effects on key physiological and performance measures in a simulated game-specific circuit for netball. Using traditional statistical analysis, performance enhancing effects of compression garments were non-significant ($p > 0.05$). However, effect size analysis (using Cohen's d) revealed a large ($d = 0.86$) improvement in distance travelled at a fast pace ($>3.5\text{ m}\cdot\text{s}^{-1}$), a moderate decrease in blood lactate concentration ($d = 0.63$), and small improvements for mean sprint time ($d = 0.23$) and counter-movement jumps ($d = 0.24$), in favour of the compression intervention.

Given the lack of published data assessing the efficacy of compression garment wear during basketball-specific exercise, alongside the inconsistencies in methodologies and garments used, despite some promising initial findings (MacRae et al., 2011), further research is clearly warranted. Therefore, the aim of the current study was to evaluate the effect of wearing lower-body compression garments during dynamic exercises as well as during a basketball-specific circuit on performance and perceptual ratings in male basketball athletes.

2. Methods

2.1 Participants

Twenty trained male basketball athletes (mean age: 22 ± 5 years, height: 179 ± 5 cm, body mass: 72 ± 7 kg) volunteered to take part in the study. Inclusion criteria required the participants to be free from lower-limb injury for the previous 6 months prior to participation, be playing competitive basketball at the regional club level in Beijing, and pass a Physical Activity Readiness Questionnaire (PAR-Q) and medical clearance. The study took place during the pre-season phase of the basketball competition. Participants were recruited from different local universities and their average basketball training experience was 6 ± 5 years and they were performing basketball-specific training on average 3 times (± 1) per week. Written informed consent was obtained from each participant, and ethical approval was approved by the University of Waikato Human Research Ethics Committee.

2.2 Experimental Design

Implementing a randomized, crossover study design, participants performed an experimental trial (COMP) and a control trial (CON) separated by 48-72 hours (Figure 1). Participants were to refrain from performing any vigorous exercise in the 24 h leading up to the testing session. On arrival at the laboratory, participants performed a standardised 10-minute warm-up and were familiarised with the Basketball Exercise Simulation Test (BEST) (Scanlan et al., 2014) and a run-through of each of the testing protocols. Participants then completed countermovement jump testing and stair-climb testing, followed by 12-minutes of the BEST and further countermovement jump and stair-climb testing (Figure 1). The purpose of performing the jump and Margaria-Kalaman stair-climb testing before and after the BEST was to evaluate not only performance in COMP vs. CON at those specific time points, but also to investigate if there were any differences between trials with respect to performance maintenance pre to post the exercise simulation.

For the entire testing session (~ 45 minutes), participants wore either loose-fitting clothing (CON) or full-length, lower-body compression garments (COMP; Li-Ning, PowerShell AULM043-I, Beijing, China). The size of compression garments was selected based on the height and body mass of each individual, according to the manufacturer's sizing guidelines, where one size smaller than the suggested size was used, based on previous research using the same garments (Atkins et al., 2020). The garment pressures were recorded at the ankle, calf, and thigh immediately after they were put on (Atkins et al., 2020). Testing was completed at the same time each day for both trials to account for diurnal variations in performance. Participants were also asked to record and repeat their same diet in the <12 hours prior to testing for each intervention.

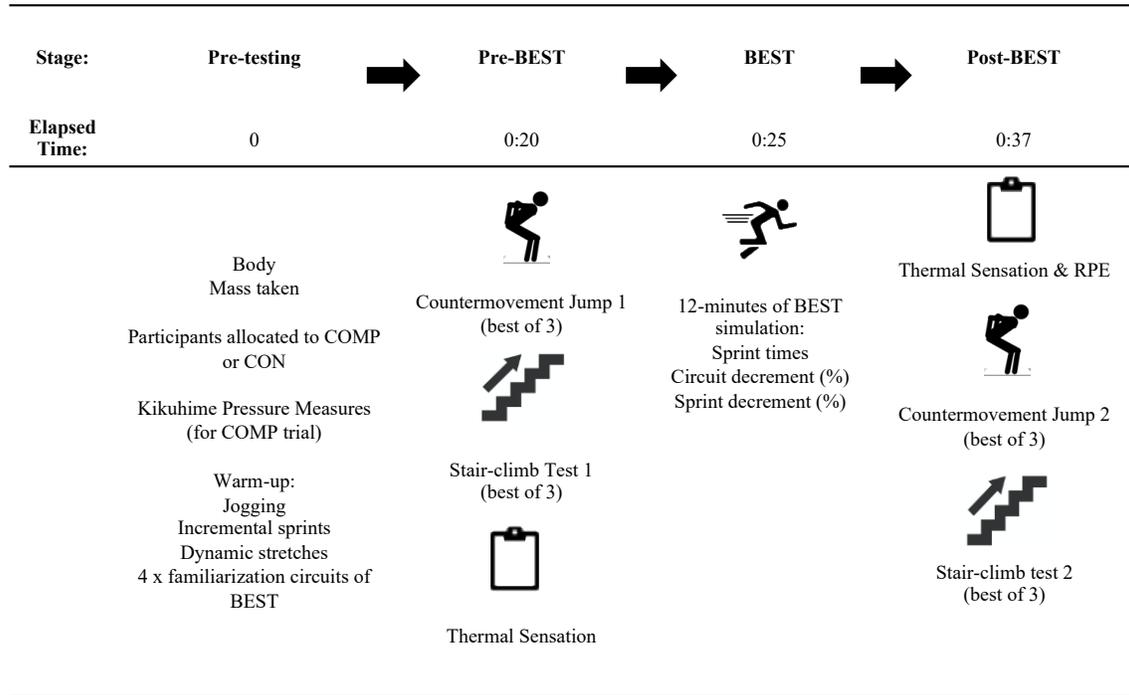


Figure 1: Timeline of study design. BEST = Basketball Exercise Simulation Test; COMP = compression trial; CON = control trial; RPE = Rate of Perceived Exertion.

2.3 Procedures

The standardised warm-up (~10 minutes) consisted of moderate-intensity jogging (5 minutes), running/sprinting efforts of increasing intensity (2 minutes) across the length of the basketball court and a range of dynamic stretches (3 minutes). Furthermore, three submaximal- and one maximal-effort circuits of the BEST were completed as part of the warm-up/familiarisation of the test (see Figure 1). All testing was performed indoors, inside a climate-controlled indoor stadium.

2.4 Countermovement jump

A countermovement vertical jump was used to assess lower-body power. Outcome measures gathered included jump height using a Vertec apparatus (Sports Imports, Columbus, OH, USA) as well as vertical jump power (W) using a force plate sampling at 1000 Hz (AMTI, Watertown, NY, USA). Three countermovement jumps were performed pre and post BEST (Countermovement Jump 1 and Countermovement Jump 2) involving participants initially standing with feet shoulder-width apart on the force plate (Lam et al., 2020). Participants were asked to jump as high as possible using a self-selected squat depth. Participants jumped from both feet and were permitted to use a swinging arm movement. Prior to the first jump at each time-point, the hand reach height (baseline) was measured when the participant displaced the vanes of the Vertec apparatus with their fingertips. This jump test was performed by participants while adopting a relaxed shoulder position. At the peak of the jump, participants

had to displace the Vertec vanes lightly with their fingertips to indicate maximum jump height. Jump height was then calculated by subtracting the participant's baseline reach height from the maximum jump height. The jumps were performed with ~5 s between each jump. The highest jump of the three trials was used for analysis at each time point. Excellent reliability of both Vertec apparatus and force plate for measuring jump height has been reported previously, with ICC values >0.99 (VanderZanden et al., 2010) and test-retest intrasession coefficient of variations (CV's) of ~5% (Nuzzo et al., 2011).

2.5 Margaria-Kalamen stair climb test (SCT)

Unilateral power was estimated using the Margaria-Kalamen stair-climb test (SCT). The test involves sprinting up a staircase of specified height from a specific distance (6 m from the base of the staircase), stepping only on the third, sixth, and ninth steps. The test is performed on a series of stairs with a rise of 17 cm per step. The time started at initial contact with the third step and stopped at contact with the ninth step. Participants were instructed to complete the sprint up the stairs with maximum velocity. The total power produced during the test was calculated using the following formula: [Power (W) = mass (kg) x 9.8 m·s⁻¹ x distance (m) / time (s)]. All participants were weighed without shoes and in minimal clothing prior to testing so that power could be calculated. The test was performed three times at each time point (pre and post BEST), with 20 s rest between trials and the fastest time was used for subsequent analysis. Timing was performed using a high-speed video camera (Casio EX-F1, Casio, Japan) set

at a recording rate of 300 Hz and perpendicular to the stair/movement plane. The SCT has been shown to be a good predictor of lower-body power and has good levels of test-retest reliability, with CV's of 2% being reported in healthy males (Margaria et al., 1966).

2.6 The Basketball Exercise Simulation Test

The BEST (Scanlan et al., 2014) was used to simulate the movement patterns and intensities performed during basketball game-play. Participants completed a 12-min trial of the BEST to represent the average playing time of basketball athletes during one quarter of basketball. During the test, participants were required to complete repeated circuits of basketball-specific activity, with each circuit being allotted a 30-s timeframe (24 circuits in total - Figure 2). When athletes finished before the 30-s period, they waited at the starting point before commencing their next circuit. Participants were instructed to maintain similar speed/intensity during the running, jogging and walking segments of the circuit, but to focus on sprinting as fast as they could during each 6 m sprint. The following measures collected during the BEST circuit were used for subsequent analysis; average sprint time (6 m), circuit time decrement (%) and sprint time decrement (%) (Scanlan et al., 2014). The sprint times were measured using instrumented timing lights (Smart Speed Timing Gates, Coopers

Plains, Australia). The test-retest reliability of these measures during the BEST in male basketball athletes expressed as a coefficient of variation (CV) are 1.7% for average sprint time (TEM = 0.03 s). The CV's for circuit decrement (16.8%) and for sprint decrement (14.6%) are somewhat less-reliable (Scanlan et al., 2014), and should be interpreted with caution.

The Borg's 6-20 Rate of Perceived Exertion (RPE) scale was also used immediately following the BEST to determine whether compression garments influenced perceived exertion during exercise.

2.7 Compression garment pressure measurement

The applied pressure of the compression garments was tested using the Kikuhime device (MediGroup, Melbourne, Australia) at the medial malleolus of the ankle, and maximal circumference of the calf and thigh. These landmarks have been used previously when measuring the pressure of full-length compression garments (Atkins et al., 2020). Garment pressure measurements were taken when the garments were first put on at the start of the COMP trial. The Kikuhime pressure monitor has been shown to be a valid (ICC = 0.99, CV = 1.1%) and reliable (CV = 4.9%) tool for compression measurement in sports settings (Brophy-Williams et al., 2014).

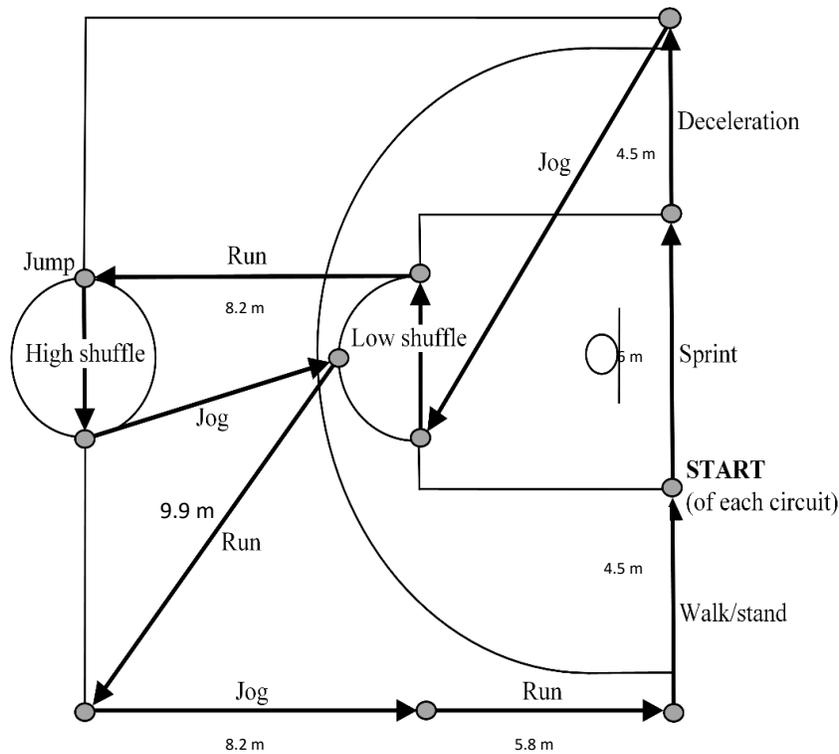


Figure 2: The Basketball Exercise Simulation Test (BEST), adapted from Scanlan et al. (2014).

2.8 Statistical analysis

Descriptive statistics are shown as means ± standard deviations. Statistical analyses were performed using IBM SPSS statistics (Version 22, IBM Corporation, Armonk, NY) and effect sizes were calculated using Microsoft Excel. Statistical significance was set at $p \leq 0.05$ for all analyses. To examine the differences between COMP and CON trials, a two-way repeated-measures ANOVA, with 2 (condition: CON, COMP) x 2 (time: pre-BEST, post-BEST) factors was performed for countermovement jump and SCT variables. Analysis of the studentised residuals was verified visually with histograms and also by the Shapiro-Wilk test of normality. Sphericity for the interaction was assessed by Mauchly’s test of sphericity ($p > 0.05$). Bonferroni post-hoc tests were applied if significant effects were detected. To examine the differences between COMP and CON trials during the BEST, a Student’s Paired *t*-test was used. Effect size statistics (Cohen’s *d* with 90% confidence intervals) were also calculated to quantify the sizes of mean differences between COMP and CON groups. The magnitude of each effect size was interpreted using thresholds of 0.2, 0.5 and 0.8 for small, moderate, and large, respectively. An effect size of <0.2 was considered trivial. Where the 90% confidence limits overlapped the thresholds for small positive and small negative values, the effect was considered unclear.

3. Results

The mean level of pressure exerted by the compression garments in the COMP trial were; 7.6 ± 2.6 , 14.0 ± 2.6 and 8.3 ± 1.8 mmHg at the ankle, calf, and thigh, respectively.

There were *small* effect size differences between conditions for SCT power 1 and SCT power 2, in favour of the COMP over CON (Table 1). There were no significant condition (CON vs. COMP) x time (pre and post BEST) interactions for vertical jump height; $F(1,38)$, $p = 0.26$, vertical jump power; $F(1,38)$, $p = 0.13$ or SCT power, $F(1, 38)$, $p = 0.83$, (Table 2), all resulting in *unclear* or *trivial* effect sizes (Table 2).

During the BEST, there was a significant ($p = 0.03$), *small* ($d = -0.37$) difference between trials for average sprint time in favour

of COMP, but no differences for sprint and circuit decrement measures (Table 3).

4. Discussion

This study examined the efficacy of lower-body compression garments worn during high-intensity, basketball-specific exercise in trained basketball athletes. The main findings in this study were that despite no significant interactions between trials for pre to post measures ($p > 0.05$), compression garments were associated with small differences in lower-body power during two stair-climb tasks and small but significantly faster repeated-sprint times over 6 m during the exercise circuit, in trained basketball athletes. Our repeated-sprint results are consistent with the study by Higgins et al. (2009), who reported small to large effect sizes in favour of a compression trial for high-speed distances and sprint times during a netball-specific circuit. The small ($d = -0.37$, $p = 0.03$) improvement in average sprint time for COMP over 6 m during the basketball circuit is greater than the previously reported CV for this measure of 1.7% (Scanlan et al., 2014). Furthermore, our results are similar to those reported in the earlier studies of Kraemer et al. (Kraemer et al., 1996; Kraemer et al., 1998), who reported enhanced repetitive jump power in volleyball, basketball and track athletes when wearing compression shorts. While the current study did not include a repeated jump test, and our results were not statistically significant ($p > 0.05$), the stair-climb test, which resulted in small ($d = 0.21$ to 0.34) improvements during the COMP trial, could be considered a similar test of neuromuscular function and lower-body power. Our improvements with compression garments in the stair-climb test of 50-60 W (~4%) at both time points (pre and post) are also greater than the previously reported reliability of ~2% (Margarita et al., 1966). However, it should be noted that these studies used compression shorts, and that different lower-body compression garments (e.g., socks, shorts, leggings, stockings) will likely exert different levels of pressure on different muscle groups and possible physiological responses (Brophy-Williams et al., 2015; Brophy-Williams et al., 2020).

Table 1: Mean ± SD for performance measures for control (CON) and compression (COMP) conditions. SCT = Magaria-Kalamen stair climb test. * significant difference between trials ($p \leq 0.05$).

Measure	Δ COMP – Δ CON (mean ± 90% confidence interval)	P-value (ANOVA)	Effect size (<i>d</i>) ±90% confidence interval
Countermovement jump height change (cm)	0.1 ± 0.2	0.26	0.10 ± 0.16 <i>trivial</i>
Countermovement jump power change (W)	-57 ± 61	0.13	-0.12 ± 0.13 <i>trivial</i>
SCT power change (W)	6.8 ± 53	0.83	0.04 ± 0.31 <i>unclear</i>

Table 2: The raw change (mean \pm SD) in measures pre to post BEST (test 1 – test 2) for the two conditions. CON = control, COMP = compression. BEST = basketball exercise simulation test. SCT = Magaria-Kalamen stair climb test.

Measure	Condition	Mean \pm SD	Effect size (<i>d</i>) \pm 90% confidence interval
Countermovement jump height 1 (cm)	CON	52 \pm 1	0.02 \pm 0.07
	COMP	52 \pm 1	<i>trivial</i>
Countermovement jump power 1 (W)	CON	4152 \pm 446	-0.02 \pm 0.65
	COMP	4144 \pm 464	<i>unclear</i>
SCT power 1 (W)	CON	1326 \pm 158	0.21 \pm 0.14
	COMP	1378 \pm 183	<i>small</i>
Countermovement jump height 2 (cm)	CON	50 \pm 1	0.11 \pm 0.12
	COMP	51 \pm 1	<i>trivial</i>
Countermovement jump power 2 (W)	CON	4153 \pm 448	-0.14 \pm 0.68
	COMP	4089 \pm 479	<i>unclear</i>
SCT power 2 (W)	CON	1303 \pm 167	0.34 \pm 0.19
	COMP	1362 \pm 165	<i>small</i>

Although purely speculative, the mechanisms responsible for improvements in these previous studies, along with the repeated-sprint performance in the current study are likely due to a number of factors. As suggested by Higgins et al. (2009), the compression garments may facilitate the role of the circulatory system during low to moderate activity, reducing energy expenditure and therefore assisting in the conservation of high energy phosphates for the short anaerobic bursts required in the power activities during the exercise circuits (e.g., sprinting). MacRae et al. (2011) also suggested that the influence of compression becomes more apparent as physical fatigue develops. Lastly, the psychological or psychophysical effect of wearing compression should also be considered. While RPE following the exercise circuit in the current study was not significantly different between trials, previous research has shown that perceived benefits of wearing compression are common during short, powerful tasks such as jumping and sprinting (MacRae et al., 2011).

In addition to no differences in RPE between trials, the current study failed to find significant interactions between interventions across pre to post BEST trials. Countermovement jump performance (height and power) was not significantly different between COMP and CON trials ($p > 0.05$, unclear or trivial effects), and the pre to post change in performance for both trials was less than the smallest worthwhile change or CV of the test ($\sim 5\%$). This result is actually similar to the earlier work of Kraemer et al. (1996) who, despite finding significant improvements in mean power during repeated-jump performance (10 countermovement jumps on a force-plate), did not find any benefit of compression in the best single-jump performance. As mentioned previously, the authors would speculate that the possible benefits of improved proprioception and reduced oscillation with compression garments may have had more benefit to repeated high-intensity movements (e.g., stair-climb and sprint) than to one-off performance.

Interestingly, the compression levels were lower in the current study (~ 14 mmHg at the calf) than many of the previous studies on compression garments (Beliard et al., 2015). While the optimal pressure of compression garments is yet to be determined, Liu and colleagues (2008) suggested that a pressure >18 mmHg was required to instigate positive responses in haemodynamics. Conversely, Hill and colleagues (Hill et al., 2017) suggested that >14 mmHg was more effective than <14 mmHg for strength and power measures, while a meta-analysis of 23 studies by Beliard et al. (2015) suggested that there is no relationship between the effects of compression and the pressures applied.

There are a number of limitations that need to be acknowledged in the current study. The lack of a placebo trial meant that psychological factors could not be discounted for the positive effects associated with the compression garment intervention. Previous research has shown that belief in the benefit of compression garments may positively influence results (Brophy-Williams et al., 2017). However, we would also suggest that it is difficult to design a placebo garment in compression studies and any attempt to do so can be disingenuous. Accounting for their beliefs on the effectiveness of compression garments prior to participating in the study would have been beneficial and should be considered in future research. Furthermore, it would have been advantageous to use a longer exercise simulation task to determine whether compression garments would help to maintain physical performance pre to post a more fatiguing exercise bout. The duration of the BEST (12 minutes, the equivalent to a quarter of a basketball match) in the current study was not likely to cause adequate levels of fatigue. The inclusion of strength and endurance measures to the battery of tests would have also helped to elucidate the effects of compression garment use during exercise.

Table 3: Measures taken during the basketball exercise simulation test (BEST) for control (CON) and compression (COMP) trials.

* significant difference between trials ($p \leq 0.05$).

Measure	Condition	Mean \pm SD	P-value	COMP – CON Effect size (d) \pm 90% confidence interval
Average 6 m sprint time (s)	CON	1.52 \pm 0.09	0.03*	-0.37 \pm 0.28 <i>small</i>
	COMP	1.48 \pm 0.07		
Sprint decrement (s)	CON	0.325 \pm 0.102	0.65	0.11 \pm 0.53 <i>unclear</i>
	COMP	0.337 \pm 0.131		
Sprint decrement (%)	CON	24 \pm 8	0.96	0.01 \pm 0.55 <i>unclear</i>
	COMP	24 \pm 10		
Circuit decrement (s)	CON	2.773 \pm 1.295	0.47	-0.17 \pm 0.50 <i>unclear</i>
	COMP	3.007 \pm 1.348		
Circuit decrement (%)	CON	15 \pm 7	0.37	0.21 \pm 0.48 <i>unclear</i>
	COMP	17 \pm 8		
RPE	CON	15 \pm 3	0.57	-0.09 \pm 0.26 <i>trivial</i>
	COMP	15 \pm 3		

Conclusion

Wearing lower-body compression garments during short, anaerobic/power activities and basketball-specific exercise were associated with small improvements during a stair climb task and in repeated-sprint times, but largely negligible benefits to performance maintenance when compared to a control condition in trained basketball athletes. Future research on the use of compression garments during longer simulated basketball exercise, utilising additional measures of strength and endurance, is warranted.

Conflict of Interest

Wing-Kai Lam is an employee of Li Ning Company Limited, which supplied the compression garments in the current study. Li Ning was not involved in decisions regarding experimental design, data collection, data analyses, and data dissemination/publication. All other authors declare no conflict of interests.

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The activity demands and physiological responses observed in professional ballet: A systematic review

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ABSTRACT

The aim of this study was to systematically review research into the activity demands and physiological responses observed in professional ballet. PubMed, Web of Science, SPORTDiscus, and ProQuest were searched for original research relating to 1) the session-specific activity demands of professional ballet, 2) the general activity demands of professional ballet, 3) the immediate physiological responses to professional ballet, or 4) the delayed physiological responses to professional ballet. From an initial 7672 studies, 22 met the inclusion criteria. Methodological quality was assessed using the Mixed Methods Appraisal Tool and a modified Downs and Black Index. Professional ballet is intermittent; however, activity characteristics and intensity vary by session type and company rank. Performances involve high volumes of jumps (5.0 ± 4.9 jumps \cdot min $^{-1}$), pliés (11.7 ± 8.4 pliés \cdot min $^{-1}$), and lifts (men - 1.9 ± 3.3 lifts \cdot min $^{-1}$), which may result in near-maximal metabolic responses. Ballet classes are less metabolically intense than performance during both barre and centre ($< 50\%$ $\dot{V}O_{2max}$). Neither the activity demands nor the physiological responses encountered during rehearsals have been investigated. Day-to-day activity demands are characterized by high volumes of rehearsal and performance (> 5 h \cdot day $^{-1}$), but half is spent at intensities below 3 METs. Evidence is mixed regarding the delayed physiological responses to professional ballet; however, metabolic and musculoskeletal adaptations are unlikely to occur from ballet alone. The mean Downs and Black score was 62%. Appraisal tools revealed that a lack of clarity regarding sampling procedures, no power calculation, and a poor quality of statistical analysis were common limitations of the included studies. Given the large working durations and high rates of jumps, pliés, and lifts, managing training loads and recovery may be a focus for strategies seeking to optimize dancer health and wellbeing. Ballet companies should provide dancers with opportunities and resources to engage in supplementary physical training. Further research is required into the physical demands of rehearsals and the longitudinal training loads undertaken by professional ballet dancers.

