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Physical characteristics of New Zealand Army, Navy and Airforce officer trainees' over a 6-week joint officer induction course

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ABSTRACT

Fitness levels of military personnel have been well researched around the world, however limited data exists on the New Zealand Defence Force (NZDF). This study identifies NZDF officer trainees' physical characteristics during a Joint Officer Induction Course (JOIC) and compares differences across groups. 116 participants (Army n = 75; Navy n = 25; Airforce n =16) were tested over 2.4km run, muscular-endurance (press-ups and curl-ups), body-mass and Y-balance musculoskeletal screening, pre and post a 6-week JOIC. Army performed better in the 2.4km run and press-ups compared to other services ($p < 0.05$), Navy performed better in curls-ups. At completion, there were significant improvements in 2.4km run ($p < 0.01$), press-ups ($p < 0.01$) and curl-ups ($p < 0.01$) across all services. Army officers performed better when compared to Navy and Airforce pre-post. Significant improvements were found for aerobic fitness, upper-body and core muscular-endurance across all services, following a 6-week JOIC.

1. Introduction

The physical fitness levels of recruits and officers entering military service is a major area of interest for defence forces worldwide (Knapik et al., 2006; Knapik, Sharp, & Montain, 2018; Robinson et al., 2016; Rosendal, Langberg, Skov-Jensen, & Kjær, 2003; Rudzki & Cunningham, 1999). Optimal levels of fitness are essential for daily task completion and for safe operation during military deployment (Kyröläinen, Pihlainen, Vaara, Ojanen, & Santtila, 2017) as there is still an essential need for physically capable men and women to deploy and fight on ground, sea and air spaces in the modern military world (Friedl et al., 2015). This has been illustrated by Lovalekar et al. (2018) when measuring physical performance/fitness was ranked in the top five of 44 priority research areas identified via survey from attendees at the 2018 International Congress on Soldiers Physical Performance in Melbourne Australia; with eight of the top ten ranked topics focused on physical demands in operational environments and measuring physical performance adaptation (Lovalekar et al., 2018).

While there is research on other forces in the world in relation to physical training and fitness assessment, including the USA (Deuster & Silverman, 2013), Finland (Kyröläinen et al., 2017), Australia (Rudzki & Cunningham, 1999), and Britain (Brock & Legg, 1997), there is limited research on the New Zealand Defence Force (NZDF) and especially new officer trainees. Although it is clear that physical fitness is vital for military forces, the physical characteristics of recruits and officers entering the NZDF has not been fully understood, and as a result an unwanted outcome of certain forms of training is high injury rates (Davidson, Chalmers, Wilson, & McBride, 2008). Such rates have been revealed both internationally (Andersen, Grimshaw, Kelso, & Bentley, 2016) and in New Zealand (Brooks, Fuller, Kemp, & Reddin, 2008). Previous research suggests military recruit physical performance has generally focused on load carriage and physical preparedness, and its effect on the body. Literature has established that four key factors play a major role in contributing to poor physical-condition and physical-state in military recruits: 1) time and distance on feet (Knapik et al., 2006); 2) entry level fitness (Molloy, Feltwell, Scott, & Niebuhr, 2012); 3) lower limb strength (Bullock, Jones, Gilchrist, & Marshall, 2010); and 4) pre-

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existing injuries (Knapik et al., 2001). These four defined areas combined with a lack of research and data in New Zealand has impacted adversely on the success of the NZDF joint officer induction course (JOIC). Furthermore, research suggests physical training approaches for the modern military service person need to focus on a flexible integration of strength, power and aerobic performance training programs (Kraemer & Szivak, 2012). It is of the utmost importance that forces are physically ready for deployment and physical assessments play vital role in ensuring this occurs. It is also internationally accepted that military personnel need to be physically fit to perform their normal duties, which are likely to be more physically demanding than that of the normal civilian population (Lovalekar et al., 2018), and as previously indicated, will substantially vary within the NZDF. Therefore, it is essential that physical training in the military positively facilitates fitness and conditioning improvement from the on-set of recruit and officer training.

Successful completion of the JOIC, which is the initial training phase for all new officers joining the NZDF, has been compromised by trainees entering the course at low levels of fitness. These low levels have contributed to a lack of ability to progress in the physical training program (Davidson et al., 2008). However, if initial military training is well structured, fitness can be improved with concurrent reductions in injury (Rudzki & Cunningham, 1999). Although an important wider topic, injury is not the focus of this paper. Brock and Legg (1997), investigated the effects of 6-weeks of physical fitness training in female British Army recruits and found 6-weeks was effective for recruits to respond with significant increases ($p < 0.05$) in mean VO_2 max (45.7 $ml.kg.min^{-1}$ to 46.7 $ml.kg.min^{-1}$). This study showed that aerobic fitness can increase effectively over a 6-week military training period. Also observed in the same 6-week period was a significant reduction in mean percentage body fat by 3.3% ($p < 0.001$), indicating that the training period also influences energy balance.

The purpose of the current study was to characterize and assess the effectiveness of the physical training program prescribed within the NZDF JOIC. A further aim of this study was to compare the entry level physical characteristics of the recruits from different services.

2. Methods

2.1. Participants

A total of 116 newly recruited healthy officer trainees (n = 95 male, n = 21 female, age 24 ± 12 years [mean ± SD]) from the NZDF participated in the current study. Participant demographics for each sex and area of service (Army, Navy and Airforce) are displayed in Table 1. Participation in the study was voluntary and ethical approval for the study was obtained from the institution's Human Research Ethics Committee and the NZDF. Volunteers were all from the same course and no trainees declined to be involved. Volunteers were explained the procedures and requirements, and signed consent was provided.

Table 1: Participant demographics. Data shown as means ± standard deviations.

	n	Age (yr)	Height (cm)	Body Mass (kg)
Male				
Army	65	25 ± 9.2	181 ± 5.5	78 ± 12.6
Navy	18	26 ± 2.6	179 ± 6.5	82 ± 13.2
Airforce	12	24 ± 2.8	178 ± 7.5	74 ± 17.4
Male Mean	**95**	**25 ± 2.8**	**179 ± 7.5**	**78 ± 14.6**
Female				
Army	10	24 ± 12	173 ± 7.5	73 ± 10.3
Navy	7	25 ± 5.2	168 ± 9	72 ± 13.8
Airforce	4	21 ± 2.6	174 ± 7.5	74 ± 5.2
Female Mean	**21**	**23 ± 13**	**171 ± 8**	**73 ± 9.8**
Total Mean	**116**	**24 ± 12**	**175 ± 8**	**75 ± 12.1**

2.2. Experimental Design

The experimental design included a single-group longitudinal study, whereby all participants were tested for physical characteristics and performance pre and post a 6-week JOIC. Fitness and musculoskeletal data were collected in weeks one and six of the JOIC across two 90-minute sessions. These tests were selected as they were standard NZDF protocols in place.