1. Introduction

Ballet is a performance art in which dancers express an idea or narrative through movement of the human body. A ballet dancer's movement is founded in classical technique, characterized by

vertical alignment of the body, minimal displacement of the pelvis from a central position, external rotation of the lower limbs (i.e., turnout), and extension through joints of the lower body (Ward, 2012). Whilst historically ballet dancers may have been perceived solely as performing artists, increasingly ballet professionals are

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considered artistic athletes (Koutedakis & Jamurtas, 2004), facing comparable physical demands to elite sportspeople. Ballet has been compared to aesthetic sports such as gymnastics (Twitchett et al., 2009b), with which it shares classically based movement sequences and extreme ranges of motion. The activity profile of ballet performance, however, appears to be similar to sports such as tennis (Fernandez et al., 2006) or basketball (Conte et al., 2015); ballet is intermittent, involving bouts of high intensity movement, as well as lower intensity periods during which dancers may be acting or off-stage (Cohen et al., 1982a).

Injury incidence in professional ballet (4.4 time-loss injuries per 1000 h; Allen et al., 2012) is comparable to that observed in sports such as cricket match-play (1.9–3.9 injuries per 1000 h; Orchard et al., 2002) and association football training (4.1 injuries per 1000 h; Hawkins & Fuller, 1999). As a result, there have been calls for ballet companies to adopt more robust approaches to science and medical provision (Allen & Wyon, 2008). The periodization of workload (Wyon, 2010), implementation of screening protocols (Armstrong & Relph, 2018), increased strength and conditioning provision (Twitchett et al., 2009b), and introduction of specialized healthcare services (Russell, 2013) have been proposed as potential methods of mitigating injury risk. The development of science and medicine provision in professional ballet, however, requires a thorough understanding of the physical demands of the activity. A systematic review is therefore needed to synthesize research into the physical demands of professional ballet, making the evidence accessible to those working in the field, and providing guidance for future research.

The purpose of this systematic review was therefore to identify, evaluate, and summarize research on the activity demands and physiological responses observed during professional ballet, and provide recommendations to direct future investigations.

2. Methods

2.1. Design and Search Strategy

The systematic review was conducted in accordance with the Preferred Reporting Items of Systematic Reviews and Meta-analyses statement (Moher et al., 2009). A systematic search of the electronic databases SPORTDiscus, Web of Science, ProQuest, and PubMed (MEDLINE) was performed for scientific literature published prior to January 2021. The following Boolean phrase was used to search each database: (Ballet* OR Ballerina* OR dancer OR dancing) AND (demand* OR response OR responses OR intensity OR volume OR load OR physical OR cardiovascular OR metabolic OR workload OR physiologic* OR schedule OR jump* OR lift* OR pointe OR flexib* OR mobility OR strength OR power OR muscul* OR endurance) NOT Title (collegiate OR elderly OR older OR obesity OR cancer OR disease OR “cerebral palsy” OR education). Results from Web of Science and ProQuest were further filtered to include relevant subject areas only; a full list of excluded subject areas can be found in Supplemental Content 1. Hand-searches of each included study’s reference list and the reference lists of review papers pertinent to the topic were completed to identify further relevant

articles. Activity demands were further divided into two subsections: (1) Session-specific activity demands - the activity taking place within a specific session (e.g., the number of jumps completed in a ballet class); or (2) General activity demands - activity characteristics not limited to a single session (e.g., the number of jumps completed during a week). Physiological responses were divided into two subsections: (1) Immediate physiological responses – those recorded on the same day as the activity; and (2) Delayed physiological responses – those recorded on a different day to the activity. To be included, delayed physiological responses must have reported a physiological measurement both pre- and post-ballet activity; studies which measured a physiological characteristic at a single time point were not included. All relevant study designs were included in the review. Studies were excluded if (1) data were reported on a mixed group of dancers (e.g., ballet and contemporary dancers, professional and non-professional ballet dancers), and data for a professional ballet subgroup could not be extracted, (2) no methodology was provided for variables of interest, (3) data were only reported on injured dancers, or (4) only contractual hours were used as a measure of dance exposure. Data pertaining to hormonal responses related to professional ballet were not included in this review.

2.2. Study Screening

Searches and screening processes were independently conducted by two reviewers. Following the completion of searches, duplicate results were automatically removed, and the remaining articles were screened. Four reviewers met, and discrepancies in included articles were resolved by consensus.

2.3. Data Extraction and Analysis

Data were extracted from each study by the lead reviewer. For each study, publication details (author, year, journal) and demographic data (age, height, weight, sex, ballet company, company rank) were extracted. Methodological details (sample size, participant characteristics, session type, study duration, phase of season, equipment, protocol, measurements), and results (descriptive data regarding activity demands and/or physiological responses, results of statistical analyses) were recorded. Data displayed in figures were extracted using WebPlotDigitizer v.4.3 (Rohatgi, 2020). Where further details were required, authors of the study were contacted for clarification. Given the heterogeneity in subject areas and variables reported, a meta-analysis was not conducted.

2.4. Assessment of Methodological Quality

Due to the heterogeneity of study designs used, included studies were evaluated using the Mixed Methods Appraisal Tool (version 2018; MMAT; Hong et al., 2018). A modified version of the Downs and Black checklist for the assessment of methodological quality (Downs & Black, 1998) was used to identify more specific strengths and weaknesses of included studies. For each of the

criteria, a single point was available (yes – 1, no – 0, unable to determine – 0), except question five, for which two points were available. Question 27 was adjusted to read: “Was a power analysis conducted, and if so, did the sample size provide sufficient statistical power to detect an effect?”. Downs and Black scores were interpreted using the following thresholds: ≤ 50% - Poor, 50–70% - Fair, 70–90% - Good, > 90% - Excellent (Hooper et al., 2008). Risk of bias was assessed at a study level. No articles were excluded based on their methodological quality.

3. Results

3.1. Search Results

The hand-search and search of electronic databases yielded an initial 7672 results of which 1258 were duplicates. Following title and abstract review, 6293 articles were excluded. Full texts of the remaining 121 articles were screened, of which 99 did not meet the inclusion criteria. Twenty-two studies were therefore included in the review. A comprehensive search and selection flow diagram is presented in Figure 1.

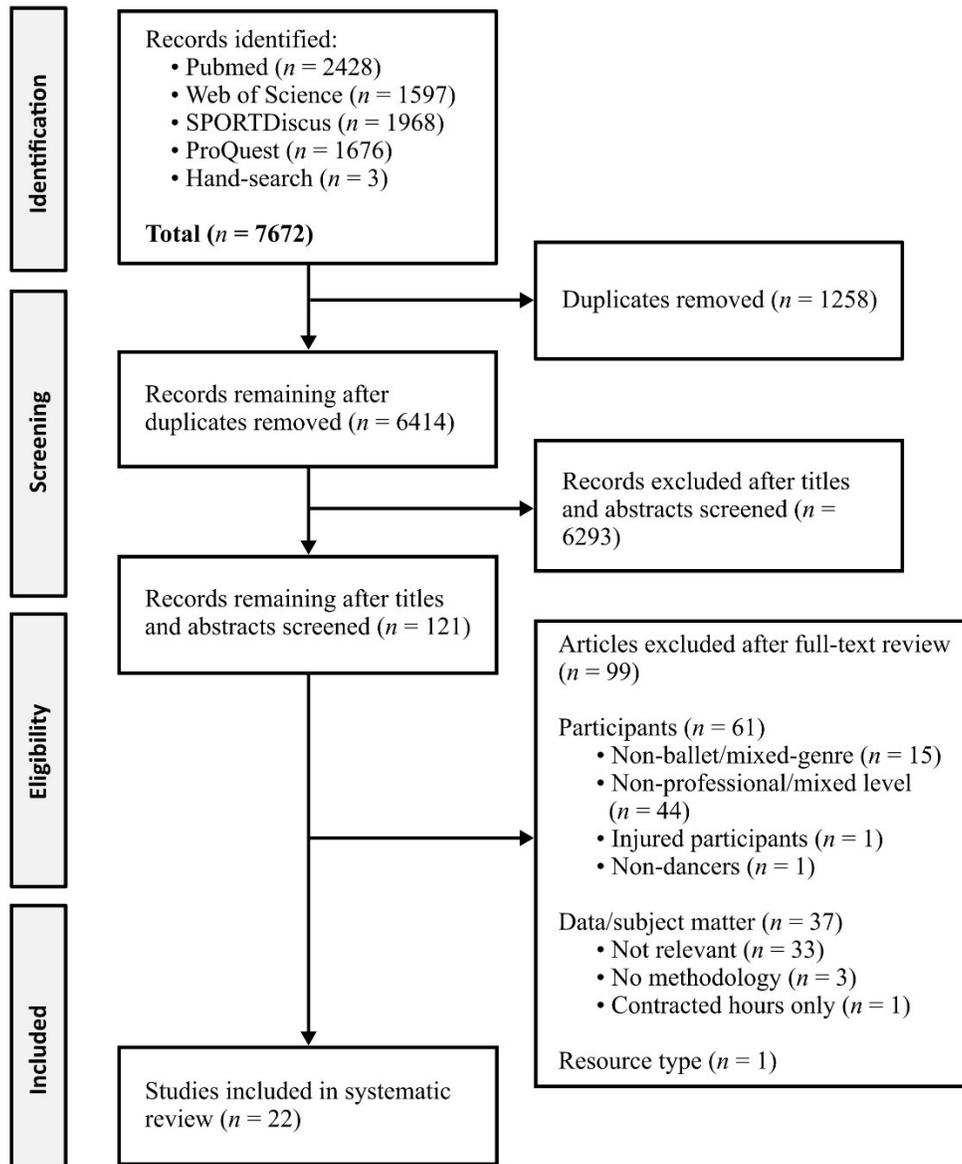


Figure 1: Flow diagram of the systematic search process.

3.2. Study Characteristics

Detailed characteristics of each included study can be found in Supplemental Content 2. Five studies investigated session-specific activity characteristics of professional ballet (class: $n = 2$; Cohen et al., 1982b; Schantz & Åstrand, 1984 performance: $n = 3$; Cohen et al., 1982a; Twitchett et al., 2009a; Wyon et al., 2011), ten studies investigated the general activity characteristics involved in professional ballet (Allen et al., 2012, 2013; Cohen et al., 1980; Costa et al., 2016; Doyle-Lucas et al., 2010; Kim et al., 2019; Kozai et al., 2020; Twitchett et al., 2010; Wyon et al., 2006, 2007), four studies investigated the immediate physiological responses to professional ballet (class: $n = 2$; Cohen et al., 1982b; Schantz & Åstrand, 1984; rehearsal: $n = 1$; Schantz & Åstrand, 1984; performance: $n = 3$; Cohen et al., 1982a; Schantz & Åstrand, 1984; Seliger et al., 1970), eight studies investigated the delayed physiological responses to professional ballet (Kim et al., 2019; Kirkendall et al., 1984; Koutedakis et al., 1999; Koutedakis & Sharp, 2004; Micheli et al., 2005; Ramel et al., 1997; Wyon et al., 2006, 2014). Five studies used entirely female cohorts, and 17 studies used mixed cohorts.

3.3. Quality Assessment

The mean Downs and Black score was 62%. Five studies were classified as poor Cohen et al., 1982a; Cohen et al., 1982b; Schantz & Åstrand, 1984; Seliger et al., 1970; Twitchett et al., 2009a). twelve studies were classified as fair (Cohen et al., 1980; Costa et al., 2016; Doyle-Lucas et al., 2010; Kim et al., 2019; Kirkendall et al., 1984; Koutedakis et al., 1999; Koutedakis & Sharp, 2004; Micheli et al., 2005; Ramel et al., 1997; Twitchett et al., 2010; Wyon et al., 2011, 2014), five studies were classified as good (Allen et al., 2012, 2013; Kozai et al., 2020; Wyon et al., 2006, 2007), and no studies were classified as excellent. Full results of the MMAT and the modified Downs and Black assessments can be found in Table 1 and Supplemental Content 3, respectively. All studies presented a clear research question, and collected data allowing them to address the question. Articles were most commonly marked down due to a failure to sufficiently explain sampling procedures.

3.4. Session-Specific Activity Demands

3.4.1 Class

Two studies investigated the activity characteristics of ballet class (Cohen et al., 1982b; Schantz & Åstrand, 1984). Schantz and Åstrand (1984) report class durations of 60 min (30 min effective exercise time), made up of seven barre exercises (28 min, 10 s rest intervals), and five centre-floor exercises (32 min, 2-3 min rest intervals). Cohen et al. (1982b) report class durations of 75 minutes; movement sequences during barre, centre-floor, and *allegro* phases were 65 s, 35 s, and 15 s, and rest periods were 30 s, 85 s, and 75 s, respectively.

3.4.2 Rehearsal

No studies reported data on the activity characteristics of rehearsals.

3.4.3 Performance

Three studies investigated the activity characteristics of ballet performance (Cohen et al., 1982a; Twitchett et al., 2009a; Wyon et al., 2011). During 5 roles from *Swan Lake*, *Giselle*, and *Études*, the acts/sections observed varied in duration from 14–43 min, with actual dance times ranging from 2–12.5 min (14–30% of performance; Cohen et al., 1982a). During successive variations, work-to-rest ratios of between 1:1.6 and 1:3.4 were observed (Cohen et al., 1982a). Across 48 classical roles (Twitchett et al., 2009a; Wyon et al., 2011), over half of the performance time was found to be spent at resting intensities (i.e., still or off-stage), and around a quarter at moderate or hard intensities. Male and female dancers performed jumps (5.0 ± 4.9 jumps \cdot min $^{-1}$) and *pliés* (11.7 ± 8.4 *pliés* \cdot min $^{-1}$) at similar rates, though males were involved in lifting their partners (1.9 ± 3.3 lifts \cdot min $^{-1}$), whilst females were not (Twitchett et al., 2009a; Wyon et al., 2011).

3.5. General Activity Characteristics

Ten studies reported data on the general activity demands undertaken by professional ballet dancers (Allen et al., 2012, 2013; Cohen et al., 1980; Costa et al., 2016; Doyle-Lucas et al., 2010; Kim et al., 2019; Kozai et al., 2020; Twitchett et al., 2010; Wyon et al., 2006, 2007); activity demands were the primary outcome of only 2 of these studies (Kozai et al., 2020; Twitchett et al., 2010). The results of studies reporting durations of physical activity, dance exposure, and supplementary training are presented in Figure 2.

Two studies investigated rest periods throughout the working day, reporting mean greatest rest breaks of 36 ± 31 min (Twitchett et al., 2010) and 35 ± 27 min (Kozai et al., 2020). One study describes daily self-reported energy expenditure of female dancers, which in two separate 7-day periods, was $3,571 \pm 466$ kcal and $3,154 \pm 466$ kcal (Kim et al., 2019). Two studies of the same company reported data relating to workload beyond the demands of a single week (Allen et al., 2012, 2013). The company performed between 142 and 145 shows per year, spanning between 15 and 20 productions per year (Allen et al., 2013). The first of those seasons was 46 weeks long, consisting of 26 rehearsal weeks and 20 performance weeks (Allen et al., 2012). Performance periods were 2–6 weeks in length, during which the company averaged 7 performances per week. The summer break was 5 weeks, and there was a 1-week break at mid-season.

3.6. Immediate Physiological Responses to Professional Ballet

3.6.1 Ballet Class

Two studies investigated the acute physiological responses to ballet class (Cohen et al., 1982b; Schantz & Åstrand, 1984).

Table 1: Results of the Mixed Methods Appraisal Tool assessment of methodological quality.

Study	Screening ^A		Criteria ^B				
	A	B	1	2	3	4	5
Quantitative descriptive							
Wyon et al. (2011)	Y	Y	?	?	Y	N	Y
Twitchett et al. (2009a)	Y	Y	?	?	Y	N	Y
Schantz & Åstrand (1984)	Y	Y	?	?	Y	Y	N
Cohen et al. (1982b)	Y	Y	?	?	Y	N	Y
Cohen et al. (1982a)	Y	Y	?	?	Y	N	?
Seliger et al. (1970)	Y	Y	?	?	Y	N	N
Costa et al. (2016)	Y	Y	Y	?	N	Y	Y
Twitchett et al. (2010)	Y	Y	?	?	Y	N	Y
Kozai et al. (2020)	Y	Y	Y	Y	Y	N	N
Allen et al. (2012)	Y	Y	Y	Y	Y	N	Y
Wyon et al. (2006)	Y	Y	?	?	Y	N	Y
Wyon et al. (2007)	Y	Y	Y	Y	Y	N	Y
Cohen et al. (1980)	Y	Y	?	?	Y	N	Y
Doyle-Lucas et al. (2010)	Y	Y	?	?	Y	N	N
Non-randomized							
Allen et al. (2013)	Y	Y	Y	N	Y	N	Y
Kim et al. (2019)	Y	Y	?	Y	Y	N	Y
Wyon et al. (2014)	Y	Y	?	Y	Y	N	Y
Koutedakis et al. (1999)	Y	Y	?	Y	N	Y	Y
Kirkendall et al. (1984)	Y	Y	?	Y	Y	N	Y
Micheli et al. (2005)	Y	Y	Y	Y	Y	Y	Y
Randomized controlled trials							
Ramel et al. (1997)	Y	Y	Y	?	Y	N	Y
Koutedakis & Sharp (2004)	Y	Y	Y	Y	?	N	?

Note: Y – Yes; N – No; ? – Unable to determine.

^A **Screening questions:** A) Are there clear research questions?; B) Do the data address the research questions?

^B **Quantitative descriptive criteria:** 1) Was the sampling strategy relevant?; 2) Is the sample representative of the target population?; 3) Were measurements appropriate?; 4) Is the risk of nonresponse bias low?; 5) Is the statistical analysis appropriate?

Non-randomized criteria: 1) Are participants representative of the target population?; 2) Are measurements appropriate regarding both the outcome and intervention (or exposure)?; 3) Are there complete outcome data?; 4) Are confounders accounted for in the design and analysis?; 5) Is the intervention administered (or exposure occurred) as intended?

Randomized controlled trial criteria: 1) Is randomization appropriately performed?; 2) Are groups comparable at baseline?; 3) Are there complete outcome data?; 4) Are outcome assessors blinded?; 5) Did participants adhere to the intervention?

Mean heart rate (66 vs 76% maximum; Cohen et al., 1982b), oxygen uptake ($\dot{V}O_2$; 38 vs 49% $\dot{V}O_{2max}$ - Cohen et al., 1982b; 36% vs. 45% $\dot{V}O_{2max}$ - Schantz & Åstrand, 1984), and energy expenditure (4.7 vs. 6.3 kcal·min⁻¹, Cohen et al., 1982b) were greater during centre-floor exercises than barre exercises. Little change in blood lactate concentration ([BLa]) was seen between barre, centre-floor, and *allegro* phases of class (2.8 vs. 2.8 vs. 3.1 mmol·L⁻¹, respectively, Schantz & Åstrand, 1984).

3.6.2 Rehearsal

Schantz and Åstrand (1984) investigated the acute physiological responses to (non-performance) choreographed variations or *pas de deux*. Mean $\dot{V}O_2$ was $80 \pm 7\%$ of $\dot{V}O_{2max}$ (69-92% of $\dot{V}O_{2max}$), whilst mean post-activity [BLa] was 9.9 ± 3.1 mmol·L⁻¹ (6.2-15.2 mmol·L⁻¹).

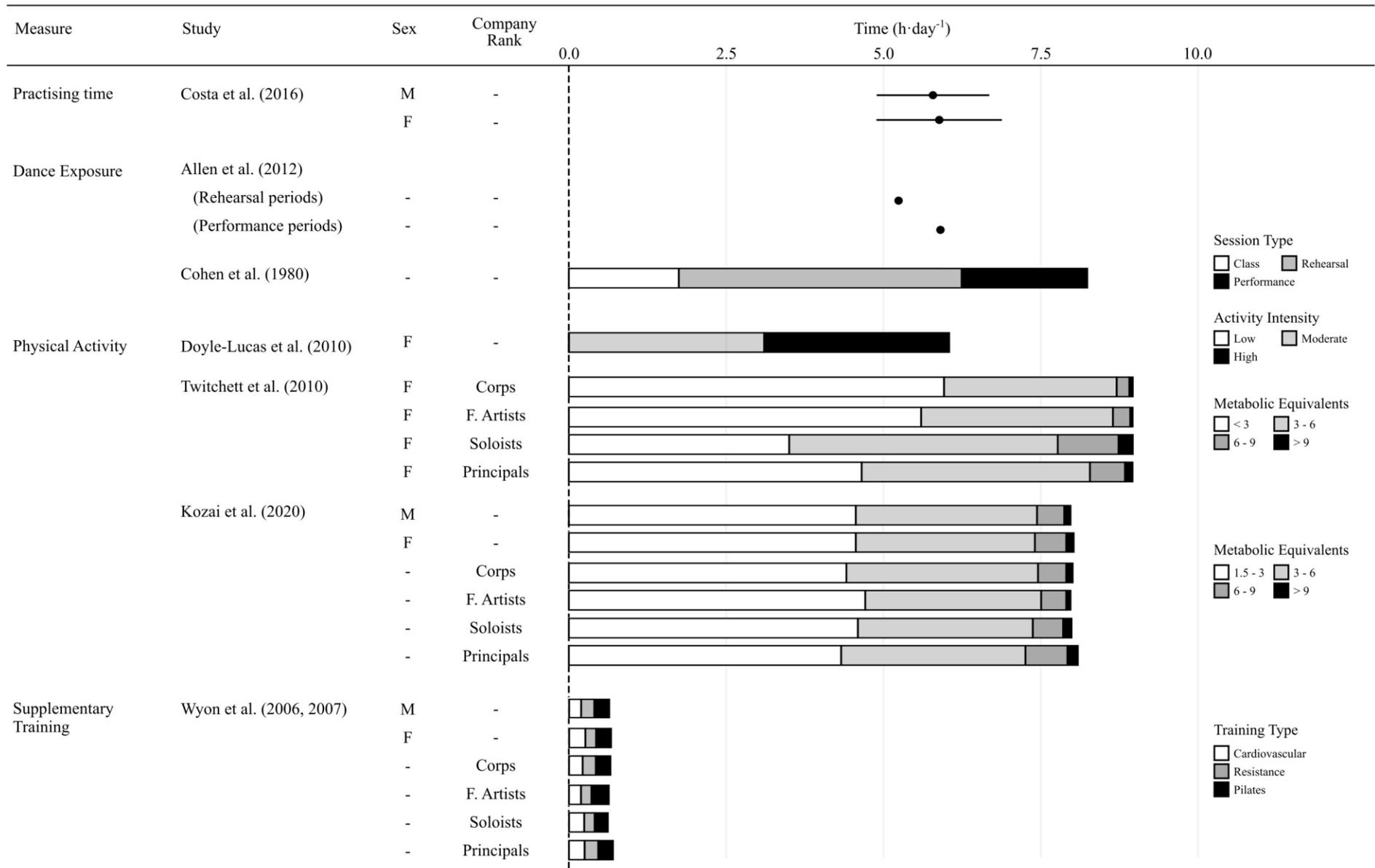


Figure 2: Overviews of studies reporting durations of physical activity, class, rehearsal, performance, or training undertaken by professional ballet dancers. Exposure reported in hours per week is converted to daily exposure assuming a 6-day week. F. Artists – First Artists; M – Male; F – Female.