2.3. Physical Training Program

Physical training (PT) comprised a controlled two-week introduction phase of body weight exercises and aerobic conditioning. In weeks three and four, the intensity of PT increased to challenge individuals. Weeks five and six then focused on functional fitness and conditioning. This included increased load carriage with a combination of field packs, day packs, webbing (military load-carrying vest with pouches for ammunition and water bottles), and weapons. There was a specified 10-minute warm-up and 5-minute cool-down period for all PT sessions. A total of 18, 90-minute periods were allocated to physical training over the 6-week period and included a combination of aerobic interval running, strength training, circuits, swimming, and bike-boxing-rowing intervals as outlined in Table 2.

Table 2: Joint Officer Induction Course Physical Training Program.

Note: A ten minute 6am early morning activity (EMA) was also conducted daily including stretching, mobility and cognitive reaction games.

Day	Physical Training Class (PT)	Military Activity	Time On-Feet
		WEEK 1	**Intensity:** High, Med, Low (H-M-L)
Monday	**Arrival**- Walking		4hr - L
Tuesday	Walking		5hr - L
Wednesday	Introduction to physical training	50min Basic Drill	5hr - M
Thursday	**(Pre) Fitness Evaluation**	50min Basic Drill	5hr - H
Friday	30 min Running + 30 min Body weight standing exercises	Class work	4hr - M
Saturday		Class work	6hr - L
Sunday	60min Curcuit: Lift / Push / Pull / Lift	Class work	6hr - H
		WEEK 2	
Monday	60min 200m swim test & water tread + body weight exrcises	Class work	6hr - M
Tuesday	60min Interval running 6x800m	3hr Survival training workshop	6hr - H
Wednesday	90min Aerobic Intervals (Off feet):Bike / Row / Box / Core	Class work	4hr - H
Thursday		16hr Endurance Activity: Leader building, marching, load carring, problem solving, PT Curcuits, Running.	18hr - M
Friday	40min Pool Recovery & Stretch	Class work	3hr - L
Saturday		7hr Weapons training	5hr - M
Sunday	OFF	OFF	
		WEEK 3	
Monday	90min Interval training: Bike / Row / Box / Core (Off Feet)	4hr Weapons training	5hr - M
Tuesday	90min Interval Run 6x 400-800m & body weight standing exercise	4hr Weapons training	5hr - H
Wednesday		4hr Weapons training	5hr - M
Thursday		4hr Weapons range activity	2hr - L
Friday		9hr Weapons range activity	6hr - M
Saturday		9hr Weapons range activity	6hr - M
Sunday		4hr Weapons range activity	2hr - L
		WEEK 4	
Monday	90min Interval Run 8x 400-800m & body weight standing exercise	3hr Land navigation	4hr - H
Tuesday	90min Interval training : Bike / Row / Box / Core (Off Feet)	6hr Land navigation	10hr - M
Wednesday	60min Curcuit: Lift / Push / Pull / Lift	4hr Sea suvival workshop (pool)	6hr - M
Thursday		4hr Land navigation	6hr - L
Friday	60min Interval running 4x800m	Class work	3hr - H
Saturday		8hr Bush craft skills	10hr - L
Sunday	OFF	OFF	
		WEEK 5	
Monday		24hr Sea & bush svrvival activity	18hr - M
Tuesday		Class work	3hr - L
Wednesday	60min Strength & Mobility + 6x 50 'strid outs'	60min Basic drill	4hr - M
Thursday	60min Pool + body weight exercise	60min Basic drill	4hr - M
Friday	**(Post) Fitness Evaluation**	Class work	4hr - H
Saturday		Tactical field exercise living outdoors: Patrolling, Vehicle checkpoints, obstical buulding, navigation	18hr - M
Sunday		Tactical field exercise living outdoors: (As above)	18hr - M
		WEEK 6	
Monday		Tactical field exercise living outdoors: (As above)	18hr - M
Tuesday		Tactical field exercise living outdoors: (As above & including 12km pack march)	14hr -M/H
Wednesday		60min Basic drill	5hr - L
Thursday		60min Basic drill	5hr - M
Friday	Course End	Course End	

2.4. Fitness Testing

The standard NZDF JOIC fitness evaluation was conducted by the same NZDF Physical Training Instructors (PTIs), at 0800 both pre and post course. This evaluation consisted of three key components, 1) 2.4km road run, 2) maximum curl-ups, and 3) maximum press-ups. The 2.4km road run, which has been shown to provide an effective evaluation of aerobic fitness (Booth, Probert, Forbes-Ewan, & Coad, 2006; Burger, Bertram, & Stewart, 1990), was completed on a sealed flat road in two groups of 58. The run was conducted in a similar fashion to that described by Knapik et al. (2006), where participants started together, but individual effort was assessed by participants completing the distance in the quickest time possible in running shoes, shorts and t-shirt. Run times were measured via stopwatch to the nearest second by a designated PTI. There was no wind for each of the tests and they were conducted at approximately (22◦C) before daily temperature increased. No alcohol was consumed during the course and no caffeine or smoking was permitted in the two hours prior to testing.

The Curl-up protocol as used by Vera-Garcia, Grenier, and McGill (2000) provided an evaluation of local muscular-endurance of the core where repetitions were completed until failure (inability to continue). The curl-up was performed with participants in a supine position with knees bent at 90º and feet flat on the floor. Hands were held in a fist with arms straight. Hands slid up the thigh until the wrist met the apex of the knee. Hands then slid back down the thigh until the shoulder blades and shoulders touched the ground. A repetition was counted by a PTI every time the wrist reached the apex of the knee until failure, where the test finished. There was no time limit on repetitions, but they were completed in a continuous fashion with a pause of only 1-2 seconds between reps.

Press-ups were used to assess upper-body muscular-endurance similar to the protocol outlined by Booth et al. (2006) and Knapik et al. (2006). They were performed on a flat wooden gymnasium surface. Hands were placed on a line in the prone press position just slightly wider than shoulder width. A ‘ready’ cue was then given where the body position was adjusted up to the start position of arms straight, feet shoulder width apart and the head looking downward. From the start position the body was lowered eccentrically with a straight-line maintained between the shoulders and heels, until the elbows were at 90º or until the chest was approximately 3-5cm from the ground. During the concentric phase arms were extended until straight while maintaining the back and head positions. A repetition was counted by a PTI every time the full range of motion was completed until failure. For both the press-ups and curl-ups, one warning was given for an incomplete repetition, prior to participants being stopped by the PTI.

Body mass was recorded at each assessment at 0800hr (two hours after breakfast) prior to the fitness assessments on a set of digital scales (SOEHNLE, Style Sense Safe 200, Germany) to the nearest 100g, while participants wore a t-shirt and shorts with shoes removed.

2.5. The Y-Balance Musculoskeletal Screening Test

To determine musculoskeletal asymmetry, the Y-balance test (YBT) was used for both the Lower (YBT-LQ) and Upper Quartiles (YBT-UQ) (Shaffer, 2013). The YBT-LQ examines unilateral reach in three different directions, anterior, posteromedial, and posterolateral. Differences in the maximum reach distance for left and right leg were compared to examine reach asymmetry for each direction, with lower limb reach normalised to leg length (anterior superior iliac spine to the most distal portion of the medial malleolus). The YBT-UQ test is designed to obtain a quantitative measure of trunk and upper extremity functional symmetry, core stability, strength and mobility. It is shown to be a reliable predictor of upper body musculoskeletal injuries, particularly in the shoulder girdle (Butler, Arms, et al., 2014; Butler, Myers, et al., 2014; Gorman, Butler, Plisky, & Kiesel, 2012). For YBT-UQ participants reach in three directions; medial, inferomedial, and superomedial to determine percentage of functional symmetry and potential injury risk. Scores are also normalised to participant’s arm length (spinous process of the cervical vertebrae C7 to the tip of the longest finger of the right arm). Individuals with asymmetries greater than 4cm are more likely to sustain injury (Plisky, Rauh, Kaminski, & Underwood, 2006).

Composite scores of less than88% for males and 85% for females (UQ), and 98% for males and 92% for female for (LQ), is a strong indicator of injury (Butler, Arms, et al., 2014; Butler, Myers, et al., 2014; Gorman et al., 2012; Plisky et al., 2006).

2.6. Statistical Analysis

Simple group scores are shown as mean ± SD values unless stated otherwise. All statistical analyses were performed using the Statistical Package for Social Science (V. 22.0, SPSS Inc., Chicago, IL), with statistical significance set at $p \leq 0.05$. A Student’s paired T-test was used to compare pre to post performance measures for the entire group, for each sex (male, female), and for each service (Army, Navy, Airforce). To examine whether there were any differences between subgroups, Group (e.g., male vs female, service comparisons) x Time (pre and post) two-way multivariate analysis of variance (MANOVA’s) were performed. A Bonferroni adjustment was applied if significant main effects were detected. Analysis of the distribution of residuals was verified visually with histograms and also using the Shapiro-Wilk test of normality. Magnitudes of the standardized effects between pre and post were calculated using Cohen’s *d* (Cohen, 1988) and interpreted using thresholds of 0.2, 0.5, and 0.8 for *small, moderate* and *large*, respectively.

3. Results

A total of 119 officer trainees started the JOIC with 116 completing the course, representing a drop-out rate of 2.5%. Those that dropped out were not injured but left due to personal choice. At baseline, Army trainees performed significantly better in the 2.4km run and press-ups than their Navy and Army counterparts ($p < 0.05$) (table 3), however Navy trainees at baseline performed significantly better in curls ups than both Army and Airforce (p = 0.01).

Following 6-weeks of JOIC training, there was statistically significant decreases in body mass for Army males (78 ± 10.1 to 76.1 ± 9.2, $p < 0.01$, d = -0.18), Navy males (81.1 ± 13.8 to 79.3 ± 12.4, $p < 0.01$, d = -0.20), and all females collectively (73 ± 13.0 to 71.4 ± 11.8, $p < 0.01$, d = -0.120, Table 3). The total mean across all groups also showed a decrease in body mass from (75.5 ± 11 to 73.7 ± 10, $p < 0.01$, d = -0.20).

Performance improvement was evident (Table 3, Figure 1) over the duration of the JOIC with statistically significant decreases in 2.4km run time for all males (644 ± 83 to 589 ± 82, $p < 0.01$, d = -0.57), all females (708 ± 48 to 661 ± 42, $p < 0.01$, d = -0.86), and for all JOIC participants collectively (676 ± 83 to 625 ± 82, $p < 0.01$, d = -0.57). Following the 6-weeks of training there were also significant increases in maximum repetitions for press-ups (26 ± 12 to 33 ± 11, $p < 0.01$, d = 0.48), and curl-ups (42 ± 21 to 56 ± 39, $p < 0.01$, d = 0.67) for all JOIC participants (Table 3).

The MANOVA resulted in a significant difference when comparing gender for pre-post 2.4km run time ($p < 0.01$), and press-ups ($p < 0.01$). However, there were no significant differences found for curl-ups ($p > 0.05$). There was a significant group interaction for service pre press-ups for Army vs Navy ($p < 0.01$) and Army vs Airforce ($p = 0.01$). There was a significant interaction for post press-ups for Navy vs Army ($p = 0.01$). No significant interaction was found for any other measures.

YBT musculoskeletal screening following 6-weeks of JOIC showed no significant mean improvement, with only *small* to *moderate* improvements in some limb scores (Table 4).

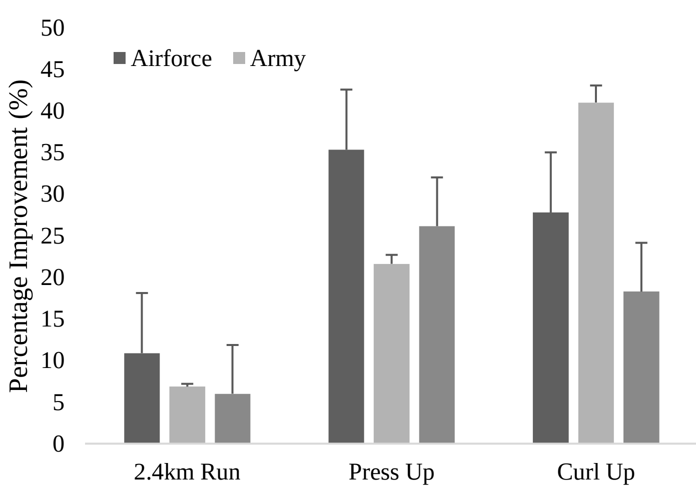

Figure 1: Percentage improvement pre to post for fitness testing scores for 2.4km run, press-ups and curl-ups for all trainee officers of the 6-week JOIC.