3.6.3 Performance

Three studies investigated the physiological responses to professional ballet performances (Cohen et al., 1982a; Schantz & Åstrand, 1984; Seliger et al., 1970). Mean heart rates during performance were 134 (Seliger et al., 1970) and 169 bpm (87% maximum, Cohen et al., 1982a) and mean peak heart rates were 177 (Seliger et al., 1970) and 184 beats·min⁻¹ (94% maximum, Cohen et al., 1982a). One study (Schantz & Åstrand, 1984) simply states that heart rates during performance were frequently close to maximum, peak [BLa] were similar to those observed following maximal cycling (~11 mmol·L⁻¹), and mean post-performance $\dot{V}O_2$ for two dancers was 85% of $\dot{V}O_{2max}$. One research group (Seliger et al., 1970) reported an increase in both systolic (131 to 172 mmHg) and diastolic (73 to 96 mmHg) blood pressure from pre- to post-performance.

3.7. Delayed Physiological Responses to Professional Ballet

Delayed physiological responses to professional ballet have been reported in 7 studies (Kim et al., 2019; Kirkendall et al., 1984; Koutedakis et al., 1999; Koutedakis & Sharp, 2004; Micheli et al., 2005; Ramel et al., 1997; Wyon et al., 2014), the results of these studies are presented in Table 2. In 4 studies (Kim et al., 2019; Kirkendall et al., 1984; Koutedakis et al., 1999; Micheli et al., 2005), the primary aim was to investigate a response to ballet, whilst in 3 studies (Koutedakis & Sharp, 2004; Ramel et al., 1997; Wyon et al., 2014), the primary aim was to investigate the effect of an intervention (Wyon et al., 2014 - vitamin D supplementation; Koutedakis & Sharp, 2004 - strength training; Ramel et al., 1997 - cardiovascular training), and consequently data for this review were taken from control groups.

4. Discussion

This is the first systematic review to synthesize research exploring the activity demands and physiological responses observed in professional ballet. A total of 22 articles were identified, spanning the subcategories of immediate and delayed physiological responses, and session-specific and general activity demands. We aimed to provide a summary to inform current practice in professional ballet companies, as well as identify gaps in the current body of literature, providing direction to researchers working within this field.

4.1. Session-Specific Physical Demands of Professional Ballet

Ballet is an intermittent activity, though the intensity of that activity varies by session-type. High intensity activity takes place during the latter phases of ballet class (Cohen et al., 1982b), however, the short duration of these bouts, and large inter-exercise rest periods limit the metabolic intensity of the session (Cohen et al., 1982b; Schantz & Åstrand, 1984). Ballet performance is of a greater metabolic intensity; bouts of dancing are longer in duration (Cohen et al., 1982a) and are higher in both average and peak intensity (Cohen et al., 1982a; Schantz & Åstrand, 1984; Seliger et al., 1970). However, studies investigating ballet performance have not randomly sampled

productions or roles, and one research group (Schantz & Åstrand, 1984) explicitly states that only moderately strenuous to very strenuous roles were analysed. It therefore appears that current research on the immediate physiological responses to ballet performance is representative of more physically demanding roles. In contrast, video analyses of 48 roles across classical repertoire (Twitchett et al., 2009a; Wyon et al., 2011) suggest that most of a performance is spent at rest, particularly in the case of non-principal dancers. Only two studies reported the physical demands of specific performance roles (Cohen et al., 1982a; Schantz & Åstrand, 1984); greater granularity in this regard may benefit science and medicine staff when preparing dancers for a specific role.

During performance (Twitchett et al., 2009a; Wyon et al., 2011), dancers jump at a greater rate than that observed during volleyball (Maciel Rabello et al., 2019) or basketball match-play (Scanlan et al., 2015). Whilst average values (5.0 ± 4.9 jumps·min⁻¹) alone are high (Wyon et al., 2011), it is evident from the standard deviation that there is large variation between roles. Recent research in sport has emphasized the importance of preparing athletes for the worst-case-scenarios they may encounter; neither study (Twitchett et al., 2009a; Wyon et al., 2011), however, reports the maximum rate of jumping observed. The most physically demanding segments are likely to exceed the values reported (Wyon et al., 2011). A recent editorial highlighted jump load as an important injury analytic (Moran et al., 2019). To this end, almost a quarter of injuries in one professional ballet company have been attributed to jumping movements (Allen et al., 2012). The volume and biomechanics of jumping in professional ballet may therefore be important directions for future research, and are potential targets of injury prevention interventions.

No studies were identified investigating the activity demands taking place in rehearsals, and only one study (Schantz & Åstrand, 1984) reported data on the immediate physiological responses to rehearsals. Although near-maximal intensity responses were observed, the ‘rehearsals’ were sessions in which dancers completed solo variations or *pas de deux* from classical repertoire, and not rehearsals as they might occur *in situ*. Subsequently, these responses may not be directly comparable to rehearsals, during which dancers may be learning choreography, practicing shorter segments, or stopping frequently to receive technical guidance. The physical demands of rehearsals therefore remain almost entirely unexplored within scientific literature, and no definitive conclusions can be made. This is particularly notable for two reasons; firstly, unlike classes—which follow a consistent structure, and performances—which are strictly choreographed, rehearsals are inherently more variable from day-to-day; secondly, rehearsal makes up most of a dancer’s activity (Cohen et al., 1980). Further research is therefore required to elucidate the demands of ballet rehearsals, enabling science and medicine practitioners to better prepare dancers for their day-to-day demands, and understand the training loads they undertake.

4.2. General Activity Demands of Professional Ballet

Overtraining syndrome and overuse injuries are common in professional ballet dancers—to this end, ballet dancers have suggested the imbalance between load and load-capacity is the

Table 2: Overviews of studies reporting data on the delayed physiological responses to professional ballet.

Measure	Study	Methods	Timepoints	Results
Body composition	Koutedakis & Sharp (2004)	Body mass; skinfold thickness (4 sites); thigh circumference.	(1) Mid-January. (2) + 12 weeks.	No significant differences.
	Kirkendall et al. (1984)	Hydrostatic weighing.	(1) Pre-season (August). (2) December	No significant differences.
	Micheli et al. (2005)	Body mass; skinfold thickness (7 sites).	(1) Preseason (August). (2) Postseason (May)	In females, body mass (51.6 ± 4.6 kg to 50.4 ± 4.5 kg, $p < .001$) and BF% ($12.8 \pm 2.7\%$ to $11.5 \pm 2.1\%$, $p < .001$) decreased. No significant differences seen in males.
	Kim et al. (2019)	Body mass; bioelectrical impedance.	(1) 7 days pre- (2) 7 days-post a 3-day performance period.	Significant increases were seen in BMI ($+ 0.12$ kg·m ² , $p = .032$), LBM ($+ 0.5$ kg, $p = .002$), and TBW ($+ 0.2$ L, $p = .021$), but not in body mass or BF%.
	Koutedakis et al. (1999)	Skinfold thickness (4 sites).	(1) Post-season. (2) Pre-season. (3) + 2-3 months	No significant differences.
Lower-body strength/power	Koutedakis & Sharp (2004)	Isokinetic knee flexion and extension.	(1) Mid-January. (2) + 12 weeks.	No significant differences.
	Kirkendall et al. (1984)	Isokinetic knee flexion and extension.	(1) August. (2) December	Significant differences in torque only observed at $180^\circ \cdot \text{sec}^{-1}$ (males + 12%, females + 16%). For males and females, respectively, relative quadriceps torque increased by 3 and 6% for the right leg, and by 9 and 7% for the left leg.
	Koutedakis et al. (1999)	Isokinetic knee flexion and extension; Peak Wingate power.	(1) Post-season. (2) Pre-season. (3) + 2-3 months	Knee extension and flexion torques, and peak Wingate power all increased following the summer break.
	Wyon et al. (2014)	Isometric knee extension; vertical jump height.	(1) January. (2) May.	No significant differences.
Aerobic Capacity	Koutedakis et al. (1999)	Maximal incremental treadmill test (gas analysis).	(1) Post-season. (2) Pre-season. (3) + 2-3 months	$\dot{V}O_{2\text{max}}$ (mL·kg·min ⁻¹) increased following the summer break (41.2 ± 8.5 to 45.2 ± 7.1), and again following preseason (48.4 ± 6.8).
	Ramel et al. (1997)	Maximal incremental cycle test (gas analysis, blood lactate concentration).	(1) Preseason. (2) +10 weeks.	No significant differences in $\dot{V}O_{2\text{max}}$, [BLa], workload at 4 mmol·L ⁻¹ , or maximum workload.
Anaerobic Capacity	Koutedakis et al. (1999)	Wingate mean power.	(1) Post-season. (2) Pre-season. (3) + 2-3 months	No significant differences.
Flexibility	Koutedakis et al. (1999)	Hamstring, trunk, and shoulder flexibility.	(1) Post-season. (2) Pre-season. (3) + 2-3 months	Hamstring, trunk, and shoulder flexibility all increased following the summer break.

Note: $\dot{V}O_{2\text{max}}$ – Maximum rate of oxygen consumption; [BLa] – Blood lactate concentration; TBW – Total body water; BF% - Body fat percentage.

underlying cause (Bolling et al., 2021). Durations of dance exposure reported in included studies vary, though most studies support the notion that dancers complete over 5 h of dance activity per day (Allen et al., 2012, 2013; Cohen et al., 1980; Costa et al., 2016; Doyle-Lucas et al., 2010; Kozai et al., 2020; Twitchett et al., 2010). To our knowledge, no published research exists demonstrating comparable training and performance exposure times in any other athletic population (Brooks et al., 2008; Dellavalle & Haas, 2013; Maciel Rabello et al., 2019). However, whilst scheduled dance time and self-reported activity is high (Allen et al., 2012; Cohen et al., 1980; Costa et al., 2016), accelerometry studies (Kozai et al., 2020; Twitchett et al., 2010) suggest that much of a dancer's day may be spent at intensities below 3 METs. Additionally, these studies revealed that activity profiles vary by company rank. Future research should therefore avoid the use of company-wide exposure hours, and applied science and medicine practitioners should adopt individualized approaches to load management (Allen et al., 2012, 2013; Cohen et al., 1980; Doyle-Lucas et al., 2010).

Despite the recent influx of studies publishing data on the longitudinal workloads of athletes within sporting organizations, little research has explored longitudinal workloads in professional ballet. Although two studies (Kozai et al., 2020; Twitchett et al., 2010) conducted longitudinal activity monitoring, data are only reported pertaining to the demands of an average day. Furthermore, as data collection periods were only one (Kozai et al., 2020) and three (Twitchett et al., 2010) weeks, reported values may not account for changes in activity which may occur as the repertoire changes across the course of a season. Although the count of shows performed by a professional touring company each season (142–145 shows, 15–20 productions) has been reported on two occasions (Allen et al., 2012, 2013), it is not stated in how many of these shows in individual dancers were involved. Further research is warranted exploring the longitudinal training load demands faced by professional ballet dancers.

Longitudinal activity monitoring in professional ballet may be facilitated by the use of wearable technology. Several studies have been published exploring and/or validating the use of wearable technology in professional ballet (Almonroeder et al., 2020; Hendry, Chai, et al., 2020; Hendry, Leadbetter, et al., 2020); however, the application of these devices and algorithms is not yet evident. Ballet companies may face financial barriers to the implementation of wearable technology, however, methods such as session rating of perceived exertion (Shaw et al., 2020) may provide a cost-effective alternative. Whilst cultural barriers to the implementation of load monitoring in dance may also exist, research in other dance genres, (Jeffries et al., 2020) and at a non-professional level (Da Silva et al., 2015), suggests load monitoring may be of value.

4.3. Delayed Physiological Responses to Professional Ballet

It has previously been suggested that participation in ballet alone is insufficient to elicit meaningful physiological adaptation (Koutedakis & Sharp, 2004; Wyon et al., 2007); included studies reported mixed results in this regard. Increases in lower limb strength (Kirkendall et al., 1984; Koutedakis et al., 1999) and aerobic capacity (Koutedakis et al., 1999) have been

demonstrated following a ballet pre-season, though the validity of the changes in one study (Koutedakis et al., 1999) are hard to determine, as only a subset of the participants were investigated following the pre-season. Furthermore, in both studies the initial performance level was indicative of an untrained population and increases in performance were relatively small. Several studies have observed no differences in lower-body strength (Koutedakis & Sharp, 2004; Wyon et al., 2014), lower-body power (Wyon et al., 2014), aerobic capacity (Ramel et al., 1997), or anaerobic capacity (Koutedakis et al., 1999) following a professional ballet schedule. The identified studies therefore concur with several cross-sectional studies of professional ballet dancers, reporting aerobic capacities comparable to non-endurance trained athletes (Cohen et al., 1982b; Wyon et al., 2007), and lower-limb strength values below those of other athletic populations (Kirkendall et al., 1984). It therefore seems likely that supplementary physical training is needed to elicit significant physiological adaptation.

An improvement in physical performance following the end of a ballet season has been demonstrated by one group of researchers (Koutedakis et al., 1999), wherein lower-body strength, lower-body power, flexibility, and aerobic capacity all improved following a six-week summer break. Detraining effects might typically be expected following the cessation of the season (Kovacs et al., 2007). Instead, an improvement in physical performance may be indicative of recovery from non-functional overreaching, or overtraining syndrome (Koutedakis et al., 1990), which may be related to the high volumes of physical work completed in ballet companies (Cohen et al., 1980). Future research involving concurrent measurements of workload and physical performance across the course of a season may be helpful in further elucidating this relationship.

Investigations into changes in body composition in response to professional ballet reported mixed results. Three studies observed no changes in body composition (Kirkendall et al., 1984; Koutedakis et al., 1999; Koutedakis & Sharp, 2004), one saw small increases in lean body mass over a 17-day period (Kim et al., 2019), and another saw decreases in body mass and body fat percentage over the course of a season (Micheli et al., 2005). There was, however, some evidence suggesting female dancers were not adequately meeting their nutritional requirements (Kim et al., 2019; Micheli et al., 2005), consistent with previous cross-sectional research in this population (Frusztajer et al., 1990). Two included studies also identified the limited opportunity dancers are given to refuel throughout the working day (Kozai et al., 2020; Twitchett et al., 2010). Dancers have previously been identified as an at-risk group for relative energy deficiency in sport (Mountjoy et al., 2014). Given the potential consequences for multiple physiological systems, and for both health and performance (Mountjoy et al., 2014), ballet companies should ensure they are facilitating screening and monitoring processes and promoting good day-to-day nutritional practices or guidelines.

4.4. Methodological Quality

Only five of the 22 studies were classified as good, and no studies were classified as excellent following the Downs and Black assessment. Similarly, only one study (Micheli et al., 2005) received a 'yes' across all of the five criteria outlined in the

MMAT. The most common reason that studies were marked down was the lack of description of the method used to sample participants. Most studies appear to have used a convenience sample of dancers from a single ballet company. When generalizing results to another company, the reader should therefore consider the degree of similarity between the company on which the study was completed, and the company to which the results are being extrapolated. Ballet companies are likely to differ widely in factors such as their size, repertoire, and touring schedule, all of which may influence the physical demands faced by dancers. For studies which investigated the demands of performance roles (Cohen et al., 1982a; Twitchett et al., 2009a; Wyon et al., 2011), it is difficult to ascertain the extent to which the measured roles are representative of all roles. The potential researcher bias stemming from a lack of random sampling should also be considered, as researchers may have consciously or unconsciously chosen to analyze more physically demanding roles.

The quality of analysis across the included studies was inconsistent. Only two (Doyle-Lucas et al., 2010; Kozai et al., 2020) of the 22 included studies included a power calculation, and 8 (Cohen et al., 1982a; Cohen et al., 1982b; Doyle-Lucas et al., 2010; Kozai et al., 2020; Micheli et al., 2005; Ramel et al., 1997; Schantz & Åstrand, 1984; Seliger et al., 1970) studies used inappropriate or no statistical analyses. Fifteen studies did not include confounding factors in their analysis; this was most often a failure to account for the dancers' company ranks. Those authors who included company rank as a covariate observed significant differences across levels (Allen et al., 2012; Kozai et al., 2020; Twitchett et al., 2010; Twitchett et al., 2009a; Wyon et al., 2011).

Due to the mixed quality of included studies, the heterogeneity of subject areas, and the lack of replicated studies, few findings are supported by strong levels of evidence. Ballet staff and researchers should consider the number and quality of studies supporting an outcome when implementing findings.

4.5. Limitations

Four databases, the reference lists of included studies, and the reference lists of relevant review articles were searched to conduct a comprehensive literature search. However, it is possible that we did not identify studies from journals which are not indexed. Given the artistic nature of the field, we also acknowledge that much of the knowledge regarding the physical demands faced by professional ballet dancers is published in non-scientific literature. Furthermore, as only published research was included, this review may be limited by publication bias. We were also unable to include articles not written in English; given the popularity of ballet around the globe this may have led to the exclusion of relevant articles. Finally, whilst standardized templates were used, only one reviewer completed data extraction and critical appraisals.

4.6. Practical Applications and Further Research

The results of this review reinforce previous suggestions that professional ballet dancers should be considered athletes. Most notably, dancers complete large durations of rehearsal and JSES | <https://doi.org/10.36905/jses.2021.04.04>

performance, during which they are required to complete intermittent activity of mixed intensities, characterized by frequent jumps, *pliés* and lifts. Science and medicine practitioners working in professional ballet companies should implement strategies to alleviate the increases in injury risk that may be associated with these demands. For example, encouraging appropriate nutrition and rest following performance, managing dancer training loads, and developing physical characteristics such as strength, power, and aerobic and anaerobic capacity. Given that ballet activity alone does not appear to elicit meaningful physiological adaptations, professional ballet companies should ensure they are providing both the opportunities and resources for dancers to engage in supplementary physical training.

Several key areas of research have not yet been investigated. Research into the session-specific demands of professional ballet has failed to address rehearsals and has not adequately investigated the demands of performance. Understanding these demands more thoroughly may aid in the periodization of repertoire and rehearsals, and provide direction to the physical preparation of dancers. Despite the prominence of pointe work in the movement of female dancers, and its implication in foot and ankle injury risk (Mattiussi et al., 2021; Russell, 2015), no studies were identified investigating pointe activity during any session type. Finally, whilst several studies identified the large training loads undertaken by dancers as a key physical demand, no studies have investigated how these training loads fluctuate based on the time point in the season or the production being rehearsed or performed. Furthermore, only global measures of activity (e.g., duration, physical activity level) have been used to quantify training loads—several studies (Almonroeder et al., 2020; Hendry, Chai, et al., 2020; Hendry, Leadbetter, et al., 2020) have demonstrated the use of wearable sensors to provide more detailed insight into the musculoskeletal demands of ballet, though these have yet to be used in professional ballet research.

5. Conclusions

This study systematically reviewed research investigating the physical demands of professional ballet. Professional ballet activity is characterized by frequent jumps, *pliés*, and lifting movements, as well as high rehearsal and performance exposure time. To ensure dancers are physically prepared for these demands, ballet companies should provide opportunities and resources for supplementary physical training. Future research should focus on the physical demands of rehearsals and the longitudinal training load characteristics of professional ballet. There is a need for greater methodological rigour in this field of research, particularly regarding analysis of data and detail around sampling procedures.

Conflict of Interest

The authors declare no conflict of interests.

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Supplemental Content 1: Included and excluded subject areas in the searches of *Web of Science* and *ProQuest*.

Web of Science

Included

Sport Sciences, Nutrition Dietetics, Dance, Rehabilitation, Neurosciences, Music, Public Environmental Occupational Health, Engineering Biomedical, Medicine General Internal, Physics Applied, Hospitality Leisure Sport Tourism, Psychology, Social Sciences Biomedical, Multidisciplinary Sciences, Surgery, Theater, Biochemistry Molecular Biology, Physiology, Psychology Biological, Medicine Research Experimental, Physics Multidisciplinary, Biology, Biophysics, Endocrinology Metabolism, Health Care Sciences Services, Primary Health Care, Orthopedics.

Excluded

Communication, Psychology Social, Computer Science, Software Engineering, Cultural Studies, Computer Science Theory Methods, Literature, Criminology Penology, Area Studies, Economics, Education Scientific Disciplines, Education Educational Research, Environmental Sciences, Environmental Studies, , Geography, Evolutionary Biology, Management, Women's Studies, Astronomy Astrophysics, Psychology Experimental, Radiology Nuclear Medicine Medical Imaging, Cell Biology, Psychology Multidisciplinary, Religion, Law, Asian Studies, Business, Family Studies, Humanities Multidisciplinary, Engineering Electrical Electronic, Physics Nuclear, Anthropology, Entomology, Art, Chemistry Physical, Sociology, Computer Science Artificial Intelligence, Film Radio Television, Behavioral Sciences, Oncology, Genetics Heredity, Geriatrics Gerontology, Psychology Developmental, Computer Science Cybernetics, Social Sciences Interdisciplinary, Substance Abuse, Linguistics, Zoology, Political Science, Psychology Clinical, Computer Science Information Systems, Social Issues, Ecology, Integrative Complementary Medicine, Urban Studies, History, Obstetrics Gynecology, Biotechnology Applied Microbiology, Gerontology, Health Policy Services, Materials Science Multidisciplinary, Psychology Applied, Philosophy, Pharmacology Pharmacy, Rheumatology, Engineering Mechanical, Pediatrics, Computer Science Interdisciplinary Applications, Instruments Instrumentation, Psychiatry, Clinical Neurology, Language Linguistics, Robotics.

ProQuest

Included

Theater, Studies, Dance, Humans, Research, Dancers & Choreographers, Experiments, Hypotheses, Researchers

Excluded

Politics, Poetry, Literary Criticism, Art, Motion Pictures, Music, Books, Novels, Culture, Women, Drama, Writers, Philosophy, Musicians & Conductors, Actors, Musical Performances, Motion Picture Directors & Producers, Audience, History, Religion, Aesthetics, Essays, Feminism, Animals, Narratives, Reading, Poets, Linguistics, Writing, Creativity, African Americans, Cultural Identity, Male, Female, Literature, Audiences, Fiction, Ideology, Gender, Theory, Language, Society, Opera, Sexuality, Children, Females, Traditions, Collaboration, Films, Animal Behavior, Behavior, Ethics, Semantics, Brain, Consciousness, Composers, 20th Century, Violence, Christianity, Cognition & Reasoning, Algorithms, Adult, 19th Century, Metaphor, Motion Picture Criticism, War, Archives & Records, Modernism, Historical Text Analysis, Memory, Neurosciences, Proteins, Bees, Emotions, English, Sound, Artists, Painting, Computer Simulation, French Language, Popular Music, Self Concept, Spirituality, Postmodernism, Race, Communication, Psychology, Television, Semiotics, 18th Century, Social Networks.

Supplemental Content 2: Characteristics of included studies.