4. Discussion

The purpose of the current study was to compare and characterize New Zealand Army, Navy and Airforce officer trainees' pre and post a 6-week joint officer induction course. The 6-weeks of military training resulted in improved physical fitness markers as seen by significant improvements ($p < 0.01$) in all three measures; 2.4km run, press-ups and curl-ups. Although Army and Navy trainees performed better at baseline, Airforce percentage improvement for 2.4km run (11%) and press-ups (36%) was better than both other services. For curl-ups, the greatest improvement was seen in the Army trainee's (41%). Other international military studies have also shown comparable changes in aerobic fitness and strength-endurance over similar durations (Brock & Legg, 1997; Hendrickson et al., 2010; Hoffman, Chapnik, Shamis, Givon, & Davidson, 1999; Hofstetter, Mäder, & Wyss, 2012).
The current study demonstrated similar findings as Brock and Legg (1997) and Hofstetter et al. (2012), with the transition from civilian daily routine to a physically more demanding military routine leads to significant improvements in muscular-endurance and aerobic fitness (Hofstetter et al., 2012). This effect was particularly evident in Airforce recruits who had the lowest fitness level pre JOIC, but made the best overall improvements. Hendrickson et al. (2010) and Hoffman et al. (1999), also found similar outcomes in aerobic fitness and muscular-endurance with college athletes and new recruits joining the Israeli military respectively.

Regardless of service and initial aerobic fitness level, all officer trainees in the current study made notable increases in aerobic fitness over the 6-week duration. The mean improvement observed is comparable with Brock and Legg (1997), who found an increase in aerobic fitness when measuring VO_{2max} and strength in female recruits in the British army over a 6-week period. Brock and Legg (1997), also found a statistically significant ($p < 0.05$) increase in aerobic fitness occurred (45.7 $ml.kg.^{-1}min^{-1}$ to 46.7 $ml.kg.^{-1}min^{-1}$) and was reflected in a 6.1% improvement in maximal cycling time in a cycle ergometer test. In a study by Hofstetter et al. (2012), at the Fusilier Infantry Training School in Switzerland, recruits completing 7-weeks of infantry training displayed similar aerobic fitness improvement to the trainees in the current study regardless of starting level of fitness. Hofstetter et al. (2012) outlined that over 7-weeks, results showed there was significant improvement in the distance and velocity covered in the Conconi Progressive Endurance Run Test (Conconi et al., 1996).

Of the three services in the current study, Army trainees performed better in the 2.4km run at baseline and showed significant improvement pre-post JOIC for both males and females. Regardless of initial aerobic fitness, results show that all trainees improved in the current study. It has previously been found that recruit trainees who possess low levels of fitness will often make considerable physical performance gains due to having more room for improvement (Orr, Pope, Johnston, & Coyle, 2010). This finding was supported in the current study.

Table 3: Joint Officer Induction Course Pre-Post Scores.

	Body Mass (kg)				**2.4km Run (sec)**				**Press-Ups (Repetitions)**				**Curl-Ups (Repetitions)**			
	Pre	**Post**	**p-value**	**Effect Size**	**Pre**	**Post**	**p-value**	**Effect Size**	**Pre**	**Post**	**p-value**	**Effect Size**	**Pre**	**Post**	**p-value**	**Effect Size**
Male																
Army	78 ± 10.1	76.1 ± 9.2	<0.01*	-0.18	681 ± 68	567 ± 82	<0.01*	-0.71○	39 ± 9	43 ± 10	<0.01*	0.31■	43 ± 16	76 ± 40	<0.01*	1.02+
Navy	81.1 ± 13.8	79.3 ± 12.4	<0.01*	-0.20■	648 ± 76	623 ± 70	0.14	-0.32■	30 ± 10	35 ± 10	<0.01*	0.51○	36 ± 14	42 ± 10	0.04*	0.56○
Airforce	74 ± 5.2	72.8 ± 4.3	0.08	-0.32■	667 ± 157	577 ± 79	0.08	-0.69○	32 ± 10	39 ± 10	<0.01*	0.78○	42 ± 36	49 ± 33	0.02*	0.18
Male Mean	**77.9 ± 10.6**	**76.1 ± 9.6**	**0.08**	**-0.23■**	**644 ± 83**	**589 ± 82**	**<0.01***	**-0.57○**	**34 ± 10**	**39 ± 11**	**<0.01***	**0.53○**	**40 ± 19**	**56 ± 38**	**<0.01***	**0.02**
Female																
Army	72.8 ± 12.6	71.3 ± 11.3	0.06	-0.13	694 ± 30	655 ± 24	<0.01*	-1.09+	21 ± 6	30 ± 7	0.05*	0.68○	32 ± 9	44 ± 15	0.02*	0.77○
Navy	71.9 ± 13.1	70.5 ± 12.8	0.18	-0.11	681 ± 45	642 ± 28	0.15	-0.88+	21 ± 9	29 ± 7	<0.01*	0.95+	58 ± 46	69 ± 7	0.17	0.26■
Airforce	74.4 ± 17.4	72.5 ± 15.0	0.22	-0.13	750 ± 118	686 ± 127	0.06	-0.60○	12 ± 5	21 ± 8	0.02*	1.12+	40 ± 25	56 ± 30	0.38	0.15
Female Mean	**73 ± 13.0**	**71.4 ± 11.8**	**<0.01***	**-0.12**	**708 ± 48**	**661 ± 42**	**<0.01***	**-0.86+**	**18 ± 7**	**27 ± 7**	**<0.01***	**0.91+**	**43 ± 28**	**56 ± 41**	**0.01***	**0.39■**
Service Mean																
Army	74.5 ± 13	73.7 ± 10	<0.01*	-0.17	656 ± 49^	611 ± 54	<0.01*	-0.68○	30 ± 8^	37 ± 9	<0.01*	0.32■	37 ± 13^	60 ± 27	<0.01*	0.89+
Navy	76.8 ± 13	74.9 ± 13	<0.01*	-0.17	665 ± 61#	633 ± 50	0.07	-0.37■	25 ± 9#	32 ± 9	<0.01*	0.54○	47 ± 30#	56 ± 43	0.01*	0.28■
Airforce	74.2 ± 11	72.6 ± 10	0.02*	-0.27■	708 ± 138	631 ± 104	0.04*	-0.66○	22 ± 8	30 ± 9	<0.01*	0.58○	41 ± 31	52 ± 31	0.01*	0.17
Total Mean	**75.5 ± 11**	**73.7 ± 10**	**<0.01***	**-0.20■**	**676 ± 83**	**625 ± 82**	**<0.01***	**-0.57○**	**26 ± 12**	**33 ± 11**	**<0.01***	**0.48■**	**42 ± 21**	**56 ± 39**	**<0.01***	**0.67○**

* Significant difference between pre and post values ($p < 0.05$).
# Significant difference between Airforce and Navy at baseline.
^ Significant difference between Army and Navy at baseline.
■ Small effect size
○ Moderate effect size
+ Large effect size

Table 4. Joint Officer Induction Course Pre-Post Y-Balance Musculoskeletal Screen Scores.

	Right Upper Limb				**Left Upper Limb**				**Right Lower Limb**				**Left Lower Limb**			
	Pre	**Post**	**p-values**	**Effect Size**	**Pre**	**Post**	**p-values**	**Effect Size**	**Pre**	**Post**	**p-values**	**Effect Size**	**Pre**	**Post**	**p-values**	**Effect Size**
Male																
Army	93 ± 6	95 ± 7	0.80	-0.05	93 ± 4	96 ± 6	0.04*	0.17	96 ± 11	96 ± 11	0.52	-0.08	95 ± 6	96 ± 7	0.80	-0.05
Navy	92 ± 7	94 ± 7	0.09	0.35■	92 ± 8	95 ± 7	0.12	0.23■	94 ± 6	96 ± 7	0.29	0.16	94 ± 10	97 ± 10	0.09	0.35■
Airforce	92 ± 7	94 ± 10	0.07	0.55○	94 ± 4	94 ± 7	0.09	-0.44■	98 ± 11	96 ± 9	0.45	-0.11	99 ± 10	96 ± 11	0.07	0.55○
Male Mean	**92 ± 6**	**94 ± 8**	**0.32**	**0.29■**	**93 ± 7**	**95 ± 7**	**0.08**	**-0.01**	**96 ± 8**	**96 ± 8**	**0.42**	**-0.01**	**95 ± 8**	**96 ± 8**	**0.32**	**0.29■**
Female																
Army	95 ± 6	99 ± 5	0.04*	1.11+	97 ± 4	100 ± 6	0.13	0.22■	98 ± 6	98 ± 10	0.49	0.17	96 ± 8	97 ± 7	0.04*	1.11+
Navy	90 ± 12	93 ± 9	0.48	0.93+	87 ± 8	95 ± 6	0.79	-0.10	98 ± 9	97 ± 7	0.19	0.44■	97 ± 8	98 ± 7	0.48	0.93+
Airforce	88 ± 3	88 ± 9	0.82	-1.37+	90 ± 4	90 ± 6	0.21	0.72○	90 ± 9	96 ± 7	0.15	0.98+	88 ± 5	91 ± 7	0.82	-1.37+
Female Mean	**92 ± 9**	**95 ± 8**	**0.45**	**0.22■**	**92 ± 7**	**96 ± 6**	**0.38**	**0.28■**	**97 ± 8**	**97 ± 7**	**0.28**	**0.53○**	**95 ± 8**	**96 ± 7**	**0.45**	**0.22■**
Service Mean																
Army	94 ± 6	97 ± 6	0.38	0.16	95 ± 4	98 ± 6	0.01*	0.19	97 ± 9	97 ± 11	0.88	0.02	96 ± 7	97 ± 7	0.38	0.16
Navy	91 ± 10	94 ± 8	0.15	0.34■	90 ± 8	95 ± 7	0.15	0.19	96 ± 8	96 ± 7	0.24	0.19	95 ± 9	98 ± 9	0.15	0.34■
Airforce	90 ± 5	91 ± 10	0.29	0.35■	92 ± 4	92 ± 7	0.16	-0.27■	94 ± 10	96 ± 8	0.75	0.06	94 ± 8	93 ± 9	0.29	0.35■
Total Mean	**92 ± 8**	**95 ± 8**	**0.28**	**0.28■**	**93 ± 7**	**96 ± 7**	**0.11**	**0.04**	**96 ± 8**	**96 ± 8**	**0.62**	**0.09**	**95 ± 8**	**96 ± 8**	**0.28**	**0.28■**

* Significant difference between pre and post values ($p < 0.05$).

■ Small effect size

○ Moderate effect size

+ Large effect size

Findings from the present study show a significant increase in maximal press-ups pre-post for all JOIC officer trainees collectively ($p < 0.01$). This appears to have been achieved through a combination of both daily prescribed PT and daily manual-handling of equipment (field-stores, pack and weapon). Previous research by Williams, Rayson, and Jones (2002) also documented a similar relationship between traditional prescribed PT (6-8 weeks), manual-handling and muscular-endurance improvement. Interestingly however, although Williams et al. (2002) research was focused on lower body, a similar mean improvement of 28% for maximum repetitions during squatting was found. This supports the muscular-endurance improvement observed in the current study from a similar combination of training.

With core muscular-endurance, although not a specifically targeted training modality, the inclusion of 'functional core training' throughout the course (gym circuits, pack walks, running, swimming, log lifts and tyre flips), likely contributed to an increase in core muscular-endurance. Similar to that observed by Haddock, Poston, Heinrich, Jahnke, and Jitnarin (2016), when prescribed strength training is combined with core strength and functional training within the PT program, it can be very effective in addressing the requirement of improving general strength condition and local muscular-endurance. As there was a requirement to lift, carry and manual-handle equipment on a daily basis further to prescribed PT, a functional training effect may have been gained from such activities (Knapik et al., 2003; Kraemer & Szivak, 2012). This also tends to indicate the prescribed volume of PT and functional training improved core muscular-endurance.