Study	Design	Participant Characteristics					Activity Demands		Phys. Responses		Common Dataset
		n	Age (y)	Height (m)	Mass (kg)	BMI (kg/m ²)	Session	General	Immediate	Delayed	
Wyon et al., (2011)	Cross-sectional	24 M	-	-	-	-	•				1
		24 F	-	-	-	-					
Twitchett et al., (2009a)	Cross-sectional	24 M	-	-	-	-	•				1
		24 F	-	-	-	-					
Schantz & Åstrand, (1984)	Cross-sectional	6 M	28 ± 6	1.80 ± 0.04	70.0 ± 4.0	-	•		•		
		7 F	25 ± 8	1.66 ± 0.55	52.0 ± 5.0	-					
Cohen et al., (1982b)	Cross-sectional	7 M	24	1.78	68.0	-	•		•		
		8 F		1.66	49.5	-					
Cohen et al., (1982a)	Cross-sectional	6 M	25 ± 3	1.76 ± 0.03	63.9 ± 1.5	-	•		•		
		7 F	24 ± 4	1.66 ± 0.03	48.9 ± 3.9	-					
Seliger et al., (1970)	Cross-sectional	3 M	31 ± 8	1.81 ± 0.06	72.3 ± 6.7	-			•		
		3 F	35 ± 12	1.64 ± 0.05	53.3 ± 4.1	-					
Costa et al., (2016)	Retrospective descriptive	22 M	34 ± 7	-	-	23.6 ± 1.1					
		31 F	34 ± 6	-	-	19.5 ± 1.1		•			
Twitchett et al., (2010)	Cross-sectional	51 F	28 ± 5	1.61 ± 0.03	46.1 ± 4.5	-			•		
Kozai et al., (2020)	Cross-sectional	25 M	26 ± 5	1.78 ± 0.04	70.7 ± 5.6	22.3 ± 1.3			•		
		23 F	27 ± 5	1.63 ± 0.04	49.5 ± 4.9	18.5 ± 1.4					
Allen et al., (2012)	Incidence study	25 M	23 ± 5	1.80 ± 0.04	71.7 ± 4.7	22.2 ± 1.4			•		
		27 F	25 ± 6	1.62 ± 0.04	49.2 ± 4.0	18.9 ± 1.6					
Allen et al., (2013)	Pre-post	27 M ^A	24 ± 4	1.79 ± 0.04	71.7 ± 5.5	-			•		
		28 F ^A	25 ± 5	1.63 ± 0.03	49.9 ± 4.6	-					
Wyon et al., (2006)	Cross-sectional	21 M	-	1.81 ± 0.04	69.5 ± 5.6	21.3 ± 1.4			•		2
		21 F	-	1.66 ± 0.03	50.9 ± 4.5	18.5 ± 1.4					
Wyon et al., (2007)	Cross-sectional	21 M	-	1.81 ± 0.04	69.5 ± 5.6	21.3 ± 1.4			•		2
		21 F	-	1.66 ± 0.03	50.9 ± 4.5	18.5 ± 1.4					
Cohen et al., (1980)	Cross-sectional	15 M	24 ± 4	1.77 ± 0.05	66.5 ± 4.8	-			•		
		15 F	23 ± 4	1.65 ± 0.04	49.6 ± 3.9	-					
Doyle-Lucas et al., (2010)	Cross-sectional	15 F	24 ± 1	-	-	18.9 ± 0.2			•		
Kim et al., (2019)	Pre-post	43 F	26 ± 3	1.64 ± 0.04	49.4 ± 4.4	18.4 ± 1.0			•		
Wyon et al., (2014)	Non-randomised controlled trial	2 M	28 ± 0	1.79 ± 0.02	66.5 ± 0.4	-				•	
		5 F	27 ± 5	1.64 ± 0.02	50.7 ± 6.5	-					
Koutedakis & Sharp, (2004)	RCT	22 F	25 ± 1	-	45.0 ± 4.5	-				•	
Koutedakis et al., (1999)	Pre-post	17 F	27 ± 1	1.60 ± 0.06	-	-				•	
Kirkendall et al., (1984)	Pre-post	14 M	25 ± 3	1.78 ± 0.06	67.2 ± 8.3	-				•	
		14 F	24 ± 4	1.67 ± 0.07	53.9 ± 6.1	-					
Micheli et al., (2005)	Pre-post	29 M	24 ± 6	-	71.6 ± 6.4	-				•	
		39 F	22 ± 4	-	51.6 ± 4.6	-					
Ramel et al., (1997)	RCT	6 M	24	-	-	-				•	
		4 F		-	-	-					

Note: ^AMean sample size across three consecutive seasons

BMI – Body mass index; M – Males; F – Females. RCT – Randomized controlled trial

Supplemental Content 3: Results of the Downs and Black assessment of methodological quality.

Study	Reporting									Ext. Validity			Bias						Confounding						Power	Score	Criteria	Percentage	Descriptor	
	1	2	3	4	5	6	7	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26					27
Costa et al., (2016)	1	1	1	1	1	1	0	-	1	1	0	1	-	-	1	-	1	-	0	1	0	-	-	0	-	0	12	19	63%	Fair
Schantz & Åstrand, (1984)	1	1	1	0	1	1	0	-	0	0	0	1	-	-	1	-	0	-	1	-	0	-	-	0	-	0	8	18	44%	Poor
Cohen et al., (1982b)	1	1	1	1	1	1	1	-	0	0	0	1	-	-	0	-	0	-	1	-	0	-	-	0	-	0	9	18	50%	Poor
Kozai et al., (2020)	1	1	1	1	2	1	1	0	1	1	1	1	-	1	-	0	-	1	-	0	-	-	1	1	1	17	20	85%	Good	
Cohen et al., (1982a)	1	1	1	1	1	0	0	-	0	0	0	1	-	-	-	-	0	-	1	-	0	-	-	0	-	0	7	17	41%	Poor
Doyle-Lucas et al., (2010)	1	1	1	1	1	1	1	-	0	0	0	1	-	-	1	-	0	-	0	-	0	-	-	0	-	1	10	18	56%	Fair
Twitchett et al., (2009a)	1	1	0	0	1	1	0	-	0	0	0	1	-	-	1	-	1	-	0	-	0	-	-	1	-	0	8	18	44%	Poor
Wyon et al., (2011)	1	1	0	0	1	1	1	-	0	0	0	1	-	-	1	-	1	-	1	-	0	-	-	1	-	0	10	18	56%	Fair
Micheli et al., (2005)	1	1	0	1	1	1	1	0	1	1	0	1	-	-	1	1	0	-	1	-	0	-	-	0	1	0	13	21	62%	Fair
Kirkendall et al., (1984)	1	1	0	1	1	1	1	0	0	0	0	1	-	-	1	1	1	-	1	-	1	-	-	0	0	0	12	21	57%	Fair
Twitchett et al., (2010)	1	1	1	1	2	1	0	-	0	0	0	1	-	-	1	-	1	-	1	-	1	-	-	1	0	0	13	19	68%	Fair
Wyon et al., (2007)	1	1	1	1	2	1	1	-	0	1	1	1	-	-	1	-	1	-	1	-	1	-	-	1	-	0	16	18	89%	Good
Allen et al., (2013)	1	1	1	0	1	1	1	-	1	1	1	1	-	-	1	1	1	0	1	-	1	-	-	0	0	0	15	21	71%	Good
Seliger et al., (1970)	1	1	1	0	1	1	1	-	0	0	0	1	-	-	-	-	0	-	1	-	0	-	-	0	-	0	8	17	47%	Poor
Allen et al., (2012)	1	1	1	1	2	1	1	0	0	1	1	1	-	-	1	1	1	-	1	-	1	-	-	1	1	0	18	21	86%	Good
Kim et al., (2019)	1	1	1	0	1	1	1	0	1	0	0	1	-	-	1	1	1	1	1	-	1	-	-	0	1	0	15	22	68%	Fair
Koutedakis et al., (1999)	1	1	0	1	1	1	1	0	0	0	0	1	-	-	1	0	1	1	1	-	1	-	-	0	0	0	12	22	55%	Fair
Ramel et al., (1997)	1	1	0	1	1	1	0	0	1	1	1	1	0	0	1	1	0	0	1	1	1	1	0	0	0	0	15	27	56%	Fair
Koutedakis & Sharp, (2004)	1	1	0	1	1	1	1	1	0	0	0	1	0	0	1	1	1	0	1	1	1	1	0	0	1	0	16	27	59%	Fair
Wyon et al., (2014)	1	1	1	1	1	1	1	1	1	1	0	1	0	0	1	1	1	0	1	1	1	0	0	0	1	0	18	27	67%	Fair
Wyon et al., (2006)	1	1	0	1	2	1	1	-	0	1	1	1	-	-	1	-	1	-	1	-	1	-	-	1	-	0	15	18	83%	Good
Cohen et al., (1980)	1	1	1	1	1	1	1	-	0	0	0	1	-	-	1	-	1	-	1	0	0	-	-	0	-	0	11	19	58%	Fair
Mean	1.0	1.0	0.6	0.7	1.2	1.0	0.7	0.2	0.3	0.4	0.3	1.0	0.0	0.0	1.0	0.9	0.6	0.5	0.9	0.8	0.5	0.7	0.0	0.3	0.5	0.1	12.7	19.4	62%	

Note: Ext. Validity – External Validity. Downs and Black criteria: 1) Clearly described hypothesis; 2) Main outcomes clearly described; 3) Participant characteristics described; 4) Interventions clearly described; 5) Distributions of principal confounders described; 6) Main findings clearly described; 7) Estimates of random variability given; 9) Characteristics of patients lost to follow-up described; 10) Actual probability values reported; 11) Subjects asked to participate were representative of the entire population; 12) Subjects who participated were representative of the entire population; 13) Facilities and equipment were representative of normal practice; 14) Subjects blinded; 15) Investigators blinded; 16) Any data dredging was made clear; 17) Analyses adjusted for follow-up lengths; 18) Statistical tests were appropriate; 19) Compliance with the intervention was reliable; 20) Main outcome measures were valid and reliable; 21) Intervention and control groups recruited from the same population; 22) Subjects were recruited over the same period of time; 23) Subjects randomized to intervention groups; 24) Randomization concealed from subjects and investigators; 25) Adequate adjustment for confounding factors; 26) Losses of patients to follow-up taken into account; 27) A power analysis was conducted, and sufficient power was achieved.

Effects of weighted arm sleeve loading on golf shot parameters

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Golf performance

ABSTRACT

Golfing performance is dependent on the distance and trajectory of an athlete's shot. The aim of this study was to determine how unilateral and bilateral loading strategies between 100-400 g placed on the forearms affected golf shot parameters related to carry distance and carry side distance. Nine experienced right-handed golfers, eight males (age: 24.5 ± 11.1 yrs; body mass: 84.8 ± 13.0 kg) and one female (age: 16.0 yrs; body mass: 73.6 kg), with an average handicap of 3.8 ± 2.6 performed golf shots with and without wearable resistance (WR) on their forearms. Unilateral loading on the lead arm resulted in increased carry distances from 1.68-1.78%, with 200 g loading significantly enhancing performance ($p = 0.04$; $ES = 0.72$). Unilateral loading of both 200 g and 400 g on the lead arm resulted in a large and very large change to carry side distance leading to a leftward ball trajectory ($p = 0.02$ and 0.01 , respectively; $ES = -2.07$ and -4.43 , respectively). No clear trends in individual performance were observed, apart from WR loading tending to cause a leftward carry side distance change back towards the target line in most of the subjects. These findings indicate that arm-loaded WR may be used to influence swing mechanics, which may assist ball carry trajectory in the desired direction, depending on a golfer's individual abilities and needs.

1. Introduction

Golf has become one of the most popular sports which is practiced by 10-20% of adult populations in many countries (Thériault & Lachance, 1998), equating to roughly 55-80 million participants worldwide (Evans & Tuttle, 2015). Golf performance is determined by a person's ability to hit the ball into the hole in as few shots as possible. In order to achieve this outcome, golfers must be able to hit the ball accurately and at high velocities (Hume et al., 2005). Given the importance of both approach shot distance and accuracy (Broadie, 2012), it is no surprise that a number of acute strategies such as stretching protocols (Fradkin et al., 2004), post-activation potentiation schemes (Read et al., 2013), and wearable resistance (WR) loading (Macadam et al., 2019) have been explored to enhance golf shot performance. Interestingly, static stretching appears to diminish shot distance and accuracy (Gergley, 2009). Therefore, dynamic strategies are recommended to acutely enhance golf performance (Moran et al., 2009). One

such strategy is the use of WR, which enables golfers to perform dynamic actions specific to the swing.

A number of research teams have found that limb-loaded WR can be used to overload sport-specific movements, such as running, sprinting, and jumping with minimal technical disruptions (Field et al., 2019; Macadam et al., 2017; Uthoff et al., 2020) and can be used as a training stimulus during normal practice sessions to enhance athletic capabilities (Bustos et al., 2020). Based on the equation for rotational inertia (i.e., inertia = mass x perpendicular distance from the axis of rotation²), it has been postulated that distal loading of the limbs (i.e., away from center of mass) provides specific rotational overload, otherwise not accomplished with traditional, linear, resistance training (Macadam et al., 2017; Macadam et al., 2018). Therefore, the addition of WR applied to the distal aspect of the arm of a golfer might contribute to increased rotational inertia, and therefore, affect shot parameters such as distance and trajectory.

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Using a cross-over design, researchers have loaded the trail side trunk and hip of well-trained golfers with loads of 1.6 kg (~2.8% body mass [BM]) attached posteriorly, to find 3.5% increases in club head speed and 7.2% increases in shot distance, relative to an unloaded condition (Macadam et al., 2019). While the effects of WR on carry distance are promising, it is important to note that the effects of WR on golf shot accuracy has yet to be investigated. Furthermore, it is currently unknown how load and placement strategies on a golfer’s arms affect shot distance and accuracy. Therefore, we examined how unilateral and bilateral loading between 100-400 g placed on the forearms affected golf shot parameters related to carry distance (i.e., the distance a ball travels in the air) and accuracy. A secondary aim of this project was to determine if any potentiation, or unloading affect, was observed for carry distance or accuracy once the WR was removed.

2. Methods

2.1. Study Design and Experimental Overview

A single session, acute randomised cross-sectional design was used to examine the effects of different arm loading patterns on drive shot parameters. Subjects warmed up as per their usual procedures. They then performed five unloaded swings of their own 7 iron club. Thereafter, five swings were performed under seven randomised loading conditions (4 loads and 3 positions). Finally, five unloaded swings were performed after the loading conditions.

2.2. Participants

Eight male golfers (age: 24.5 ± 11.1 yrs; body mass: 84.8 ± 13.0 kg) and one female golfer (age: 16.0 yrs; body mass: 73.6 kg) with an average handicap of 3.8 ± 2.6 agreed to participate in this study. All were healthy and injury free for the duration of the testing period. Individual athlete information can be found in Table 1. Due to COVID-19 restrictions, this was a convenience sample of

skilled golfers available to us at the time. Subjects provided written informed consent prior to participating in this study. This research was approved by Auckland University of Technology’s Ethics Committee (20/66) and adheres to the Declaration of Helsinki.

2.3. Apparatus

Foresight Sports (San Diego, CA, USA) GC Quad camera-based launch monitor was placed beside the ball and used to determine impact conditions of the ball and club in order to calculate carry distance (i.e., the distance the ball travels in the air down the field of play) and side carry distance (i.e., the perpendicular distance from the target line to the landing point of each shot) (Leach et al., 2017). The GC Quad launch monitor collects images of the golf ball during its initial flight at 3,000 Hz. It then performs calculations using proprietary Foresight GC Quad built-in software algorithm to estimate the dependent variables (i.e., carry distance and carry side distance) (McNally et al., 2019).

The WR equipment worn by the subjects during the loaded conditions were Lila™ Exogen™ compression sleeves (Sportboleh Sdh Bhd, Malaysia). This WR garment allowed for loads of 50 g to 400 g with Velcro backing, to be attached to fixed sleeves on each lower arm. This enabled loads to be distributed either unilaterally or bilaterally without the sleeves moving during the trials.

2.4. Procedures

Subjects performed a warm-up identical to what they would normally do before playing or practicing golf prior to the testing session. Thereafter, each subject performed a total of 45 swings. The first five shots were performed under an unloaded (natural) condition. The subjects then hit five balls from each of the seven loaded conditions in a randomised order to mitigate learning, order, fatigue, and or motivation effects. The subject then hit five balls unloaded following the loaded conditions.

Table 1: Individual athlete characteristics.

Subject #	Age	Handicap	Mass (kg)	Sex
1	40	3.2	83.0	male
2	27	7.6	99.3	male
3	42	3.3	85.3	male
4	17	1.2	75.7	male
5	15	0.5	66.2	male
6	15	6.2	79.4	male
7	16	5.5	73.5	female
8	16	5.9	93.0	male
9	24	0.8	106.6	male



Figure 1: Loading placement for forearm WR with bilateral 200g

Lower arm (forearm) sleeves were used on both arms of the golfer. Neutral loading of the lower arm was placed distal to the elbow (see Figure 1). The loading conditions included: bilateral 50 g per arm, bilateral 100 g per arm, bilateral 200 g per arm, unilateral 200 g trail arm, unilateral 200 g lead arm, unilateral 400 g trail arm, unilateral 400 g lead arm.

2.5. Statistical Analysis

Outlier analysis was conducted on all data and thereafter the averaged data was used for statistical analysis. The independent variables of interest in this study were the unloaded and loaded WR conditions. The dependent variables of interest included: carry distance and carry side distance (n.b., a positive number indicates the ball landed to the right of the target and a negative number indicates the ball landed to the left of the target). Means and standard deviations were used as measures of centrality and spread of data. Homogeneity of variance was assessed via the Levene's test. Normality was analysed using the Shapiro-Wilk test. The comparison of interest was how each load affected golf shot parameters compared to the unloaded condition, and not the effects between loading conditions. Therefore, paired t-tests were used to identify pairwise differences in the mean between loaded and unloaded conditions. Percentage change in the mean was determined to identify relative changes in the mean between baseline performance and the experimental conditions. Hedges' g effect size was calculated on the mean change from baseline to determine the practical effects of WR loading conditions on

carry distance and carry-side distance. 95% confidence limits were reported, and alpha was set at $p \leq 0.05$.

3. Results

3.1. Carry Distance

3.1.1. Group changes

Bilateral loading resulted in trivial to small effects with average percentage changes ranging from -0.19 to 1.78%. Unilateral loading of 200 g on the lead arm resulted in a significant increase (1.78%; $p < 0.05$) in carry distance with a moderate effect. Results from the paired t-tests found that unilateral loading on the trail arm did not have a clear effect on carry distance, with no observable differences between the 200 g and 400 g conditions; though, both conditions demonstrated a large effect on performance ($g \leq -0.84$) with both high and low 95% CI in the 200 g condition being negative. No potentiation effect was observed for mean carry distance. See Table 2 for full carry distance results.

3.1.2. Individual changes

The individual responses for carry distance to each loading condition, presented as a percentage change relative to baseline are detailed in Figure 2. The individual responses for carry distance ranged from -16.1 to 7.42%, with no clear or identifiable trends.

Table 2: Effects of forearm WR loading on mean carry distance, percentage change, effect size and significant difference from baseline performance. * = P < 0.05.

Condition	Mean ± SD	% change (95% CL)	ES (95% CL)	P value
Baseline	151.2 ± 14.8			
Bilateral 50 g	152.8 ± 16.7	1.78 (-0.79 to 4.34)	0.40 (-0.54 to 1.33)	0.35
Bilateral 100 g	152.6 ± 17.3	0.86 (-2.08 to 3.79)	0.34 (-0.59 to 1.27)	0.58
Bilateral 200 g	151.1 ± 17.4	-0.19 (-2.36 to 1.99)	-0.03 (-0.95 to 0.90)	0.95
Final	152.3 ± 19.1	0.51 (-2.59 to 3.61)	0.25 (-0.68 to 1.18)	0.66
Unilateral lead 200 g	154.1 ± 17.0	1.78 (0.24 to 3.33)	0.72 (-0.25 to 1.68)	0.04*
Unilateral lead 400 g	154.0 ± 18.9	1.68 (-1.11 to 4.47)	0.66 (-0.30 to 1.62)	0.22
Unilateral trail 200 g	146.5 ± 17.8	-3.19 (-7.11 to 0.74)	-1.16 (-2.19 to -0.14)	0.17
Unilateral trail 400 g	147.8 ± 17.6	-2.34 (-5.21 to 0.53)	-0.84 (-1.81 to 0.14)	0.18

3.2. Carry Side Distance

3.2.1. Group changes

Bilateral loading showed mixed results. Bilateral loading with 50 g resulted in a small leftward effect on carry side distance of -135.9%, though this did not reach significance ($p = 0.235$). Unilateral loading on the lead arm had a very large effect on carry side distance, resulting in all the golfer’s carry side distances to significantly pull to the left approximately 10 m at 200 g ($p = 0.019$), and seven out of the nine participants pulled approximately 20 m to the left in the 400 g condition ($p = 0.009$).

The pairwise analysis did not clearly identify changes from baseline for the 200 g and 400 g trail arm loaded conditions; however, unilateral loading with 200 g had a large effect and 400 g loading resulted in a very large effect on golfer’s mean carry side distance pushing to the right, where all 95% CL were found to be positive. While the paired t-test did not clearly identify a change from baseline to the final unloaded condition, a large potentiation effect was observed on mean carry side distance, where both high and low 95% CI in the final condition were found to be negative. See Table 3 for full carry side distance results.

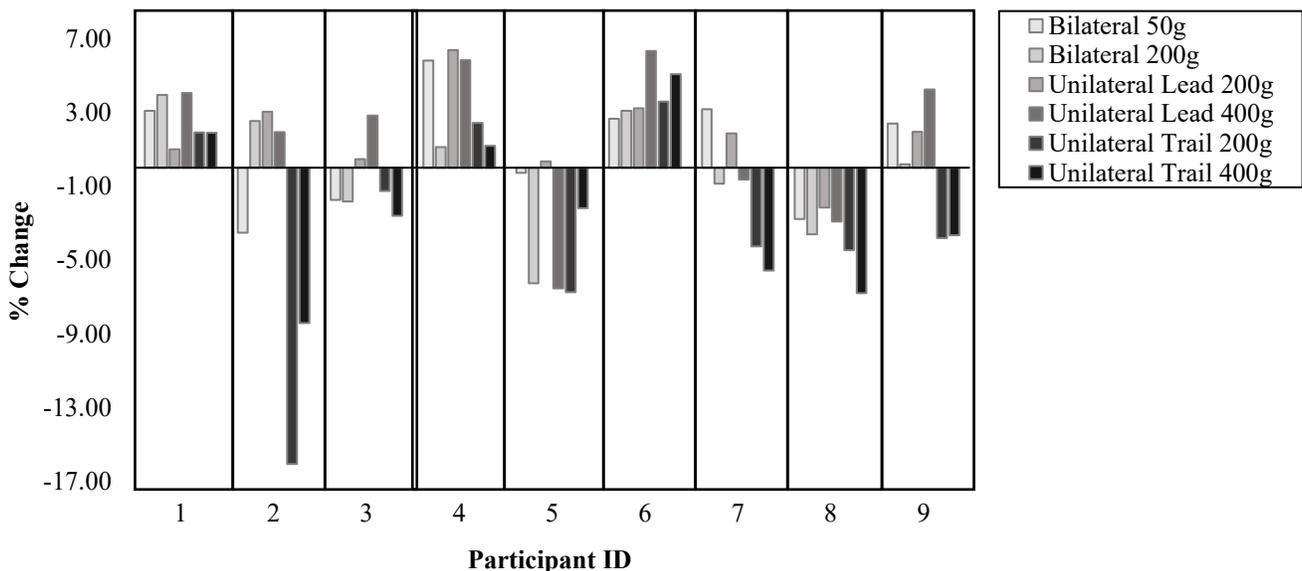


Figure 2: Individual percentage changes for golfers' carry distance for each loading condition compared to baseline.

Table 3: Effects of forearm WR loading on mean carry side distance, percentage change, effect size and significant difference from baseline performance. * = P < 0.05.

Condition	Mean ± SD	% change (95% CL)	ES (95%CL)	P value
Baseline	2.22 ± 11.1			
Bilateral 50g	1.33 ± 5.24	-135.9 (-236.0 to -35.8)	-0.37 (-1.37 to 0.63)	0.24
Bilateral 100g	2.51 ± 9.39	42.9 (-120.3 to 206.0)	0.11 (-0.84 to 1.06)	0.25
Bilateral 200g	-0.04 ± 8.80	-40.4 (-199.0 to 118.3)	-0.90 (-1.89 to 0.08)	0.49
Final	-2.51 ± 14.7	-61.9 (-212.9 to 89.1)	-1.45 (-2.53 to -0.38)	0.17
Unilateral lead 200g	-3.67 ± 11.7	-105.0 (-262.8 to 52.9)	-2.07 (-3.28 to -0.86)	0.02*
Unilateral lead 400g	-8.63 ± 8.74	-168.1 (-416.5 to 80.3)	-4.34 (-6.22 to -2.46)	0.01*
Unilateral trail 200g	7.76 ± 10.7	-15.0 (-123.6 to 93.5)	2.03 (0.83 to 3.23)	0.12
Unilateral trail 400g	9.23 ± 9.23	57.0 (-0.40 to 114.4)	2.64 (1.24 to 4.05)	0.14

3.2.2. Individual changes

The individual responses for carry side distance to each loading condition, presented as a percentage change relative to baseline

can be observed in Figure 3. The individual responses for carry side distance ranged from -1029.4% to 520.6%. No clear trends can be observed from the data apart from arm loading tending to cause a negative carry distance change in most of the subjects.

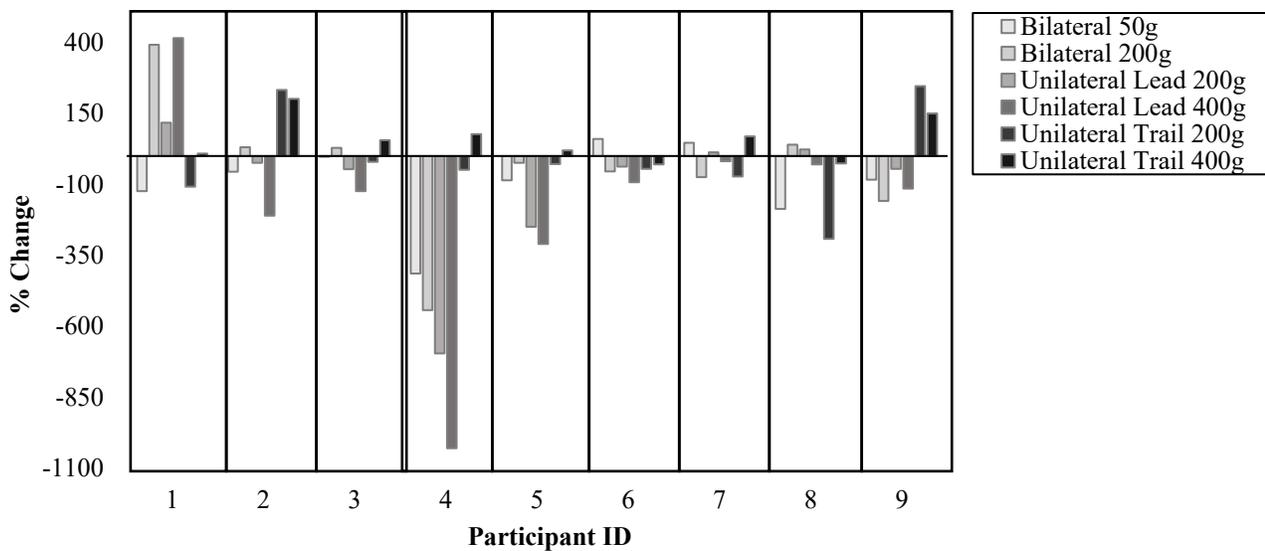


Figure 3: Individual percentage changes for golfers' carry side distance for each loading condition compared to baseline.

4. Discussion

Loading of the lead arm, particularly at 200g, may be a means to increase carry distance to a moderate degree; especially, in athletes with low handicaps. It appears that unilateral loading on the lead arm, especially at loads of 400 g, initiated club head rotation closure, resulting in a more leftward ball trajectory of approximately 20 m.

The practical applications of these findings are, if a golfer is known to have a rightward carry side distance (which generally results from an open club face at impact) then lead arm loading with up to 400g may be used to increase club face closure, resulting in a straighter, or more advantageous ball trajectory. However, if the goal is to initiate club-ball contact with a more open club face, then higher loads on the trail arm could be used to prompt changes relative to those seen with the lead arm. Please note however, the variability of the individual responses in carry distance and carry side distance to the various loading patterns. This is important as arm-loaded WR may therefore be used to correct swing mechanics, which may assist ball carry trajectory in a desired direction, depending on a golfer's individual abilities and tendencies.

Results should be interpreted with caution as this paper only tested a small population of skilled golfers. Future research would need to generalize these results to specific populations. Also, the lack of changes observed in the final unloaded condition in this study could be due to the different changes observed across different loading conditions. This study also only examined the acute effects of WR on outcome parameters. Further research should investigate whether training with a specific WR loading condition (unilateral loading of the lead arm) over time could produce more permanent changes in swing technique/mechanics when not wearing the WR in competition.

Conflict of Interest

Professor John Cronin holds the position of Head of Research at Lila Movement Technology, the manufacturer of the wearable resistance garment used in this study. However, Professor Cronin is an academic researcher first and was blinded from the data collection and analysis. His primary roles were in the conception of the study design and revision of the manuscript.

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Monitoring athletes sleep: a survey of current trends amongst practitioners

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ABSTRACT

Achieving adequate sleep is considered important for athletic performance and recovery from exercise, yet the sleep monitoring methods applied amongst practitioners within high-performance sport are not well documented. This study aimed to identify the athlete sleep monitoring practices currently being implemented by practitioners working with full-time, junior (competing at the highest level), and semi-professional athletes. An online survey was developed and disseminated via email and social media to practitioners working with high-performance athletes. A sample of 145 practitioners completed the survey. Most (88%) practitioners rated sleep as 'extremely important' for recovery and performance (79%) and 84% of practitioners had advised athletes on improving sleep. The practitioners who reported monitoring sleep used several methods, including a questionnaire (37%), diary (26%) and actigraphy (19%). The most cited barrier to monitoring sleep was lack of time/resources. Most (79%) practitioners had not determined athletes' chronotypes. Over half (54%) of the practitioners suggested their athletes did not get enough sleep outside of competition periods; the highest ranked suggested reason for this was screen time (i.e., using electronic devices). Practitioners recognise the importance of sleep for athletes and sleep education/monitoring was common amongst the practitioners; however, chronotype analysis was not widely used. Most practitioners used questionnaires and diaries to monitor athletes' sleep and suggested that their athletes often experience insufficient sleep outside of competition periods.

1. Introduction

Elite athletes have previously identified sleep as being one of the most beneficial recovery strategies (Crowther et al., 2017; Venter, 2014); however, they often experience insufficient sleep during training or competition periods due to factors such as varied training/competition schedules and international travel (Gupta et al., 2017). Insufficient sleep can impair performance, and affect physiological markers of recovery (Skein et al., 2011). Therefore, sleep behaviour of athletes has been recognised as an important area to optimise (Driller et al., 2018; Fullagar et al., 2015; Halson, 2019) and has become a popular area of investigation (Claudino et al., 2019; Venter, 2014).

The gold standard for measuring sleep is laboratory polysomnography (PSG), which involves recording multiple neural and physiological variables (e.g., brain activity, eye

movement, muscle tone). However, PSG is expensive and impractical, particularly when working with multiple athletes. Wristwatch actigraphy is a non-intrusive method of measuring sleep in the field, which has been validated against PSG for total sleep time and sleep efficiency measures (Sadeh, 2011). Consequently, actigraphy has been recommended for monitoring athletes' sleep (Sargent et al., 2016). A recent observational study, however, indicated the most popular sleep monitoring method used amongst practitioners within elite team sport was self-reported sleep diaries, with relatively little use of objective assessments or validated questionnaires (Miles et al., 2019). However, despite growing research into the area of sleep for athletes (Halson, 2019) and recommendations to monitor athletes sleep (Kellmann et al., 2018), there is limited empirical information available concerning how (and if) sleep monitoring practices are being applied within elite sport (Miles et al., 2019).

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Understanding practitioners' attitudes towards sleep and sleep monitoring practices will indicate if there are barriers to applying sleep monitoring and optimisation (e.g., sleep hygiene) interventions.

Humans typically have an interindividual preference for the timing of waking behaviours (e.g., social activities and exercise habits) and sleep, referred to as 'chronotype' (Adan et al., 2012). Those who prefer to wake and perform activities in the early morning are classified as 'early chronotypes' (ECTs); individuals who prefer to function later in the day are classified as 'late chronotypes' (LCTs), and those in between are 'intermediate chronotypes' (ICTs) (Adan et al., 2012). It has been suggested that chronotype influences sports performance, particularly amongst elite athletes (Vitale & Weydahl, 2017). Furthermore, there is potentially an interaction between chronotype and time of day that affects task performance meaning peak athletic performance occurs at different times of day between chronotypes (Facer-Childs & Brandstaetter, 2015). For example, ECTs have been shown to perform better at simple tasks (e.g., psychomotor vigilance, and grip strength) in the morning than LCTs (Facer-Childs et al., 2018). Therefore, it has been suggested that identifying athletes' chronotype could allow practitioners to optimise an athlete's performance (Facer-Childs et al., 2018), recovery (Sugawara et al., 2001) and sleep (Samuels, 2012). However, despite emerging research that highlights how chronotype and time of day could influence task performance, it is not clear if chronotype analysis is commonly adopted by practitioners.

There is currently limited information regarding how (or if) high-performance practitioners monitor athletes' sleep and identify chronotypes. The aim of this study was firstly to explore the methods of sleep monitoring and chronotype analysis adopted by practitioners working with high-performance athletes; and secondly to investigate the practitioners' attitudes regarding the importance of sleep for recovery and performance.

2. Methods

2.1. Survey development and design

An electronic database search using PubMed (MEDLINE) and Web of Science was undertaken to generate a list of sleep monitoring methods used with athletes. A thorough internal process of survey development and design was then conducted, which involved developing an online survey consisting of a combination of multiple-choice, scale/rank and Likert Scale questions using a survey provider (Jisc Online Surveys, Bristol, UK). Practitioners were asked to select answers from predetermined lists. Where applicable, a free text 'other' option was provided. The practitioners were required to provide three responses, in rank order, to one question (factors that contribute to athletes' insufficient sleep). Two questions focussed on the practitioners' attitudes towards sleep (rating the importance of sleep for recovery and performance); therefore, a balance of both positive and negative items was provided within a five-point

Likert Scale to minimise response-set bias (Oskamp & Schultz, 2005).

A pilot version of the survey was disseminated to three academics and five high-performance practitioners. Following feedback, selected questions were modified to improve clarity. The survey was circulated again for feedback before the final version was disseminated. Ethical approval for the study was granted by the University Ethics Committee and the practitioners completed an electronic consent form before commencing the survey.

2.2. Procedure

A range of practitioners, such as sport scientists and strength and conditioning (S&C) coaches, working with professional soccer, rugby union, rugby league and cricket teams, and individual athletes within the United Kingdom were contacted via email to participate in the study. The email addresses of the practitioners were sourced via the personal contacts of the authors and internet searches. A link to the survey was also circulated internationally via social media between October 2019 and January 2020.

Practitioners were eligible to complete the survey if they were aged ≥ 18 years and working with high-performance athletes at the time of the survey. High-performance athletes were defined as: (1) full-time athlete (sport is the athlete's full-time occupation), (2) junior - age 12-18 years, competing at the highest level (e.g., academy, centre of excellence), and (3) semi-professional athlete (sport is the athlete's part-time occupation, for which they are remunerated).

2.3. Participants

One hundred and forty-five practitioners working within 30 different sports completed the survey (see Table 1). Data from five practitioners was removed from analyses due to the respondents working with amateur athletes and/or missing answers. As shown in Table 1, most of the practitioners were Strength and Conditioning Coaches ($n = 62$) and Sport Scientists ($n = 29$).

2.4. Statistical approach

Frequency analysis for each question was conducted, with results presented as absolute frequency counts and percentages. Sub-group analyses to examine the relationships between selected categorical variables were conducted using cross-tabulation and Chi-Square analyses. For the question 'Why do you think your athletes do not get enough sleep outside of competition periods?' the practitioners selected three responses in rank order. Analysis of ranks was performed by assigning ranking points (primary reason = 3 points, 2nd reason = 2 points, 3rd reason = 1 point) to the three selected reasons. The total ranking scores for each reason were then summed to tabulate an overall ranking.

Table 1: Practitioner demographics

Age	Count	%
18-30	49	35%
31-40	54	39%
41-50	30	21%
51-60	5	4%
>60	2	1%
Role		
Sport Scientist	29	21%
S&C Coach	62	44%
Performance Analyst	2	1%
Sport Rehabilitator	2	1%
Exercise Physiologist	7	5%
Nutritionist	8	6%
Physiotherapist	11	8%
Doctor / Medic / Physician	3	2%
Technical Coach	6	4%
Other	10	7%
Level of athletes supported		
Senior (full-time occupation)	93	66%
Senior (semi-professional) *	25	18%
Junior (12-18 years) **	22	16%
Sex of athletes supported		
Predominantly male	78	57%
Predominantly female	18	13%
Mixed group	42	30%
Sports		
Athletics (track & field)	5	4%
Basketball	2	1%
Boxing	1	1%
Cricket	7	5%
Cycling	4	3%
Football (soccer)	33	24%
Ice hockey	4	3%
Golf	1	1%
Rugby league	2	1%
Rugby Union	23	16%
Martial arts	1	1%
Motor sport	11	8%
Running	5	4%
Rowing	2	1%
Sailing	3	2%
Strength (powerlifting, body building, weightlifting)	3	2%
Swimming	8	6%
Tennis	5	4%
Triathlon	2	1%
Winter sports	4	3%
Other	14	10%

Note: *Part-time occupation; ** Competing at the highest level (e.g., academy, centre of excellence)

3. Results

3.1. Athlete sleep education

Most (89%) practitioners reported offering advice to athletes on improving sleep. This information was provided via in-house education (74%), an external consultant (16%), app-based training (6%), and a combination of approaches (4%) – see Figure 1A. Chi-Square analysis indicated a significant association between the level of athlete supported and the type of sleep education provided (Likelihood ratio = 14.1, $p > 0.05$). Analysis of adjusted residuals indicated that practitioners working with full-time senior athletes used external consultants (n = 17) more than practitioners working with semi-professional (n = 0) and junior athletes (n = 3).

3.2. Athlete sleep monitoring

Overall, 61% of respondents had monitored athletes' sleep within the previous year. Sub-group analysis revealed that 63%, 64% and 50% of practitioners working with full-time, junior, and part-time athletes monitored sleep, respectively. The sleep monitoring methods adopted amongst all practitioners were: sleep questionnaire (37%), sleep diary/journal (26%), wrist actigraphy

(19%), mobile phone app (15%), finger actigraphy [Oura ring®] (2%) and other methods (1%) – see Figure 1C.

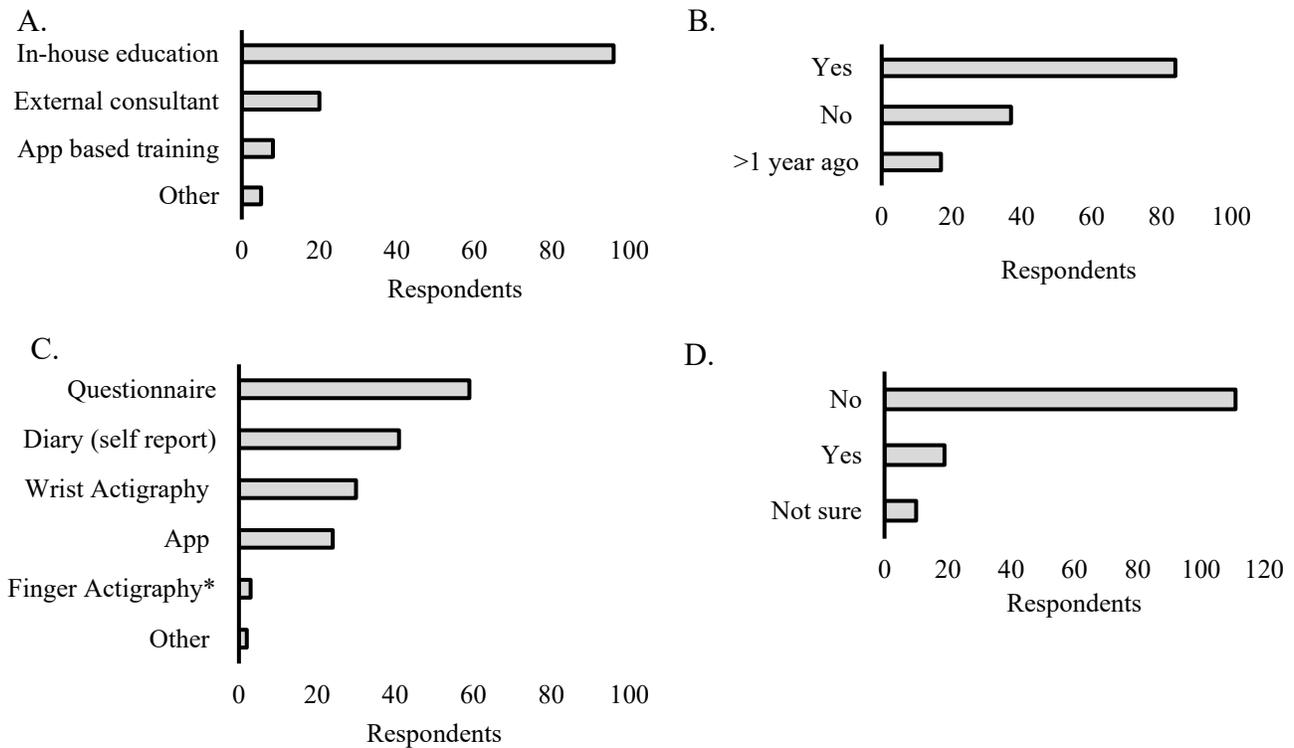
The commonly cited barriers from the practitioners (n = 44) who reported they did not monitor athletes' sleep, were a lack of time/resources (39%), poor athlete compliance (14%), and being unsure of how to measure sleep effectively (14%).

3.3. Chronotype analysis

Most (79%) practitioners had not attempted to determine their athletes' chronotypes (see Figure 1D). The practitioners (n = 19) that had assessed chronotype used the following methods: asked the athlete (n = 5), bespoke questionnaire (n = 5), Morning-eveningness questionnaire (n = 3), sleep/wake data (n = 2), Munich Chronotype questionnaire (n = 2), a combination of approaches (n = 2).

3.4. Importance of sleep

When asked to rate how important sleep was for athletes' recovery after training/competition (1-5 Likert Scale), 88% of participants specified it was 'extremely important', 11% 'very important' and 1% 'moderately important'. When rating the importance of sleep



Note: A: Sleep education method; B: Have you monitored athletes sleep?; C: Sleep monitoring method; D: Have you monitored athletes chronotype? * = Oura ring®

Figure 1: Responses to sleep and chronotype monitoring questions

for performance, 79% of practitioners specified it was ‘extremely important’, 18.1% ‘very important’, 2.2% ‘moderately important’ and 0.7% ‘slightly important’. Chi-square analysis revealed the level of athlete supported did not have a significant effect on the ratings of sleep for recovery ($X^2 = 0.92, p > 0.05$) or performance ($X^2 = 0.92, p > 0.05$).

3.5. Do athletes get enough sleep (practitioners’ perceptions)

Most (54%) respondents believed their athletes did not get enough sleep outside of competition periods; 28% of practitioners believed their athletes obtained enough sleep and 18% were unsure. The practitioners based their answer on observations/anecdotes (51%), analysis of subjective (31%) and objective (14%) sleep data and other methods (4%). The sub-group analysis revealed a higher proportion of no (not enough sleep) responses with junior (56%) and semi-professional athletes (64%) than full-time athletes (48%). However, there was no significant association between the level of athlete and reports of insufficient sleep ($X^2 = 3.97, p > 0.05$). Screen time (TV, mobile devices etc.) was the highest-ranked reason (268 points) by all practitioners for insufficient sleep. Sub-group analysis revealed that screen time was cited as the main reason by 35% of the practitioners working with full-time athletes, 48% working with junior athletes and 36% with semi-professional athletes. The ranked responses for insufficient sleep are presented in Figure 2.

3.6. Sleep supplements

Most (69%) practitioners had not recommended a sleep supplement for their athletes. A higher proportion (39.6%) of practitioners working with full-time athletes recommended sleep supplements compared to practitioners working with junior (8%) and semi-professional (22.7%) athletes. The supplements recommended by practitioners working with full-time athletes were: melatonin (n = 28), tart cherry juice (n = 19), magnesium (n = 17), ZMA (n = 11), chamomile tea, (n = 9), L-tryptophan (n = 3), 5-HTP (n = 2), valerian (n = 1), and herbal sleep tablet (n = 1).

4. Discussion

The present study explored practitioners’ views on sleep and the application of sleep monitoring methods amongst athletes. The majority of practitioners specified that sleep was ‘extremely important’ for athletes’ recovery (89%) and performance (79%). The most common sleep monitoring method was questionnaires, adopted by 37% of the practitioners. The commonly cited barriers from practitioners who did not monitor athletes’ sleep, were a lack of time/resources, poor athlete compliance and being unsure of how to measure sleep effectively. The practitioners suggested that athletes do not consistently achieve adequate sleep, and most practitioners had not explored the chronotype of their athletes.

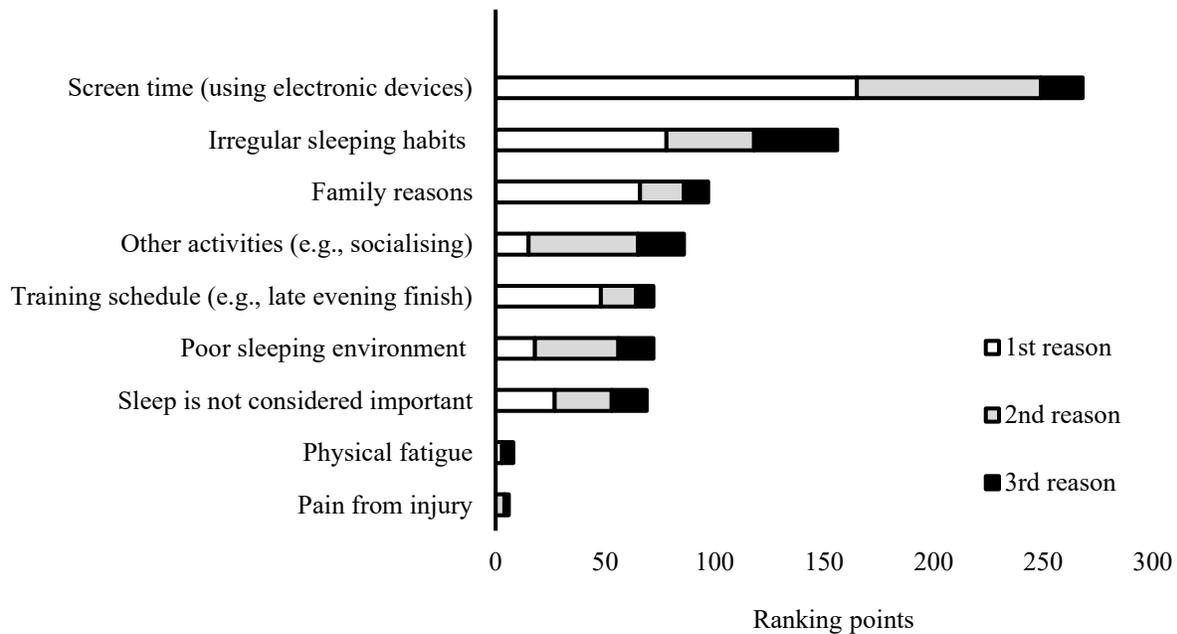


Figure 2: Practitioners perceived reasons for athletes’ lack of sleep outside of competition periods.

The majority (89%) of respondents provided sleep advice to athletes and (60%) reported monitoring athletes' sleep. These findings parallel a recent study where 56% of practitioners working within Australian high-performance sports teams reported monitoring athletes' sleep (Miles et al., 2019). In the same study, those who did not implement sleep monitoring or sleep hygiene practices with athletes specified this was due to lack of resources (60%) and lack of time (23%) (Miles et al., 2019). Similarly, the main factor for not implementing sleep monitoring practices in the present study was a lack of time/resources (39%). The lack of time/resources could explain why a sleep questionnaire (37%) and self-report diaries (26%) were the most popular methods of monitoring sleep both here and in the previous research (Miles et al., 2019).

Sleep questionnaires are commonly used in healthcare to provide a subjective measure of patients' sleep quality and were the most popular sleep monitoring method in the present study. Although several questionnaires have been validated amongst the general population, their validity for evaluating sleep amongst athletes has been questioned (Driller et al., 2018; Samuels et al., 2016). Therefore, athlete-specific sleep questionnaires, such as the Athlete Sleep Screening Questionnaire (Samuels et al., 2016) and The Athlete Sleep Behaviour Questionnaire (Driller et al., 2018), have been developed and validated. Athlete-specific questionnaires offer a practical sleep method to identify athletes with sub-optimal sleeping patterns and behaviours. However, sleep questionnaires may not be appropriate for monitoring sleep longitudinally, as adherence to completing sleep questionnaires can decrease over time compared to wearing a wristwatch actigraphy device (Thurman et al., 2018).