The current study is not without its limitations. These include the lack of control around some of the measures, (e.g., the 2.4km run was outside on the road and weather dependent), and there was no metronome for press-ups and curl-ups or standardisation for the height of the press-ups apart from full extension at the elbows. A further limitation is the difficulty to make comparisons between countries for these tests since most countries and individual militaries use different physical tests for fitness assessments. Future research should use standardised tests to make these comparisons in fitness levels across other militaries around the world. Future research should also consider implementing and comparing specific interventions to further increase physical adaptations during the 6-week JOIC, (e.g. nutrition, training, and recovery).

In conclusion, results from this study have demonstrated that regardless of gender, service and starting fitness level, aerobic capacity and muscular-endurance can be positively enhanced from a combination of both prescribed PT and military manual-handling activates over the 6-week JOIC duration. Army officer trainees possessed greater physical characteristics at baseline and post testing compared to the other two services (Navy and Airforce). Collectively, results showed that 6-weeks of JOIC improved aerobic fitness by ~8%, and muscular-endurance by ~31%. In the future, looking at strategies to improve sleep, recovery and adaptation to gain even greater benefits over the 6-week JOIC and New Zealand Defence Force training courses should be given consideration.

Conflict of Interest

The authors declare no conflict of interests.

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International cricket injury surveillance: A media-based injury report on the ICC men's Cricket World Cup 2015

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A B S T R A C T

Effective injury prevention strategies rely on accurate injury surveillance data. It became apparent that the ICC men's Cricket World Cup (CWC) 2015 One-Day tournament was not planning to have official injury surveillance. Therefore, the aim was to prospectively quantify the number and type of media-reported injuries from all CWC competing teams. Injury data were collected prospectively throughout the 49 tournament matches. The study group monitored the tournament website, official team web pages and major news websites to track availability and injury status of all 219 tournament players. Captured data included time-loss and non-time-loss injuries and also recorded the injured player position, injury site and injury onset activity. The media reported 31 total injuries from 23 players (12% of players), which resulted in these players missing a total of 69 matches. Positionally, fast bowlers (12) and batsmen (11) had a similar injury incidence, but fast bowlers missed 35% more matches (31) compared to batsmen (23). Anatomically, 17, 8 and 6 injuries occurred in the lower limb, abdominal/trunk and upper limb respectively. Crucially, hamstring injuries (17) followed by abdominal/trunk side-strains (15), hand (9), lower back (7) and shoulder injuries (6) accounted for the most tournament matches missed. Across the tournament, 4% of players experienced an injury during bowling, 4% during training and 3% while batting. Injuries reported to the media may not include all the injuries experienced by all players with teams possibly not wanting to disclose their likely playing team, too far in advance. Nevertheless, this unofficial 2015 CWC data provides a useful addition to previous injury surveillance studies and demonstrates the need for more formal and rigorous injury surveillance programmes. The large proportion (>10%) of injured players, demonstrates the importance of implementing injury prevention practises to maintain a team's overall competitive strength.

1. Introduction

Cricketers are at risk of experiencing either acute or overuse injuries (Stretch., 2003); such injuries may be personally devastating for the injured cricketer and may also affect the overall team strength. Cricket injury surveillance helps in identifying the injury-prone body areas and also to analyse the injury aetiology. This, in turn, allows the targeted implementation of preventative measures designed to reduce future sports injuries.

Effective cricket injury surveillance requires the approval of the sporting bodies and event organisers (Orchard et al., 2005). It also depends heavily on the quality of injury reporting by the medical staff, coaching staff and players (Ranson et al., 2013). Injury surveillance in cricket is meticulously conducted by several international cricketing boards (Frost & Chalmers, 2014; Orchard et al., 2002; Ranson et al., 2013). Analysis of these injury surveillances and the subsequently published studies have helped understand the extent of cricket injuries and establish their aetiology. In addition to identifying the most injury-prone player position, further analysis has helped improve the understanding of the injury mechanisms.

Injury surveillance studies have provided various explanations to describe injury prevalence rates, injury-prone positions, most frequently injured body areas and likely injury risk factors. Longitudinal studies undertaken on elite Australian male

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cricketers highlighted the increased injury risk of the fast bowling position (Orchard et al., 2002). A six-year observational study of South African national cricketers concluded that bowling accounted for the majority (40%) of all injuries (Stretch, 2003). Identification of injury prevalence among elite Australian male cricketers revealed that lumbar stress fractures (1.9%), hamstring strains (1.4%), abdominal/trunk side-strains (0.9%), and wrist/hand fractures (0.8%) (Orchard, Kountouris, & Sims, 2016 a) were the most common injuries during ten playing seasons. These injury findings have been consistently similar across different elite cricket cohorts. Based on these findings, several explanations have been proposed to understand the injury aetiology. Association between bowling style and lumbar injuries, the correlation between throwing workload and shoulder injuries, the relationship between front foot landing mechanics and knee injuries are some examples of on-going studies exploring injury aetiology in cricket.

Limited over international tournaments like the CWC may cause an acute spike in the workload of the cricketers. An association between bowling workload and injury has been suggested, with bowlers bowling a total match bowling workload of >50 overs in first-class games and a bowling workload of >30 overs in the second innings have been predicted to have a higher injury risk (McNamara, Gabbett, & Naughton, 2017). An extended period of low bowling workloads during Twenty20 matches and unprepared high bowling workloads in first-class matches has also been speculated as an aetiology for injury (Orchard et al., 2015). Prospective cohort studies amongst elite cricketers also suggest that increased throwing workload is a risk factor for the development of upper limb injury (Orchard et al., 2015). Fewer rest days and a significant increase in throwing workloads a week before the injury onset also have been observed as a cause for shoulder injuries (Saw, Dennis, Bentley, & Farhart, 2011). Research findings like these help team coaches, medical and conditioning staff to design, plan and implement strategies to reduce injury occurrence to their players. Hence, cricket injury surveillance is an essential step toward injury prevention and management.

The International Cricket Council (ICC) is the global governing body for cricket, and they conduct three formats of international championship tournaments, Test, One-Day and Twenty20 (“ICC Three Game Formats,” 2015). To date, the most popular international cricket tournament based on spectator attendance has been the 50-over ICC men's CWC (“Cricket World Cup Crowd Attendances,” 2015). The ICC has hosted 20 different national teams, across the eleven editions of the ICC men's CWC tournament (“ICC Cricket World Cup,” 2015). Worldwide, the 50-over men's CWC is one of the most viewed international sporting events, with over 2.2 billion watching the ICC men's CWC 2015 (“ICC Cricket World Cup,” 2015). Despite the 47-year tournament's history and popularity, there has only been a single official injury surveillance study undertaken, during the 2011 CWC (Ranson et al., 2013).