A sleep diary was the second most prevalent monitoring method adopted in the present study. As with questionnaires, sleep diaries are practical and cost effective. However, practitioners should be aware of the potential limitations of self-reported sleep diaries, such as athletes overestimating their sleep duration (Caia et al., 2018) and misreporting sleep onset and wake times due to a failure of memory or a reduced effort in completing sleep records (Thurman et al., 2018). Practitioners may consider using electronic, app-based sleep diaries as an alternative to paper diaries as these can be downloaded to personal devices (phones and tablets) and offer several benefits, such as being more time efficient, reducing data hoarding (completing several days data retrospectively), and providing automatic calculations (Tonetti et al., 2016). Regardless of the method, practitioners should apply caution when using subjective sleep data gathered from questionnaires and diaries to inform decision making as the long-term reliability of questionnaires (Driller et al., 2018; Samuels et al., 2015) and diaries has not been established amongst athletes.

Due to the limitations of subjective sleep monitoring methods, it is recommended that questionnaires and diaries are used in conjunction with actigraphy (Halson, 2019). Although the collection of sleep data is simple using actigraphy, data analysis from research-grade activity monitors (e.g., Philips Respironics ActiWatch 2) can be time-consuming, which could explain why actigraphy was not the most widely implemented method in the present study. Commercially available activity monitors

automatically generate sleep reports and offer a convenient and economical means to objectively measure sleep. However, several devices use proprietary algorithms and direct sensor outputs that have not been independently validated, which raises questions over their accuracy (de Zambotti et al., 2020). Actigraphy devices that automatically analyse sleep data have been developed and validated amongst athlete populations (Driller et al., 2016). These tools provide practitioners with a more time-efficient, but not necessarily economical, method to objectively monitor athletes' sleep.

In summary, validated questionnaires and sleep diaries offer an economical method of monitoring athletes sleep. To improve accuracy, and possibly long-term adherence, actigraphy used in conjunction with a validated questionnaire or sleep diary is currently the recommended sleep measurement method for athletes. In all cases, practitioners should understand the limitations of each method to ensure the data is suitably interpreted and communicated to athletes.

Researchers have suggested that the time of day when peak athletic performance occurs could be moderated by chronotype (Facer-Childs & Brandstaetter, 2015; Facer-Childs et al., 2018), and identifying inter-individual differences in circadian rhythmicity could prove valuable when planning training schedules (Vitale & Weydahl, 2017). However, 79% of practitioners in the present study had not attempted to determine their athletes' chronotype. Given that chronotype can be assessed using simple validated questionnaires, such as the Morningness-Eveningness Questionnaire (MEQ) and the Munich Chronotype Questionnaire (MCTQ), chronotype assessment could present an opportunity for practitioners to individualise schedules to minimise circadian disruption, enhance performance (Facer-Childs & Brandstaetter, 2015; Lastella et al., 2015), improve the reliability of performance/recovery assessments (Brown et al., 2008), and optimise sleep (Samuels, 2012).

Sleep has been recognised as the most beneficial recovery strategy amongst international athletes (Crowther et al., 2017). However, athletes often experience insufficient sleep within competition periods due to factors such as training/competition schedules and frequent travel (Gupta et al., 2017). Less is known regarding what factors affect athletes' sleep outside competition periods. In the present study, 'screen time' was the highest ranked reason for athletes' not achieving sufficient sleep outside of competition periods. This suggestion is consistent with observational studies that have reported the use of electronic devices before bedtime is common amongst elite youth athletes (Knufinke et al., 2018) and professional basketball players (Jones et al., 2019). Delaying bedtime, termed 'bedtime procrastination', could be due to electronic devices providing more extrinsic appeal than going to bed, i.e., individuals want to sleep, but do not want to stop using their devices (Kroese et al., 2014). Furthermore, exposure to electronic devices before bedtime can increase excitatory stimuli and suppress melatonin secretion and, consequently, reduce sleep duration/quality (de la Iglesia et al., 2015).

Regardless of the mechanism underpinning bedtime procrastination, sleep curtailment can harm recovery and

performance (Fullagar et al., 2015). Consequently, future research on strategies to reduce bedtime procrastination amongst athletes is warranted. For example, Kroese et al. (2014) suggested that strategies that do not require cognitive resources, such as implementation intentions (i.e., an “if – then” plan), could be effective in reducing bedtime procrastination. Additionally, since blue light exposure from electronic devices could be detrimental to sleep, strategies to reduce blue light exposure in the evening (e.g., blue light blocking glasses) present a further area for investigation.

Most (69%) practitioners had not recommended sleep supplements, which could be attributed to the few (n = 8) nutritionists/dieticians amongst the sample. It is also possible that practitioners recognised that the factors they suggested had a negative impact on athletes’ sleep would not be improved by supplements (e.g., screen time and irregular sleeping habits). The limited evidence for the efficacy of sleep supplements and requirement for strict batch testing for contaminants could also explain why supplements were not widely recommended. Moreover, behavioural and dietary interventions may offer a more practical and sustainable approach to optimising sleep (Halson, 2014).

4.1. Limitations

This study provides an insight into practitioners’ views on sleep and the methods currently being used to monitor athletes’ sleep. The practitioners were recruited from the authors professional network and via social media; therefore, the results are not generalisable to those working with unrepresented sports or amateur athletes. The results of this cross-sectional survey are based on the opinions of practitioners working with full-time, junior and semi-professional athletes. Although a sub-analysis was conducted, most of the practitioners worked with full-time athletes and the overall responses may not be representative of practitioners working with junior and semi-professional athletes. Furthermore, although the practitioners specified the general sleep monitoring methods used, the exact instrument(s) adopted was not specified. Future surveys may seek to target one particular category of practitioner (e.g., those working with junior athletes) and ask respondents to specify the sleep monitoring instrument(s) applied (e.g., specify the sleep questionnaire). Finally, responses based on the subjective opinions of the practitioners (e.g., athletes do not consistently achieve adequate sleep outside of competition periods) should be interpreted with caution.

4.2. Conclusions

Questionnaires and diaries were the most frequently used methods amongst those who monitored sleep; however, the long-term reliability of these subjective methods requires investigation amongst athletes. To improve accuracy, and potentially adherence, practitioners should consider using validated activity monitors and/or app-based sleep diaries. Very few practitioners attempted to determine their athletes chronotypes. Although chronotype and sports performance research is limited, understanding an athlete’s

chronotype could potentially facilitate the design of training, testing and sleep schedules. The practitioners believed their athletes experienced insufficient sleep outside of competition periods. The highest ranked reason for insufficient sleep was screen time. Previous research suggests the use of electronic devices can lead to bedtime procrastination and sleep curtailment; therefore, future research on strategies to reduce bedtime procrastination amongst athletes is warranted.

Conflict of Interest

The authors declare no conflict of interests.

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Perceptions of the role, value and barriers of sports scientists in Australia among practitioners, employers and coaches

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ABSTRACT

Sports scientists in Australia are experiencing unpaid internships, long work hours and job insecurity, and previous research has indicated that coaches have ranked sports scientists as an unlikely source for them to seek new information. These factors suggest some employers and coaches do not value sports scientists. The current preliminary study compared the perceptions of sports scientists in Australian sport between those working as sports science practitioners, their employers and coaches. Australian sports science practitioners (n = 36), current/potential employers for sports scientists (n = 20) and sports coaches (n = 10) completed an online questionnaire. The questionnaire contained items that identified perceptions of the primary role, tasks, value, effectiveness and barriers of sports science practitioners. The most commonly reported tasks of a sports scientist were 'assessments of fitness/performance', 'performance analysis' and 'training monitoring' for practitioners, employers and coaches, respectively. Coaches ranked sports scientists as the practitioner role offering the least value to an athlete (rank = 8/8), while the practitioners (rank = 3/8) and employers (rank = 2/8) ranked sports scientists as one of the most valuable. All groups 'agreed' or 'strongly agreed' that sports scientists have a necessary role in sport and are effective in improving an athlete's performance. For those in the sports team setting, employers 'somewhat agreed' that sports scientists receive fair working conditions while the practitioners 'somewhat disagreed' (p = 0.040). There are discrepancies in the perceptions of sports scientists between practitioners, employers and coaches in Australia. By addressing these discrepancies, it may be possible to improve the perceived and actual value of sports science practitioners and their working conditions.

1. Introduction

Sports science education commenced in Australia at the University of Western Australia in 1968, and the first sports science practitioners in Australia were hired at the Australian Institute of Sport in 1981 (Bloomfield, 2002). From this time until 2013, the Australian Institute of Sport became a world leader in sports science servicing and research (Blood, 2018), and Australian sports science practitioners subsequently became highly sought after internationally. The national accrediting body for sports scientists in Australia (Exercise & Sports Science Australia; ESSA) define accredited sports scientists as 'specialists in the application of scientific principles and techniques to assist coaches and athletes improve their performance at an individual level or within the context of a team environment' (Exercise &

Sports Science Australia, 2020). Exercise & Sports Science Australia has also published a scope of practice for sports scientists, which included the assessment and application of theoretical knowledge and scientific principles to maximise performance, along with responsibilities surrounding the sporting environment, the athlete's needs, and policy (Exercise & Sports Science Australia, 2020). The definition and scope of practice were developed in response to a 2013 Australian Senate enquiry that determined a lack of regulation within the sports science profession (Greenhow, 2013), and subsequent regulation has led to 351 sports scientists becoming accredited with ESSA as of December, 2020 (communication with Exercise & Sports Science Australia).

A national profile of the sports science workforce has demonstrated the continuing complexity of the sports science

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industry, with many specialised roles and tasks that exist within the umbrella term ‘sports scientist’ (Dwyer, Bellesini, Gastin, Kremer, & Dawson, 2019). Originally, sports scientists were tasked with research, development and innovation, coach and peer education, mentoring, technology evaluation and implementation, more recently, however, roles have had a greater focus on ‘service delivery’. The nature of these roles is captured by the sports science disciplines that have been categorised by ESSA; performance analysis, skills acquisition, sports biomechanics, sports physiology and strength science (Exercise & Sports Science Australia, 2020). However, debate exists as to whether a sports science practitioner should operate as a specialist in one discipline, or as a generalist across multiple disciplines (McCunn, 2019). The specific day-to-day tasks of a sports science practitioner are not well-described within original research, but a range of tasks are documented, including research and knowledge translation to increase evidence-based practice (Bartlett & Drust, 2020; Fullagar, McCall, Impellizzeri, Favero, & Coutts, 2019); interpretation of complex data, intervention development, testing and training prescription (Thompson, 2010b); optimising training/learning design and individualising training/learning programs (Renshaw, Davids, & Savelsbergh, 2010); technique enhancement and injury prevention (Elliott & Bartlett, 2006); and, most recently, critical evaluation of technology (Sandbakk, 2020).

With no award wage for sports science practitioners in Australia, many sports scientists receive pay rates independently determined by their employer’s perception of value, organisational resources and available funding (Dwyer et al., 2019). Hence, their ability to work and be paid relevant to their expertise is somewhat reliant on their employers’ perception of them and their impact. Upon graduation, many aspiring sports scientists are required to undertake an unpaid internship to gain experience, as an undergraduate degree is not necessarily considered to be worthy of paid employment in the industry (Doncaster, 2018; York, Gastin, & Dawson, 2014). Challenges for Australian sports scientists also continue after employment, including long work hours and job insecurity (Dwyer et al., 2019). Sports scientists are often required to work ten or more hours per week above their contract, and, just four out of ten positions are permanent (Dwyer et al., 2019). Sports science practitioners are also known to receive poor recognition for their work and have little opportunity for career advancement (York et al., 2014). Their working environment has also been described as ‘volatile’ given the pressure for competition success and the rapid change that can occur with coaching staff and funding at sports organisations (Thompson, 2010a; Wagstaff, Gilmore, & Thelwell, 2015). As such, longevity in sports science roles is poor, which is evident from practitioners having a lower age and a low number of years in their current position (Dwyer et al., 2019).

In a sports organisation, the sports scientist often reports to the head coach (either formally or informally), and as such, coach perceptions of sports science practitioners are crucial for sports science employment. Coaches have identified some struggles engaging with sports science practitioners, such as problems with integration into the applied setting and poor understanding of the needs of a specific sport, as well as the overuse of jargon (Martindale & Nash, 2013). Coaches have also described barriers to sports science research application, including funding, time, ‘buy-in’ and low practical relevance of research aims (Fullagar et al., 2019), while qualities such as excellent knowledge of the sport, JSES | <https://doi.org/10.36905/jses.2021.04.07>

experience and communication skills, make coaches more likely to engage with sports science practitioners (Schwarz et al., 2021). Some sports science practitioners working in the biomechanics setting have explained a dysfunctional relationship with coaches, potentially resulting from the practitioners having poor communication skills, and the coaches having a poor understanding of the discipline and the services that the practitioners can offer (Waters, Phillips, Panchuk, & Dawson, 2019). Similar challenges exist in the skills acquisition setting, where building trust with a coach is a long and challenging process for a sports scientist, and sometimes only achieved after they have delivered results (Dehghansai, Headrick, Renshaw, Pinder, & Barris, 2020). As such, coaches have ranked sports scientists (and their research) as a very unlikely source for them to seek new information (Reade, Rodgers, & Hall, 2008). These barriers, combined with sports science employment that is characterised by unpaid internships, high workload and a lack of job security, suggest that some employers and coaches may place low value in sports science practitioners, however, this has not been investigated.

Therefore, our focus was to determine the perceptions of sports science practitioners in Australia. More specifically, this preliminary study will compare the perceptions of the primary role, tasks, value and barriers of sports science practitioners between their employers, coaches and the sports science practitioners themselves. By addressing these aims, we will determine any differences in understanding that can be addressed and potentially improved for the profession. Since there is information available on the career experiences of sports scientists (Dawson et al., 2013; Dwyer et al., 2019; York et al., 2014), we explored reasons for these experiences from the perspectives of key stakeholders. We envisage that the findings following on from this preliminary study can guide a more extensive study toward key areas of differentiation identified in the current study.

2. Methods

2.1 Design

An online questionnaire was developed (Qualtrics Core XM, Provo, Utah, USA) to measure participants' perceptions of the primary role, value and barriers of sports science practitioners. The survey had mixed response types with different questions suited to quantitative (e.g., likert scale) and qualitative analysis (open text). This design is based on similar studies on related professions including sports psychology (Johnson, Andersson, & Fallby, 2011; Pain & Harwood, 2004; Zakrajsek, Martin, & Wisberg, 2016) and physiotherapy (Lee & Sheppard, 1998; Puckree, Harinarain, Ramdath, Singh, & Ras, 2011). The study was approved by the Southern Cross University Human Research Ethics Committee in the spirit of the Helsinki Declaration and the participants provided written, informed consent before commencing the questionnaire.

2.2 Participants

The questionnaire was completed by 66 participants recruited from three populations, including; i) sports science practitioners

(n = 36); ii) employers with hiring responsibilities of sports science practitioners (n = 20), and; iii) sports coaches (n = 10). Sports coaches were included as an additional group due to their advocacy role in sports science employment. Inclusion criteria stipulated that participants must have been currently working in Australia and aged over 18 years. Potential participants were contacted via email (where contact details were available online) with an invitation to complete the questionnaire. Snowball sampling (Biernacki & Waldorf, 1981) further increased recruitment as this sample is difficult to reach. Screening questions were used to ensure that each participant was from one of the populations of interest and met the inclusion criteria. The demographics of each group, including level and setting of work, are presented in Table 1. Typically, use the following subheadings: Participants, Apparatus, Task, Procedure, and Statistical Approach. Include a statement regarding consent to participate and a statement of institutional or organisational ethical approval.

2.3 Procedures

The questionnaire contained 23 items, as detailed in Appendix 1. Seven items were used for screening and the collection of demographic information. Ten items delved into the participants' perceptions, including knowledge and attitudes toward sports scientists. The remaining questions explored the barriers to employment and working conditions for sports scientists. As part of a pilot study, ten volunteers (8 practitioners and 2 employers; 5 male and 5 female) completed the questionnaire to check clarity, comprehension, timing, and understanding of the questionnaire. This procedure enabled the researchers to amend the wording of some questions and insert an additional question about sports science disciplines. This pilot also allowed the development of a list of tasks performed by sports scientists for one of the items. Following the pilot, it was determined that the questionnaire was

appropriate and had face validity. The questionnaire was open between June-July, 2019.

2.4 Statistical Analysis

Frequency distributions were calculated where necessary and rank order responses were assigned numerical values (i.e., 8 for highest, 1 for lowest etc.) that were summed to determine the mean rank order (i.e., highest total score equals highest rank). The level of agreement to quantitative statements was determined via 7-point Likert scale (where 1 = strongly disagree, 7 = strongly agree) and presented as median ± interquartile range (ICR). Data from each questionnaire item were analysed via a Kruskal-Wallis H Test and pairwise comparisons where significant differences were observed, with alpha set at <0.05 (SPSS Statistics, 2012). All Likert scale distributions were similar for all groups within each item, as assessed by visual inspection of a boxplot. The qualitative data were interpreted using principles of thematic analysis (Clarke, 2015) by clustering answers around underlying uniformities from which key ideas emerged. Upon examining the data, themes were observed and grouped together and then labelled by two researchers separately. Any differences in this labelling were discussed before reaching an agreement. Quotes were also extracted from the data and presented without editing.

3. Results

Participants were asked ‘In your role or context, what is (or would be) the main role of a sports scientist’ and ‘what are the main tasks of a sports scientist’. The responses are summarised in Figure 1 and Table 2, respectively. The results of the participants ranking different sports practitioner and sports science disciplines in order of their value and priority are summarised in Table 3.

Table 1: Group demographics.

Group	Age (y)	Female (%)	Level (%)	Setting (%) ²
Practitioners (n = 36)	34.3 ± 9.9	42	Professional = 50 National = 42 State = 6 Local = 3	Sports team = 31 Institute/Academy = 50 NSO = 31 University = 25
Employers ¹ (n = 20)	45.4 ± 10.8	25	Professional = 20 National = 40 State = 30 Local = 10	Sports team = 35 Institute/Academy = 25 NSO = 40 SSO = 15
Coaches (n = 10)	45.8 ± 8.0	20	Professional = 30 National = 40 State = 30	Sports team = 50 Institute/Academy = 50 NSO = 50 Consultant = 10

Note: ¹Employers included high performance managers (n = 11) and sports executives/administrators (n = 9). ²Multiple settings could be selected (NSO=National Sporting Organisation, SSO=State Sporting Organisation)

Table 2: Most common selections between groups in response to item ‘In your role or context, what are the main tasks of a sports scientist’.

Tasks	Practitioners		Employers		Coaches	
	#	%	#	%	#	%
Assessments of fitness/performance	20	56*	9	45	7	70
Training monitoring	19	53	10	52	8	80*
Designing, implementing and modifying training programs	15	42	4	20	4	40
Research	15	42	3	15	4	40
Recovery	12	33	9	45	6	60
Recording performance in training and competition	12	33	7	35	4	40
Performance analysis	11	31	11	55*	7	70
Athlete education	11	31	5	25	5	50
Implementing interventions	10	28	3	15	4	40
Assessments of technique/skill	9	25	3	15	2	20
Technique development	9	25	3	15	2	20
Injury prevention	7	19	5	25	4	40
Injury rehabilitation	6	17	6	30	5	50
Aggregating and curating records	4	11	4	20	1	10
Goal setting	3	8	2	10	3	30

Note: *Represents most common response

For the statement ‘A sports scientist is effective in improving an athlete’s performance’ practitioners responded ‘strongly agree’ (median ± IQR; 7.0 ± 1.0), employers responded ‘strongly agree’ (7.0 ± 1.0) and coaches responded ‘agree’ (6.0 ± 1.5), with no significant differences between groups, $H(2) = 3.655, p = 0.161$. For the statement ‘Sports scientists have a necessary role in sport today,’ practitioners responded ‘strongly agree’ (7.0 ± 0.3), employers responded ‘agree’ (6.0 ± 1.0) and coaches responded ‘strongly agree’ (7.0 ± 0.8), with no significant differences between groups, $H(2) = 3.880, p = 0.144$. For this question, participants could explain their answer, and the responses are

presented in the supporting information. For the statement ‘In an ideal situation, with no barriers, I would employ a sports scientist (or more sports scientists) to support my athlete/team,’ practitioners responded ‘strongly agree’ (7.0 ± 1.0), employers responded ‘strongly agree’ (7.0 ± 1.0) and coaches responded ‘agree’ (6.0 ± 1.75), with no significant differences between groups, $H(2) = 2.388, p = 0.303$. For this question, participants could explain their answer, and the responses are presented in the supporting information.

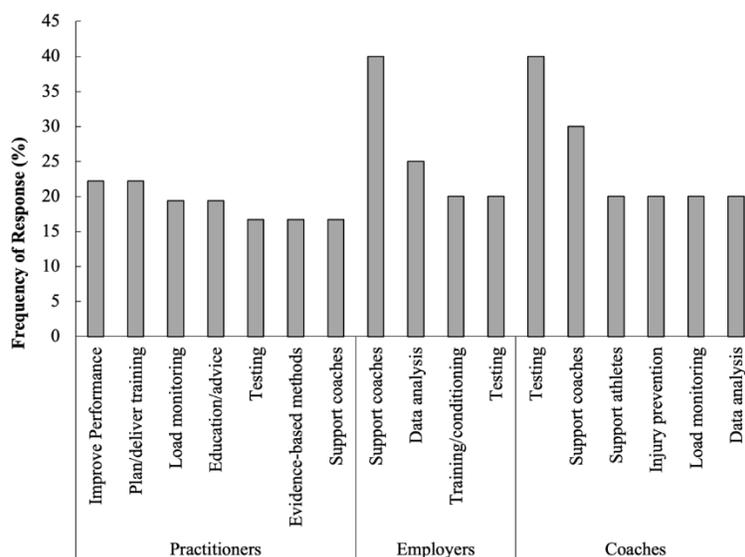


Figure 1: Most common themes between groups in response to item ‘In your role or context, what is (or would be) the main role of a sports scientist’.

Table 3: Rank order responses by group for items ‘In your role or context, rank the following practitioners in order of their value to an athlete’ and ‘In your role or context, rank the following sports science disciplines in order of their priority’.

	Rank order of practitioners in order of their value to an athlete (score)	Rank order of sports science disciplines in order of their priority (score)
Practitioners	<ol style="list-style-type: none"> 1. Coach (278) 2. Strength and conditioning (181) 3. Sports scientist (168) 4. Sports psychologist (155) 5. Sports physician/medic (149) 6. Dietitian/nutritionist (148) 7. Physiotherapist (135) 8. High performance manager (98) 	<ol style="list-style-type: none"> 1. Sports physiology (127) 2. Strength and conditioning (123) 3. Performance analysis (104) 4. Motor control and skill acquisition (94) 5. Sports biomechanics (93)
Employers	<ol style="list-style-type: none"> 1. Coach (144) 2. Sports scientist (98) 3. Strength and conditioning (92) 4. Sports physician/medic (92) 5. Sports psychologist (85) 6. High performance manager (79) 7. Physiotherapist (73) 8. Dietitian/nutritionist (57) 	<ol style="list-style-type: none"> 1. Motor control and skill acquisition (70) 2. Sports physiology (60) 3. Strength and conditioning (59) 4. Sports biomechanics (56) 5. Performance analysis (55)
Coaches	<ol style="list-style-type: none"> 1. Coach (79) 2. Physiotherapist (47) 3. Sports psychologist (45) 4. High performance manager (42) 5. Strength and conditioning (39) 6. Sports physician/medic (38) 7. Dietitian/nutritionist (36) 8. Sports scientist (34) 	<ol style="list-style-type: none"> 1. Motor control and skill acquisition (34) 2. Sports biomechanics (30) 3. Sports physiology (29) 4. Strength and conditioning (29) 5. Performance analysis (28)

Note: ‘Score’ represents the sum of responses to the 7-point Likert scale.

When asked ‘What are the most important barriers preventing the employment of a sports scientist,’ practitioners responded with ‘lack of opportunities/a large number of graduates’ (52.8%, n = 19) and ‘lack of practical applications, experience or knowledge’ (30.6%, n = 11). Employers responded with ‘finance’ (75%, n = 15) and ‘lack of practical applications, experience or knowledge’ (20%, n = 4). Coaches responded with ‘finance’ (70%, n=7), personality/communication issues (20%, n = 2) and ‘lack of practical applications, experience or knowledge’ (20%, n = 2).

For the statement ‘Sports scientists generally receive fair working conditions’ practitioners responded ‘somewhat agree’ (5.0 ± 1.5), employers responded ‘somewhat agree’ (5.0 ± 2.0), and coaches responded ‘somewhat agree’ (5.0 ± 2.0), with no significant differences between groups, H(2) = 1.356, p = 0.508. Since there was a lower agreement for this item, further comparisons were made after practitioners and employers were broken into groups based on their work setting. For those in the sports team setting, practitioners responded ‘somewhat disagree’ (n = 11, 3.0 ± 2.0), employers responded ‘somewhat agree’ (n = 7; 5.0 ± 2.5) and coaches responded ‘neither agree nor disagree’ (n = 5, 4.0 ± 2.0), with significant differences between groups, H(2) = 6.497, p = 0.039, and specifically, a significant difference between practitioners and employers (p = 0.040).

For those in the institute/academy setting, practitioners responded ‘somewhat agree’ (n = 18, 5.0 ± 1.0), employers responded ‘somewhat agree’ (n = 5, 5.0 ± 0.0) and coaches responded ‘neither agree nor disagree’ (n = 5, 4.0 ± 2.0), with no significant differences between groups, H(2) = 4.453, p = 0.108. For those in the national sporting organisation setting, practitioners responded ‘somewhat agree’ (n = 12, 5.0 ± 1.0), employers responded ‘somewhat agree’ (n = 8, 4.5 ± 1.8) and coaches responded ‘agree’ (n = 5, 6.0 ± 3.0), with no significant differences between groups, H(2) = 1.082, p = 0.582. Other work settings were not included in this analysis due to having less than 5 participants in some groups.

4. Discussion

This preliminary study aimed to conduct a novel comparison between sports science practitioners, employers and coaches in their perceptions of sports scientists. Differences were identified in the primary role and tasks of sports scientists, and coaches ranked sports scientists as the practitioner with the least value for an athlete out of eight practitioner roles in the sport setting. However, sports scientists, employers and coaches all ‘agreed’ or ‘strongly agreed’ that sports scientists have a necessary role in sport today and that they are effective in improving an athlete’s performance. Barriers for sports science employment were also

identified, such as a lack of opportunities, finance and a lack of practical applications and experience. Finally, in the sports team setting specifically, employers 'somewhat agreed' that sports scientists receive fair working conditions, while the practitioners 'somewhat disagreed' with this statement.

Sports scientists believed their two primary roles were to 'improve performance' and to 'plan/deliver training' while employers and coaches both described the primary roles of the sports scientist as 'supporting the coach', 'data analysis' and 'testing'. Indeed, there was much crossover between the responses of the three groups (see Figure 1), but these data suggest that sports scientists see themselves as directly impacting the athletes' performance and training. In contrast, employers and coaches see the sports scientist as supporting the coach to achieve these outcomes. There were also differences in the perceived main task of a sports scientist, however, a large number of tasks have been identified as common across the sample, highlighting the potential complexity of a sports scientist's employment and consequently, the difficulty in defining the profession (Dwyer et al., 2019). A Scope of Practice for accredited sports scientists has been published by ESSA (Exercise & Sports Science Australia, 2020), which includes statements such as 'Provision to apply knowledge to influence individual sporting needs.' Indeed, such a statement is inexplicit to allow a broad scope for the needs of different sports and innovative practice. There are five separate disciplines of sports science (see Table 3) that perform various tasks, and as such, the term 'sports scientist' actually represents a group of different sports professionals. While some sports scientists perform their role as specialists (e.g., a biomechanist hired solely for biomechanics servicing) others are required to perform a more general role including duties across multiple disciplines. Hence, the use of the umbrella term 'sports scientist' may contribute to the disparity in the understanding of the role and tasks of practitioners that have a more specific job description.

Coaches ranked sports scientists as the practitioner role with the least value to an athlete, which presents a significant issue for sports scientists in their opportunities for employment and job security. If the coach views the role of a sports scientist as less important compared to other practitioner roles, then in circumstances where the coach has influence over sports science employment, when resources are limited, their program would be less likely to employ a sports scientist. Although, the low ranking is not surprising given that coaches perceive a poor transfer of sports science knowledge to coaching practice (Martindale & Nash, 2013). Further, the regulation of the sports science industry has been enhanced only recently in response to a Senate inquiry into the practice of sports science in Australia (Greenhow, 2013), and improvements in the value and professionalism of practitioners will take some time to filter to coaches who may have had a negative experience with a sports scientist previously. Coaches have stated that sports scientists need to take a gradual and collaborative approach, and understand the language of the sport to have a greater positive influence (Dehghansai et al., 2020). It should be noted that the current study had a small coach sample, and this low ranking should be confirmed in a larger population and with interview data to explore the problem and potential solutions further. Despite this rank order, all groups in the current study agreed or strongly agreed that sports scientists have a necessary role in sport today and are effective in improving an athlete's performance. Indeed, a large amount of positive

feedback on the work of sports science practitioners was provided from all groups in the current study (see Appendix 2). The sports science discipline that is perceived by employers and coaches to be of highest priority was 'motor control and skill acquisition', which may be explained by coaches perceiving themselves to have great knowledge in this area (Fullagar et al., 2019). Such a finding suggests that education providers should have a focus on the applied practice of the motor control and skill acquisition discipline.

The key barriers noted by employers and coaches for sports science employment were 'finance', 'lack of practical applications, experience or knowledge' and 'personal/communication issues.' While finances will always be an issue in the high-performance sport setting, the other barriers may be addressed, perhaps with an increased emphasis on practical experiences and interpersonal skills within the education or accreditation pathway of practitioners. Coaches in the UK also deemed experience and practical knowledge acquired from the field to be more valuable than sports science knowledge (Martindale & Nash, 2013). Therefore, internship programs for developing sports science practitioners may be useful to assist with the development of these aspects, however, sport and exercise science graduates are known to be exploited within internships in Australia (Stevens, Lawrence, Pluss, & Nancarrow, 2018), consequently, resulting in the recent publication of the ESSA Sports Science Graduate Internship Guidelines (Exercise & Sports Science Australia, 2019). These guidelines describe how an unpaid intern should receive a 'meaningful learning experience, training or skill development' and assigning the intern with work that would usually be undertaken by an employee is considered exploitation and is against the law.

Perceptions of unsatisfactory working conditions of sports scientists in the sports team setting in the current study are consistent with data indicating they are the most unsatisfied with their jobs, likely due to high amounts of unpaid overtime potentially leading to burnout, as well as feelings of insufficient support (Dawson et al., 2013). As a result, those working at sporting clubs experience poor job longevity and are more likely to be in their position for less than five years. The current study demonstrated that employers did not recognise this issue and therefore this problem is expected to persist if action is not taken. In comparison, we found that those working at an institute or academy were somewhat satisfied with their working conditions, which explains why previous data demonstrated they are more likely to remain in their position for six years or more (Dawson et al., 2013). Employers of sports scientists in the sports team setting would likely benefit from engaging with employers in the institute/academy setting to understand how they can improve working conditions and job longevity for their staff.

It should be highlighted that this was only a preliminary study that should be used to inform future research. The current research informs further studies with the goal to establish the need to introduce title protection in line with healthcare professionals, develop resources that explicitly identify the role of a sports scientist, establish a Fair Work award for sports scientists and publish best practice position statements on sports science topics (i.e., to clarify best practice methods to complete the tasks of a sports scientist). To strengthen future studies on these themes, interview data should be included, and the limitations of the current study should also be addressed. For example, the

employers were not specifically the employers of the sports science practitioners surveyed, and hence, employers may have different roles and expectations that have been outlined clearly with their actual sports science employees. Therefore, in future studies, sports science practitioners should be recruited together with their employer and the coach that they support. Future researchers should include more participants, and better define their experience, sporting focus and the sport science discipline of these participants, and determine whether these factors contribute to variation in responses, which was not done in the current study. These considerations are needed to ensure accuracy of these results across the broad spectrum of workplaces and focus areas of sports scientists. It is likely that the roles and perceptions of sports scientists are different between individual and team sports, and even between sports within these categories.

This study identified important disparities between sports science practitioners, employers and coaches in their perceptions of sports scientists, which should be investigated further (Dehghansai et al., 2020; Waters et al., 2019). Specifically, the reasons coaches perceive sports scientists to be the practitioner role with the least value to an athlete, and secondly, reasons why sports science practitioners in the sports team setting believe they have unfair working conditions, and why employers do not recognise this. Sports science practitioners should be aware that the coach they support might perceive them to have a lower value than many other practitioners in their organisation and might find their communication styles somewhat limiting (Martindale & Nash, 2013). Sports science practitioners should demonstrate their value individually while also supporting the important work of other practitioners within their organisation. Sports science employers in the sports team setting should be aware that their sports science practitioners could perceive their working conditions to be poor (Dwyer et al., 2019). Employers should avoid poor employment practices (Wagstaff et al., 2015) and implement strategies to increase job satisfaction to prevent burnout and increase the longevity of sports science employment.

Conflict of Interest

The authors declare no conflict of interests.

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Appendix 1: Questionnaire

Q1 Are you a sports scientist, sports administrator/sports executive (who is/would be responsible for hiring a sports scientist) or a sports coach currently working in Australia?

- Yes
- No

Q2 What is your age (years)?

Q3 What is your gender?

- Male
- Female
- Other _____
- Prefer not to say

Q4 Describe your current role?

- Sports Coach
- Sports Executive/Administrator (who is/would be responsible for hiring a sports scientist)
- Sports Scientist

Q5 Describe the setting of your work (select all that apply)

- Sports team
- Sports institute or academy
- National sports organisation
- University
- Other _____

Q6 What best describes the level of the sport you're involved in?

- Professional
- National
- State
- Local

Q7 How many sports scientists are currently employed in your organisation (answer for your main organisation)?

Q8 What words first come to mind when you think of a sports scientist? (list up to 5)

Q9 In your role or context, what is (or would be) the main role of a sports scientist?

Q10 In your role or context, what are the main tasks of a sports scientist (select 3)?

- Training monitoring
- Athlete education
- Assessments of fitness/technique/skill/performance
- Recovery
- Goal setting
- Technique development
- Implementing interventions
- Injury prevention
- Injury rehabilitation
- Research
- Performance analysis
- Recording an athletes performance in training and competition
- Aggregating and curating records
- Designing, implementing and modifying training programs
- Other _____
- Other _____
- Other _____

Q11 In your context, rank the following sports science disciplines in order of their priority (drag and drop in to place)

- _____ Sports Biomechanics
- _____ Sports Physiology
- _____ Strength and Conditioning / Strength Science
- _____ Motor Control and Skill Acquisition
- _____ Performance Analysis
- _____ Sports Psychologist

Q12 Rank the following practitioners in order of their value to an athlete (drag and drop in to place)

- _____ Coach
- _____ Nutritionist
- _____ Physiotherapist
- _____ Sports Physician / Sports Medicine
- _____ Sports Psychologist
- _____ Sports Scientist
- _____ Strength and Conditioning Coach
- _____ High Performance Manager

Q13 Sports scientists have a necessary role in sport today

- Strongly agree
- Agree
- Somewhat agree

- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

Q14 In your response to the previous question 'Sports scientists have a necessary role in sport today' please explain your answer

Q15 A sports scientist is effective in improving an athlete's performance

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

Display This Question:

If Describe your current role? = Sports Coach

Or Describe your current role? = Sports Executive/Administrator (who is/would be responsible for hiring a sports scientist)

Q16 I am exposed to the work of a sports scientist

- Daily
- Weekly
- Fortnightly
- Monthly
- Annually
- Never

Q17 What is the minimum qualification required to be a sports scientist?

- None
- Diploma
- Bachelor degree
- Masters degree
- PhD

Q18 What are the most important barriers preventing the employment of a sports scientist?

Q19 In an ideal situation, with no barriers, I would employ a (or more) sports scientists to support my athlete/team?

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

Q20 Why would/wouldn't you employ a (or more) sports scientists?

Q21 Sports scientists generally receive fair working conditions

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

Display This Question:

If Describe your current role? = Sports Coach

Or Describe your current role? = Sports Executive/Administrator (who is/would be responsible for hiring a sports scientist)

Or Describe your current role? =

Q22 Describe your level of involvement with sports science?

- Strongly involved
- Involved
- Somewhat involved
- Neither involved nor uninvolved
- Somewhat uninvolved
- Uninvolved
- Strongly uninvolved

Display This Question:

If Describe your level of involvement with sports science? = Strongly involved

Or Describe your level of involvement with sports science? = Involved

Or Describe your level of involvement with sports science? = Somewhat involved

Q23 How are you involved with sports scientists?

Appendix 2: Open text responses to item: ‘Please explain your answer to ‘Sports scientists have a necessary role in sport today’.

Practitioners Sport can't move forward without research and innovation, which is what sports scientists do on a daily basis. Our role isn't fully understood by athletes and coaches, which means we tend to be underutilized; Sport Scientist's understand the body's function and movement at a deeper level. It is the role of the Sport Scientist to help advance and maintain an athlete's performance, with coaches potentially overlooking particular areas due to focusing on the skill of the sport.

Sport Scientist's play the hard-working role in the background, often providing information and guidance for the coach/athlete, which may help to enhance performance. Without sport science, advancements in athlete performances may not occur, or may occur at a slower rate.

Necessary to gain an advantage against other teams who are utilizing sport scientists for an advantage. Monitoring player load, prevent injury, designing training periodization is all the job of a sport scientist.

We are the bridge between the AT's, Strength coach and Coach in general and you have to know how to communicate also not only work but understand each position.

Performance gaps are getting smaller, and sport scientists play an important role in identifying and helping improve an athlete for those 1%ers.

Quality control on data collection is required in an elite sport so we can trust what we can collect; sports science plays a major role here.

Events are won by narrow margins, to give yourself the best chance of winning you want to ensure you are doing everything you can to succeed.

Protecting the integrity of sport through athlete management and long-term development.

Sport scientists provide a structure that allows coaches making more objective and individualized decisions. They keep track of fundamental data giving coaches a solid background helping them understand why a program/plan is successful or is not.

I believe that there is no longer an advantage in a sporting setting in having a good sport scientist, however I do believe there is a disadvantage in not having one.

Mainly a sport scientist's role is to raise more questions through answering that of the coaching staff and organization.

With many athletes, I believe that they could still achieve certain goals despite our input and help. Others seem to rely on and know how to use sports science better so work this in to their support team and use it to their advantage.

Today's coaches and athletes have access to more data and measures than ever before, but ensuring the quality of these measures and interpreting the results could mean the difference between completing the right program and completing the wrong program. Sport scientists are more important than ever because of this vast availability of products, the sellers of which are more focused on making money and reflected glory than they are on genuinely supporting elite athletic performance.

Depends on the sport and its requirements and also where the sport is at with regards to performance. Often sport scientist are not required if those people are 50% behind the game.

The sport scientist can have a crucial role if they find how to be effective in the program they work in and this will vary program to program.

To help guide the coach and athlete in terms of training loads, recovery and ergogenic aids.

We live in a high-performance environment driven by scientific and technological advancements.

Some sports could manage to perform at a very high level without a sport scientist, but in other sports (namely endurance sports), things like load management and training optimisation are critical for not tipping the athletes over breaking point. In these instances, scientists are key for providing coaches with evidence (both from the athletes they're currently working with and from the literature) to educate coaches, but ultimately it is the coach who makes the final call about what is prescribed to the athlete.

There is so much capacity for monitoring but need sport scientists to understand and apply data.

Agree. In my position it is integrated with the S&C coach which makes it more important as there is a stronger link with the team on a session to session basis.

Scientists ensure athletes get the best return for their efforts by taking a holistic approach to understanding performance and training.

Athlete wellbeing is at upmost importance to keeping athletes injury free and performing to their optimal capacities.

We have the skills to quantify the performance of individuals and teams. We equate all the information gathered from training and competition and provide this vital information to other staff and coaches. We also are the educator and motivator to the athletes. As having an individual specialise in exercise prescription benefits the athlete's development and progressions.

With technology and research constantly evolving sport science will play an important role in the translation of new research and the implementation of new technologies into sport. Sport science plays a key role in ensuring this is done safely, ethically and to high standards or accuracy.

They provide an objective, scientific foundation to training decisions and practices.

An effective coach working with any level of athlete should be able to achieve 80% of the desired adaptations and athletic developments, however an effective sport scientist can or should be able to optimise this 80% process to possibly reduce the time required and then be able to assist with achieving the remaining 20% of adaptation and development.

Ensuring evidence based practice.

As a sports scientist, I believe I have a key role in assisting an athlete to reach their potential.

Viewed as the "most educated in the room".

I think sports scientists can have an impact on sports performance as there's a lot of areas where small gains can be made, but without the help of a sports scientist a coach may not have the time, knowledge or resources to tap into these areas.

The plethora of data that is captured or able to be captured today requires the skills of a sport scientist. If you do not have someone in place covering the sports technology area in particular you will not be able to deal with all of the data that is coming in nor will you be able to utilize the latest technology that may give you information you have never had before.

With sport scientists, there would be no evidenced based practice or research based innovation in the applied sport setting.

Employers

Depends on the practical application of knowledge as well as the way the scientist integrates into the broader team (coach, physio, S&C, athletes). How they interpret information and discuss these strategies with coaching staff/athletes.

Sports performance is an increasingly sophisticated and competitive area, and coaches cannot be fully across all aspects of their athlete's performance without a multi-disciplinary team incorporating sports scientists. They assist to manage and inform the training/adaptation and performance development process.

For performance at an elite level, athletes need a team of experts around them to keep their body in the best shape and training and competing most effectively.

In order to gain a competitive advantage.

A science-based approach is required for modern day elite level sport. Sport's scientists are the conduit to the latest research and techniques.

With the increase in technology there's a lot more to monitor, which can impact performances. The role needs to be separated from S&C coaches so each can focus on what their specific roles are.

It's crucial to maximise performance.

As Advisor to Head Coach.

Ensuring reliability and validity.

Sports Science is just one of a number of disciplines involved in HP sport.

Amateur sports lack the funding to utilise this talent and resources. Many sports are considered amateur.

In professional sport absolutely, integrity and advancement of the preparation and resilience for athletes is key.

Few sport scientists understand our sport and are not strong in applied knowledge relevant to the sport.

The role can be very different depending on the sport, the athlete mentality and their needs.

Bringing new knowledge into sport is fundamental for continued improvement.

Sports scientists have a role. However, the nature and purpose of their work needs to have an applied outcome and answer practical questions/issues faced in the applied environment.

Depends on their skill set and coach's needs.

Necessary role in providing framework for relevant data collection and translation of data to assist in improving individual and team-based training outcomes and performance.

Coaches

If an athlete is fitter, better fuelled, recover/rehab quickly, have less injuries, improved state of mind and is confident in their support team they will perform better.

Need for sports scientists to collaborate with coaches to deliver scientific rigor to the art of coaching.

I believe that sports scientist can have a major role in the planning and monitoring of a team. I also feel at some levels they could be bought in on part time work.

How else are we going to innovate and improve our athlete's perception, decision, practice and overall performance without research and innovation?

Provide information I would not otherwise have.

Wow, how many pages do you want?? They each have unique skills and additions to each athlete. Sport is more than ever evidence based (for example selection to national team). It takes a whole team to enable an athlete to perform to the max of their ability. I'm a coach with a background in sports science so value the input of science immensely. However science does not take away from hard work and doesn't create any short cuts for the athletes, athletes don't often understand that and think because it's available they should use it. Would be better if the athletes trained their bums off first of all and use sports science services for the final few %. 95% is commitment and hard work, sports science comes into account in the last few %'s, once an athlete has a high national level or makes national teams. So as for your question below: Yes, I strongly agree to add the last final pieces towards top performance.

They work with coaches to evaluate and design/implement training programs for athletes.

Their output needs to be relevant for now while challenging status quo - a tricky balance.

Its important the athletes have a full understanding of the importance of their bodies and how to look after them both on and off the field; They provide a necessary service that is valued if given appropriate scope of practice.

Does the warm-up effect subsequent post activation performance enhancement?

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ABSTRACT

The purpose of the following study was first to identify an optimal warm-up to maximise countermovement jump (CMJ) performance, and second to investigate whether a conditioning activity (CA) of half-squats could potentiate CMJ performance above that of the optimal warm-up. Sixteen resistance trained males were recruited for the study. Participants performed six different warm-up volumes over six sessions. Warm-ups consisted of submaximal running, dynamic stretching and practice CMJs. After the warm-up, participants rested for four minutes before performing three CMJs on a force platform. The warm-up which resulted in the best CMJ relative peak power (RPP) was considered to be that individual's optimal warm-up. Participants attended another testing session where they performed their optimum warm-up followed by a pre-CMJ test. Participants then performed a CA of four half-squats with a 5RM load followed by post-CMJ tests after four- and eight-minutes recovery. No CMJ variable displayed significant improvements at either four or eight minutes recovery after the CA when compared to the pre-test. However, when everyone's optimum recovery period was considered, CMJ height significantly improved by 5.2% ($p = 0.009$) when compared with pre-CMJ performance. If the optimum recovery period is considered, a half-squat CA can further improve CMJ height above that of a general warm-up alone.

1. Introduction

Prior to training, athletes perform a warm-up to decrease the risk of injury and also to optimise performance (Behm, Blazevich, Kay, & McHugh, 2016). To maximise performance, it has been suggested that a general warm-up should include an aerobic component performed at an intensity of < 60% of an individual's VO₂max (Bishop, 2003a), a dynamic stretching component (McMillian, Moore, Hatler, & Taylor, 2006) as well as a skill specific component, where the athlete practices the specific movement they will be performing (Young & Behm, 2003). There are many mechanisms of a general warm-up that will enhance an individual's readiness to perform effectively. These include increases in muscle temperature (Bishop, 2003b), blood flow to working muscles (McCutcheon, Geor, & Hinchcliff, 1999), range of motion (McMillian et al., 2006), baseline oxygen consumption (Bishop, 2003b) and an enhanced readiness of the neuromuscular system (Young & Behm, 2003). Athletes or coaches may also try

to exploit the phenomenon of post-activation performance enhancement (PAPE) to further the benefits following a warm-up.

Post-activation performance enhancement is the phenomenon where the contractile history of a muscle acutely enhances the performance of a future voluntary contraction that is biomechanically similar after a recovery period (Blazevich & Babault, 2019; Hodgson, Docherty, & Robbins, 2005). To exploit the PAPE phenomenon, a conditioning activity (CA) is performed to enhance a subsequent movement. Typically, CA have involved heavy dynamic exercises of the lower body (for example heavy squats) in order to potentiate jumping (Boullosa, Abreu, Beltrame, & Behm, 2013; Chiu et al., 2003; Young, Jenner, & Griffiths, 1998) or sprinting performance (Seitz et al., 2016). However, more ballistic movements and plyometric activities have also been utilised as CA within the literature (Turki et al., 2011). The applications of PAPE can be used in a warm-up to acutely enhance performance for competition. Furthermore, PAPE can be used in contrast resistance training to enhance speed-strength

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variables, with the intention of producing a greater training stimulus for chronic adaptations.

Previously, the term post-activation potentiation (PAP) was used to explain the improvements in performance after a CA, however, recent literature has distinguished a difference between the terms PAP and PAPE (Blazeovich & Babault, 2019; Prieske, Behrens, Chaabene, Granacher, & Maffiuletti, 2020). Post-activation potentiation involves an enhancement in an electronically evoked twitch response almost directly after the performance of a CA (Prieske et al., 2020). Alternatively, PAPE involves an enhancement in voluntary contractions (strength, power or speed) after the performance of a CA (Prieske et al., 2020). The main mechanisms of PAP include the phosphorylation of the regulatory light chains of the myosin head (Hodgson et al., 2005; Tillin & Bishop, 2009), and changes in pennation angle of the muscles (Mahlfeld, Franke, & Awiszus, 2004). Although it is unclear, these mechanisms of PAP may influence PAPE (Blazeovich & Babault, 2019). The main mechanisms of PAPE are an increase in higher order motor unit recruitment (Tillin & Bishop, 2009) and blood flow to the muscle (Blazeovich & Babault, 2019). Previous research has investigated the underpinning mechanisms of PAP and PAPE (Klug, Botterman, & Stull, 1982), however, a majority of the literature assumes that any improvement in performance following a CA is due to potentiation and fails to consider the warm-up activities prior to the CA. Considering the current investigation assesses changes in voluntary contractions (jumping performance) after a CA, the term PAPE will be used from this point forward.