In the lead up to the 2015 ICC CWC, the information provided by ICC administrators verified that there was to be no official injury surveillance undertaken during the upcoming CWC tournament jointly hosted by Australia and New Zealand. Bureaucratically, it would be challenging to obtain injury incidence data from all teams without official permission and team management cooperation. Fortuitously, other sports injury surveillance studies have been conducted through media reports in the absence of official tournament injury surveillance. A 2009 injury surveillance study of 471 professional German football players, was solely conducted using media reports released to a sports magazine because no official injury surveillance was administered (Faude et al., 2009), in the study they recorded that 83% (392 injured players) of the players were injured during the 2004/05 playing season. This suggests that, in the absence of official sports injury surveillance, the collection of media reported injuries may be used to estimate a tournament's injury prevalence. Therefore, it would be possible to collect injury information relating to the participating squads of the ICC men’s CWC 2015 using official media channels. Reported injuries could then be collated with players missing subsequent matches. Therefore, this study was aimed at obtaining and analysing all media reported injuries during the ICC men’s CWC 2015.

2. Methods

2.1 Study design

Observational descriptive study.

2.2 Participants

The ICC men’s CWC 2015 took place from 14 February to 29 March 2015. The last date for each playing nation to submit their 15-man squad to the ICC was 7 January 2015; however, a replacement player could be added later at the expense of another player for injury or disciplinary reasons. A total of 14 playing nations and 219 players contested the 2015 tournament. Among the 219 players, 47% were specialist batsmen, 46% bowlers and 7% wicket-keepers, with the mean age being 28 ± 4 years (refer to Table 1).

Table 1: Profiles of players competing in the ICC men's Cricket World Cup 2015

Player position	n	%
Right-handed specialist batsman	67	31
Left-handed specialist batsman	37	17
Right fast-medium bowler	22	10
Right medium-fast bowler	20	9
Wicket-keeper	15	7
Right off-break bowler	12	6
Slow left-arm orthodox	11	5
Right fast bowler	9	4
Right leg-break bowler	7	3
Right medium bowler	6	3
Left fast bowler	4	2
Left medium-fast bowler	4	2
Left fast-medium bowler	3	1
Left medium bowler	2	1
Total	219	100

n = number of players

2.3 Player characterisation

All player positions were characterised according to their designated position prior to the commencement of the tournament (Orchard et al., 2005). For this study, the bowler profiles were defined according to the universally accepted characterisation as listed on ESPN ("Wisden Cricinfo," 2015, Orchard et al., 2016 b). For injury surveillance purpose in this study, all the player positions such as fast, fast-medium, medium-fast, medium bowlers were grouped and classified as fast bowlers (Orchard et al., 2005). Within the spin bowlers' category, all types of spin bowlers, off-break bowlers, slow orthodox bowlers, and leg-break bowlers were included. As the position of an "all-rounder" is not recommended for injury surveillance purpose (Orchard et al., 2005, 2016 b), we did not include the term in this study. The player positions of wicket-keeper and batsmen were also characterised according to the universally accepted listing on ESPN ("Wisden Cricinfo," 2015), this method is also recommended by both the international consensus statements on injury surveillance in cricket (Orchard et al., 2005, 2016 b).

2.4 Data collection

Data collection commenced from 7 January 2015 till the 49th match on 29 March 2015. Prior to the tournament start, information on each squad for the 14 teams was collected from several websites ("ICC Cricket World Cup," 2015, "Match Schedules and News Online," 2015 & "Making cricket CRICHQ," 2015). Player information including, date of birth, batting handedness, bowling arm and predominant playing position were collected and cross-checked between the source websites. Injury information was collected from over twenty national and international news websites, and any media reported injuries were cross-checked with source websites. In addition, each match during the ICC CWC 2015 tournament ("ICC Cricket World Cup," 2015), was monitored for checking the accuracy of reports relating to players missing matches. Collected injury information included, each injured player's position, injured body area, activity at the time of injury and the number of matches missed due to injury. Screenshots of all the injury-related media reports from all source and media websites collected during the 2015 ICC CWC are archived for future data reference.

2.5 Data analysis

Data were collated using a Microsoft Excel spreadsheet which summarised player descriptive data, tracked injury variables and tournament day availability.

The tournament injury prevalence was calculated as follows: Sum of all tournament injuries/sum of all tournament players multiplied by 100.

Injury prevalence per playing position was calculated as follows: Sum of injuries per playing position/sum of all tournament players multiplied by 100.

Percentage of injuries per body area, per playing position, was calculated as follows: Sum of injures per body area, per playing position/ sum of all tournament injuries multiplied by 100.

Percentage of injuries per body area was calculated as follows: Sum of injuries per body area/ total number of injuries multiplied by 100.

Injury prevalence per activity at the time of an injury was calculated as follows: Sum of injuries per activity/ sum of all tournament players multiplied by 100.

For the sake of this study, "*if a player missed a match due to an injury, it was considered a match time-loss injury, if there was a media report of a player being injured and if the same player was subsequently recorded playing a match the same day or the next day it was considered a non-time-loss injury"*. The total number of matches missed due to the injury was calculated by summing the first day of any match missed due to the reported injury and the reported unavailability of the same player to play subsequent matches after the injury onset. For replaced players, the number of matches missed was calculated from their first CWC 2015 match appearance till the last game date that they were replaced.

3. Results

Over the course of the tournament, 31 players sustained injuries. Therefore, the tournament injury prevalence was 14%. Between the playing positions, fast bowlers and batsmen, a similar prevalence of match time-loss injuries were recorded, as shown in Table 2.

Table 2: Injury prevalence by playing position

Player position	Time-loss injuries		Non-time-loss injuries		Total injuries	
	n	%	n	%	n	%
Fast bowler	12	5	3	1	15	7
Batsmen	11	5	1	0.4	12	5
Spin bowler	3	1	-	-	3	1
Wicket-keeper	1	0.4	-	-	1	0.4
Total	27	12	4	2	31	14[a]

n = number of injuries, [a] Sum of all injuries (31) / sum of all tournament players (219) x 100 = 14%

Overall, fast bowlers had the highest injury prevalence during the tournament. Knee and foot injuries were more prevalent in fast bowlers. No lower back injuries were reported amongst fast bowlers.