Despite the relatively large amount of literature supporting the positive benefits of PAPE (Duthie, Young, & Aitken, 2002; McBride, Nimphius, & Erickson, 2005), numerous studies have failed to identify improvements in performance after a CA (Khamoui et al., 2009; Till & Cooke, 2009). Research has suggested that the type of CA (Fiorilli et al., 2020; Wilson et al., 2013), the recovery period allocated after a CA (Seitz et al., 2016) as well as the training history of the participants (Chiu et al., 2003; Seitz et al., 2016) could all be contributing factors to the inconsistent results. However, a variable that has yet to be investigated is the warm-up performed prior to the CA.

The typical research design utilised in the PAPE literature involves a general warm-up, pre-testing, an allocated rest period (or rest periods) and post-testing (Figure 1). In terms of the

general warm-up, the procedures described within the published PAPE literature at times detail an insufficient general warm-up prior to pre-test measurements (Duthie et al., 2002; Linder et al., 2010; McBride et al., 2005; Okuno et al., 2013). For example, a participant may only perform an aerobic component of the general warm-up, with no inclusion of dynamic stretching or specific skill rehearsal (Linder et al., 2010; McBride et al., 2005; Okuno et al., 2013). Additionally, there are examples of static stretching being incorporated within the general warm-up (Duthie et al., 2002), despite the fact that prolonged static stretching may decrease subsequent performance (Behm et al., 2016).

Considering many PAPE studies have not included an appropriate warm-up prior to measuring baseline performance, these studies may not accurately reflect the performance of each individual. Therefore, positive improvements observed in explosive movements such as a jump or sprint following a CA may not be the result of PAPE, instead the improvement may be due to the CA being an extension to an inadequate warm-up prior to baseline testing. Recent research by Mina et al. (2018) has supported the notion that warm-ups prior to a CA have been insufficient within the PAPE research. Mina et al. (2018) prescribed a warm-up prior to either a free-weight back squat or a band resisted back squat CA (three repetitions with a load of 85% of 1RM) while attempting to enhance CMJ performance. When three repetitions of a free weight back squat were used as a CA, no statistically significant improvements in CMJ performance were identified leading the authors to speculate that previous PAPE literature may have only found an improvement in post-jump performance due to insufficient warm-ups being performed before the CA. Despite this, the warm-up used by Mina et al. (2018) did not include any dynamic stretching, which may have been a sub-optimal warm-up for the pre-test CMJ performance. Furthermore, the same warm-up was performed by each individual in the study, however, the optimum warm-up for jumping performance may vary between individuals.

The concept of exploiting PAPE assumes that the general warm-up prior to any pre-tests is adequate. Therefore, the CA further potentiates performance, rather than just compensating for an insufficient warm-up. There is a need for research to optimise a warm-up prior to the addition of a CA, to identify whether PAPE further improves performance.

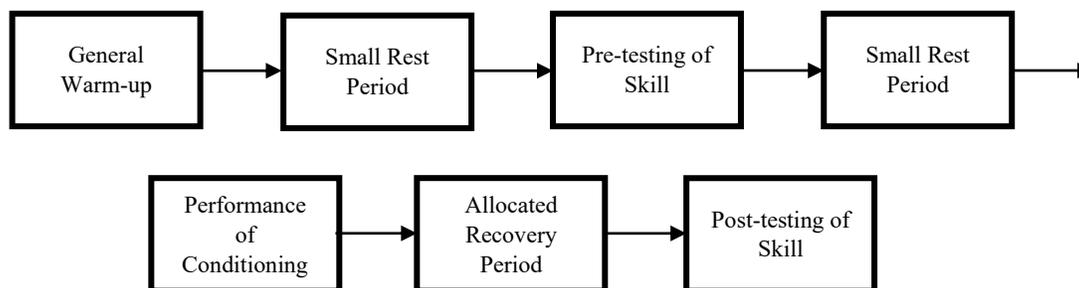


Figure 1: A representation of the “typical” procedures used within PAPE research.

Therefore, the present study aims to firstly identify an individual warm-up which maximises pre-test jumping performance. Once the optimum warm-up was established, the study aimed to identify whether a heavy back-squat CA can further improve CMJ performance by eliciting an acute performance enhancement.

2. Methods

The following study used a within-subjects repeated measures design to establish which general warm-up protocol was the most effective for each individual participant and assess the effectiveness of adding a CA to this warm-up on post-CMJ performance. After two familiarisation sessions, participants took part in six experimental procedures with varying warm-up volumes. Each of these sessions were performed 2-5 days apart. Each participant completed the sessions at consistent times of the day to control for any diurnal variations in performance and were instructed to maintain regular eating and sleeping habits throughout data collection. Participants were not allowed to consume caffeine on the day prior to any testing session and were not to perform any strenuous lower-body exercise within 48 hours. These sessions were performed in a random order to prevent any order-effect influencing results.

After completing the six experimental warm-up sessions, participants performed another testing session that involved their optimum warm-up followed by a CA of four half-squats with a 5RM load. This session was to assess if the CA could further

enhance post-CMJ performance beyond that of the general warm-up alone.

Sixteen recreationally trained males with a minimum of one-year resistance training experience completed the present study (Mean \pm SD age = 21.4 \pm 1.9 years, height = 179.9 \pm 6.1 cm, body mass = 81.7 \pm 8.1 kg, Smith machine 5RM half-squat = 166.5 \pm 36.7 kg). Two participants withdrew from the study due to injuries that occurred outside of testing sessions and were not included in any data analyses. Participants were over the age 18, free of injury or illness and able to half-squat at least 1.5 times their body weight for one repetition as previous literature has related participant strength as a requirement for a positive potentiating effect (Seitz et al., 2016). Before the commencement of the study, the procedures and potential risks were explained to all participants and informed consent was obtained. The study had ethical approval from the University's Human Research Ethics Committee (A13-151).

The participants attended two familiarisation sessions. The first session was to measure the 90° knee angle to meet the required depth for the half-squat and to determine the 5RM half-squat load for each participant. Once the participants were in the appropriate half-squat position, a marker was placed on the side of the Smith machine so that each participant's half-squat height was consistent throughout the entire study. A grid was set up on the ground so that each participant's foot position could be recorded and kept consistent throughout the study.

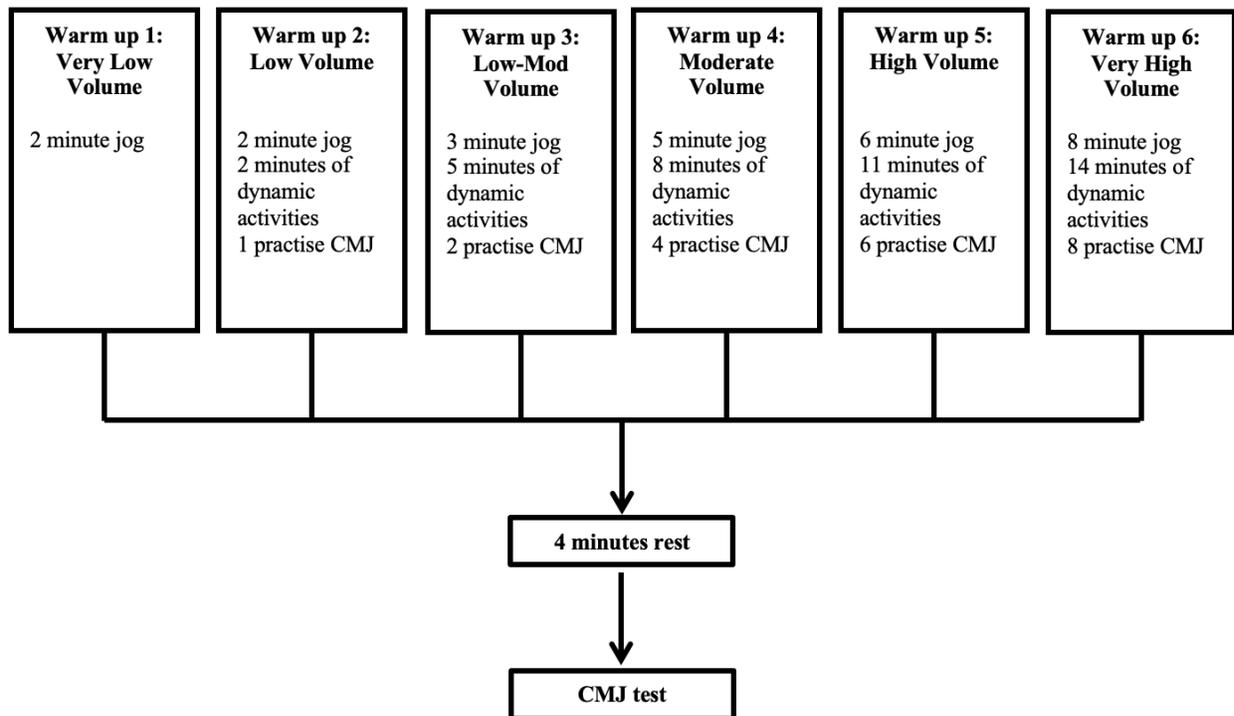


Figure 2: Representation of the procedures used within the six warm-up conditions.

Prior to determining the participant's 5RM, three warm-up sets of eight repetitions at 50%, five repetitions at 70%, and three repetitions at 90% of their self-predicted 5RM were completed with two-minutes of rest between sets. Following completion of the warm-up sets, the participant attempted five repetitions at 100% of their self-predicted 5RM load. If successful, four minutes of rest was provided and the load was increased by 5kg. If a participant failed to complete five repetitions at a particular load, their last successful lift was considered their 5RM. The second session was focused on practicing the CMJ and the warm-up protocol. Participants practised the submaximal jogging and dynamic stretches used within the warm-up before they practised the CMJ on the Ballistic Measurement System (BMS) (400 Series Force Plate-Fitness Technology, Adelaide, Australia) with the linear position transducer (LPT) (PT5A-Fitness Technology, Adelaide, Australia). Participants held a light aluminium bar across their shoulders (LPT attached) during the CMJ to prevent the use of an arm-swing and were instructed to perform the CMJ at a self-selected speed and depth before jumping for maximal height.

Participants performed seven experimental conditions, the first six involved warm-ups that differed in the total workload (ranging from "very low" to "very high") (Figure 2).

Participants began each session by performing the specific warm-up allocated for the appropriate session. The warm-up sessions included an aerobic component (jogging), dynamic stretches and activities of the lower body (Table 1) as well as practise CMJs.

After completing the allocated warm-up procedure, participants rested (seated in a chair) for four minutes before performing three CMJs. The CMJ variables assessed were jump height, relative peak power (RPP) and peak force.

In the seventh experimental condition, to specifically examine PAPE compared to simple warm-up effects, a CA of four half-squats at a 5RM load was added to each individual's optimal

warm-up routine determined from the previous conditions. The optimum warm-up was the condition that produced the greatest RPP during a single CMJ. At the start of this experimental condition, the participant performed their optimum warm-up followed by four minutes of recovery. Three CMJs were then performed as a baseline-measure, followed by two minutes recovery prior to three warm-up sets of half squats (1st warm-up set: 8 repetitions at 50% 5RM, 2nd warm-up set: 5 at 70% 5RM, 3rd warm-up set: 3 repetitions at 90% 5RM). After the final warm-up set, participants rested in a seated position for four minutes prior to performing four half-squats at a 5RM load as their CA. Following the CA, participants recovered in a seated position prior to performing CMJs four and eight minutes post-CA. The recovery period of eight minutes is within the guidelines of the meta-analysis performed by Wilson et al. (2013), who suggested that rest periods after a CA should be between seven and ten minutes for individuals with one year's training experience. Previous research has identified a potentiating response with a smaller recovery (Lowery et al., 2012), hence four minutes recovery was also selected to assess if any individuals displayed a potentiating effect with a decreased recovery time.

Considering past research has suggested that the optimum recovery time after a CA is individualised (Chaouachi et al., 2011), the recovery period that created the highest CMJ height for each individual was recorded as post-best.

All CMJs were performed on a portable force plate in conjunction with an LPT. Both the force plate and LPT were calibrated prior to every session. The sampling frequency for both the force plate and LPT was set at 500Hz and the data was filtered using a fourth order Butterworth method with a cut-off frequency of 9Hz. The LPT was attached to the end of an aluminium bar (0.4kgs in weight) that was held on the participant's shoulders. Test-retest reliability of each CMJ variable was determined by Intraclass correlation (ICC) and coefficient of variation percentages (CV%).

Table 1: The dynamic stretches and the amount of repetitions used in each warm-up condition.

Dynamic Exercise	Volume Level				
	Low	Low-Moderate	Moderate	High	Very High
Gluteal Stretch Walk	2	6	10	14	18
Quadriiceps Grab Walk	2	6	10	14	18
Bouncing on Spot (double leg)	4	16	28	40	52
Heel to Gluteal Run	2	8	14	20	26
Walking Lunges	1	3	6	9	12

Note: The number of exercises in the table are to be performed on each side of the body. The Very Low warm-up condition consisted of two minutes of jogging only.

Relative peak power was selected as the CMJ variable to determine the optimum warm-up. This was decided as enhanced power output is a targeted training outcome for many athletes and coaches therefore, changes in CMJ RPP could lead to practical applications for training both acute and chronic PAPE responses.

Means and standard deviations (SD) were calculated for all CMJ variables from each warm-up condition as well as pre- and post-CMJ variables in the session with the CA. Prior to analysis, a Shapiro-Wilk test was used to assess the distribution of the data, with all variables being normally distributed. To determine whether any significant differences in CMJ performance existed between warm-up conditions, a repeated measures Analysis of Variance (ANOVA) was performed. To establish if the inclusion of the CA had a potentiating effect on CMJ performance, a second ANOVA was performed to determine if significant differences existed at 4 or 8 minutes post CA. Two rest periods were used to determine the optimal rest period as the time course for PAPE may vary for each individual (Chaouachi et al., 2011). Therefore, the recovery period that produced the greatest jump height was considered "post-best" and a paired t-test was conducted to analyse differences between pre to post-best for all CMJ variables. Effect sizes were used to quantify the magnitude of differences between the pre to post-changes within the CA protocols. The effect sizes were classified as follows: trivial (ES = 0.00-0.19), small (ES = 0.20-0.59), moderate (ES = 0.60-1.19), large (ES = 1.2- 1.99) and very large (ES > 2.00) (Hopkins, Marshall, Batterham, & Hanin, 2009).

3. Results

The results from the repeated measures ANOVA on the different warm-up volumes as well as the mean and SD for CMJ variables are displayed in Table 2. Warm-up condition 4 (WU4) (moderate volume) had the highest mean for CMJ RPP ($59.07 \pm 7.76W$) as well as jump height ($0.507 \pm 0.079m$) whilst warm-up condition 6 (very high) had the highest CMJ peak force ($2004.9 \pm 365.3N$). For the CA condition, mean and SD for all pre-, 4-min post, 8-min post and post-best CMJ variables are displayed in Table 3. No significant changes were displayed for any CMJ variables when pre-CMJ variables were compared to either 4-min or 8-min post. When each individual's best recovery period was considered (post-best), CMJ height significantly increased when compared with the pre-jump scores ($p = 0.019$). No other significant differences were identified for any other variables of the CMJ.

Table 2: Intraclass Correlation (ICC) and Coefficient of Variation Percentage (CV%) for Counter Movement Jump (CMJ) variables to assess test-retest reliability.

	RPP	Jump height	Peak force
ICC	0.963	0.980	0.813
CV%	2.2%	2.2%	3.0%

Note: RPP = Relative peak power.

4. Discussion

The primary purpose of this study was to determine if an individualised warm-up volume could enhance CMJ performance. An additional aim was to determine if including a CA to the optimal warm-up, could potentiate subsequent CMJ performance. Considering the vast inconsistencies within the PAPE literature, it is imperative that a sufficient warm-up is performed before any pre-testing variables are assessed. Performing a sufficient warm-up, any significant increase in post-test variables following the CA, can more accurately be assumed to be due to Performance enhancement, rather than the general effects of a warm-up. This is the first study that assesses the effect of adding a heavy dynamic CA to an individual's optimum warm-up.

The results of this investigation showed that WU2, 4 and 5 lead to significantly greater CMJ RPP compared with WU1 (Table 3). Considering three of the five warm-up volumes show a significant enhancement in at least one CMJ variable compared with the very low warm-up volume (WU1), it can be suggested that this warm-up did not adequately prepare participants for CMJ performance. The only difference between the very low and low volume warm-ups was that the low volume warm-up included two minutes of dynamic activities and one practise CMJ. Considering the low WU volume exhibited significantly heightened CMJ RPP than the very low volume, it supports the suggestions from Young and Behm (2003) that a warm-up needs to consist of an aerobic, dynamic stretching and skill rehearsal component.

WU4 produced significantly greater CMJ height than WU 3 and 6 (Table 3). The decreases in CMJ height after the very high warm-up volume suggests that this volume may be too high to enhance CMJ performance. Despite this, three of the sixteen

Table 3: Descriptive statistics for each CMJ variable after the six different warm-up conditions. A statistically significant change is represented by values in bold with * meaning a significant change from WU1, † a significant change from WU3 and ° a significant change from WU6 ($p < 0.05$).

	Very Low WU (1)	Low WU (2)	Low-mod WU (3)	Moderate WU (4)	High WU (5)	Very High WU (6)
RPP (W.kg ⁻¹)	55.49 ± 5.52	57.49 ± 6.15*	57.20 ± 7.97	59.07 ± 7.76*†	58.27 ± 8.21*	56.57 ± 7.41
JH (m)	0.491 ± 0.064	0.500 ± 0.061	0.485 ± 0.087	0.507 ± 0.079†°	0.493 ± 0.076	0.480 ± 0.068
PF (N)	1996.9 ± 271.6	1963.0 ± 306.1	1993.9 ± 294.3	1985.6 ± 304.3	1983.5 ± 308.3	2004.9 ± 365.3

Note: WU = Warm-up, RPP = Relative peak power, JH = Jump height, PF = Peak force.

participants produced their best RPP following WU6, suggesting this was their optimal warm-up. Additionally, the greatest mean for a majority of the variables obtained from the CMJ was observed following the moderate volume warm-up. An explanation for the individuality in the optimum warm-ups could be the different fitness qualities amongst the population (e.g., aerobic capacity), however, apart from 5RM half-squat strength, these were not assessed in this investigation. Furthermore, an individual's optimum WU volume may vary from day to day depending on other confounding variables that could not be controlled within this study (e.g., physical activity completed at work/ during each day).

From these findings, it further suggests that past PAPE literature has not employed adequate warm-ups which could negatively affect pre-CMJ performance (Linder et al., 2010; McBride et al., 2005; Tobin & Delahunt, 2014). McBride et al. (2005) and Linder et al. (2010) both only used four and five minutes of cycling at 70 Watts respectively to warm-up prior to a sprint. Even though both studies concluded that improvements in sprint performance were due to PAPE, questions must be raised about such an assumption as the CA could have improved performance due to general mechanisms of a warm-up as opposed to performance enhancement. Furthermore, Tobin and Delahunt (2014) concluded that a CA of 40 plyometric jumps potentiated CMJ height and peak force across all post testing time points. Despite this finding, it must be questioned whether pre-CMJ performance was optimised, as no aerobic component was included within this warm-up.

When the CA of four half-squats at a 5RM load was added to the optimum warm-up, the repeated measures ANOVA showed no significant improvements in any CMJ variables after four, and eight, minutes of recovery. CMJ jump height displayed a 2.9%

improvement after four minutes recovery, and a 3.1% increase at eight minutes (Table 4), however, neither change was statistically significant, and this was considered a "trivial" effect. Lowery et al. (2012) had participants (parallel squat strength = 1.7 ± 0.2 times body weight) perform a similar CA to the present investigation (four half-squat at a load of 70% of the participants 1RM) and identified significant increases in both jump height and peak power after four minutes rest. Furthermore, Mitchell and Sale (2011) used five repetitions of the half-squat at a 5RM load (participant mean 5RM = 144.5 ± 19.4 kg) to significantly increase CMJ jump height by 2.9% after four minutes recovery. Despite the insignificant change in jump height after the CA in the present study, the percentage increase in jump height after four minutes recovery was actually the same as the significant 2.9% increase identified in the investigation by Mitchell and Sale (2011).

Previous research by Wilson et al. (2013) suggested that both the optimal rest period and CA intensity would be different between individuals. From this suggestion, a comparison between pre- and post-best recovery CMJ performance was also conducted. Post-best jump height (5.2%) showed a statistically significant but small effect after the CA was added to the individuals' optimum warm-up. Such improvements in jump height are similar to that of Young, Jenner and Griffiths (1998) and Mitchell and Sale (2011), even though they found these increases in performance at specific recovery periods. Considering a significant acute enhancement in jump height performance occurred after the performance of the CA, and an optimal WU was executed prior to any pre-CMJ testing, the increase in jump height was most likely due to performance enhancement rather than just a top-up to a general warm-up.

Table 4: Comparison between pre-CMJ variables and each recovery period (4-min, 8-min and post-best) after the performance of the CA. Statistical significance is represented by values in bold with * ($p < 0.05$).

	RPP	Jump height	Peak Force
Pre	60.17 ± 7.16	0.504 ± 0.089	2027.5 ± 276.6
Post-4 min	59.56 ± 6.70	0.519 ± 0.073	2003.0 ± 235.3
% diff pre to post-4min	-1.0	2.9	-1.2
P value	1.000	0.598	1.000
ES (95% CI)	-0.09 (-0.78 – 0.61)	0.18 (-0.51 – 0.87)	-0.10 (-0.78 – 0.61)
Post-8 min	58.37 ± 7.36	0.520 ± 0.079	2024.9 ± 283.0
% diff pre to post-8min	-3.0	3.1	-0.1
P value	0.194	0.216	1.000
ES (95% CI)	-0.25 (-0.94 – 0.45)	0.19 (-0.51 – 0.88)	-0.01 (-0.70 – 0.68)
Post-best	60.00 ± 6.80	0.530 ± 0.074	2055.1 ± 268.6
% diff pre to post-best	-0.3	5.2	1.4
P value	0.838	0.009*	0.289
ES (95% CI)	-0.02 (-0.72 – 0.67)	0.32 (-0.39 – 1.01)	0.10 (-0.59 – 0.79)

Note: RPP = Relative peak power, ES = Effect size, CI = Confidence interval

Although improvements in post-best jump height were observed, no other CMJ variable displayed significant changes from pre- to post-best, and all changes apart from jump height were “trivial”. The intensity of the CA may have been a contributing factor to these CMJ variables not displaying significant improvements. Much of the previous literature used either five repetitions at a 5RM load (Boullousa et al., 2013; Young et al., 1998) or three repetitions at a 3RM load (Kilduff et al., 2007) as a CA. The present investigation used four repetitions at a 5RM load due to the recommendations from Wilson et al. (2013), suggesting that recreationally trained participants should not perform CA that are too fatiguing. It was decided that the four repetitions would be appropriate for the sample of the present study; however, potentially a CA with an extra repetition or a greater load (three at a 3RM) could have elicited greater improvements in post-CMJ performance.

The strength of participants may have been another factor that attributed to limited evidence of PAPE at specific recovery intervals (4 or 8 minutes). Chiu et al. (2003) suggested that participants should be able to squat 1.5 times their body weight whilst Seitz, Villarreal and Haff (2014) recommended relative squat strength should exceed twice that of body weight. The participants in the present study had a relative strength in the half-squat of 2.4kg per 1kg of body weight. Although this exceeds both the strength recommendations of the previously mentioned literature, it must be noted that the squats were only half-squats (90° knee angle) and were performed in a Smith machine. From the research conducted by Chiu et al. (2003) and Seitz, Villarreal and Haff (2014), participants performed parallel squats. This increase in squatting depth would have decreased the total amount lifted during their RM testing. Although participants were asked to not participate in strenuous lower-body activity 48 hours prior to testing sessions, the differing activities participants may have performed in their general day before a session is a further limitation to the study.

Due to the significant increases in jump height after the performance of the CA (with each individual's optimal recovery period considered), a similar warm-up and CA protocol could be used in specific sports settings to take advantage of the acute enhancement of jump height. Provided sufficient equipment was available and the recovery interval could be controlled, athletes could perform a similar warm-up and CA of four half-squat at a 5RM load to potentiate jumping performance similar to that of the CMJ. Coaches and athletes would need to identify each individual's optimum warm-up and recovery time after the CA to take full advantage of the PAPE phenomenon.

Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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