Table 3: Injured body parts by playing position

Body part	Fast bowler		Batsmen		Spin bowler		Wicket -keeper		Total	
	n	%	n	%	n	%	n	%	n	%
Hamstring	1	3	3	10	1	3	-	-	5	16
Abdominal / Trunk side-strain	3	10	2	6	-	-	-	-	5	16
Knee	3	10	1	3	-	-	-	-	4	13
Foot	3	10	1	3	-	-	-	-	4	13
Hand	1	3	1	3	1	3	-	-	3	10
Lower back	-	-	2	6	1	3	-	-	3	10
Shoulder	1	3	-	-	-	-	1	3	2	6
Elbow		-	1	3	-	-	-	-	1	3
Pelvis	1	3	-	-	-	-	-	-	1	3
Quadriceps	-	-	1	3	-	-	-	-	1	3
Calf	1	3	-	-	-	-	-	-	1	3
Achilles	1	3	-	-	-	-	-	-	1	3
Total	15	48	12	39	3	10	1	3	31	100

n = number of injuries

Of all sustained injuries, hamstring injuries and abdominal/trunk side-strains caused the tournament players to miss the most number of matches.

Table 4: Overall matches missed per injured body part

Body part	Total number of injuries for all players per injured body part	Overall matches missed
Hamstring	5	17
Abdominal/Trunk side- strain	5	15
Knee	4	4
Foot	4	6
Hand	3	9
Lower back	3	7
Shoulder	2	6
Elbow	1	-
Pelvis	1	2
Quadriceps	1	2
Calf	1	1
Achilles	1	-
Total	31	69

Four percent of the tournament players sustained an injury while bowling in matches and three percent while batting in matches. Four percent of players got injured while training but information on whether it was specifically cricket training or gym training was not reported. The activity at injury onset for two injuries reported prior to the tournament start was unknown, so they are reported as "prior to tournament" in Table 5.

Table 5: Injury prevalence by activity

Activity	Injuries n	%
Bowling	9	4
Training	9	4
Batting	6	3
Fielding	5	2
Prior to tournament	2	1
Total	31	14 [a]

n = number of injuries

[a] sum of all injuries (31) / sum of all tournament players (219) x 100 = 14%

During the tournament, fast bowlers missed the highest number of matches (31) due to the sustained injuries, and this was followed by batsmen missing 23 matches, spin bowlers missing 12 matches and wicket-keepers missing three matches.

4. Discussion

Executing injury surveillance even with official permission requires strict compliance from the participating teams, even in the 2011 official CWC injury surveillance study, only 5 of 14 participating national teams agreed to participate (Orchard et al., 2005). A conjoined injury surveillance programme initiated by the ICC with cooperation from all the competing national squads during every CWC could help create direction for an evidence-based cricket injury prevention programme. Most of the existing injury surveillance reports have been conducted among elite or sub-elite cohorts separately in different countries. There is no platform to compare the injury aetiology of one country's cricket squad to another. When injury surveillance is carried out between competing nations as in the ICC CWC, it will help to determine and compare injury incidence. This will also help determine possible aetiology for those injuries and successively help create targeted injury prevention programmes, which could be implemented across all levels of cricket around the world.

The current study objective was to conduct media-based injury surveillance prospectively during the tournament. Although some players were benched during the tournament, information regarding the reason for not playing matches was not always available. As all injury data were obtained from media releases, a likely limitation of this study is biased media reporting. Injury information reports for newer players, particularly those from lower-ranked teams may have been considered less newsworthy so injuries to those players may not have been reported on media. Another limitation of the study was the reluctance of some lower-ranked teams to update information on their cricket board websites regarding their players' statistics, injuries and status of their 15 member playing squad ahead of every match, and this means that injuries sustained by players from those squads may not have been available and would not be recorded in this study data. The percentages of playing positions were similar between players who were predominantly specialist bowlers and batters. Overall, 31 players missed 69 matches, the number of injuries reported is the same as the number of players injured, because there was no report of the same player experiencing a second injury or having a recurrent injury to the same body part.

Among the player positions, fast bowlers missed the highest number of matches due to injuries relatively, fast bowlers experienced the highest percentage of total injuries and match time-loss injuries when compared with other playing positions, as shown in Table 2. One of the most recent injury surveillance studies, undertaken amongst elite senior male cricket players during the season 2006-2007 to season 2015-2016 highlighted that batsmen (7%) had the second-highest injury prevalence compared to other positions (Orchard et al., 2016 b) similarly in the current study batters (5%) experienced the second-highest injury prevalence and also missed a total of 23 matches.

The hamstring was the most injury-prone body area amongst the current study participants, and this matched the finding of injury surveillance undertaken on elite New Zealand cricketers from 2002/2003 to 2007/2008, which identified hamstring strains/tears (11%) as the most common specific diagnosis (Frost & Chalmers, 2014). Detailing injuries by specific diagnosis in the current study, hamstrings (16.1%) and abdominal/trunk side-strains (16%) both equally accounted for the highest percentage of injuries recorded, however hamstrings caused players to miss 17 matches (25%) which was higher than the 15 matches (22%) missed due to abdominal/trunk side-strains. The hamstring injuries were more commonly experienced by batsmen (10%) when compared to all other playing positions. A similar finding has been reported amongst elite Australian cricketers during 50-over international matches where batsmen had the highest hamstring injury incidence (at 31.3 injuries per 1000 team days) (Orchard et al., 2017).

A proposed explanation for the relatively higher hamstring injury incidence among the batters maybe that batsmen are required to sprint more (Petersen et al., 2011) during a 50-over match in comparison to a multi-day match. Due to the limited-overs nature of a 50-over match, there is a requirement to take every opportunity to score runs to improve a team's match-winning prospects. Consequently, batsmen may acquire more runs through running between the wickets (Orchard et al., 2017), as boundary runs may not be as easily scored given Australian stadiums tend to be relatively larger cricket grounds (“ICC Cricket World Cup,” 2015)

In the current study, fast bowlers (48%) had the highest tournament injury prevalence amongst all playing positions. Majority of the injuries for the fast bowlers occurred on the trunk, knee and foot. Abdominal/trunk side-strains caused the fast bowlers to miss the most number of matches. Previous studies have reported that abdominal/trunk side-strains mostly occur on the contralateral side to the bowling arm, with either the internal oblique or the external oblique muscle being mostly affected (Bayne et al., 2011). Abdominal/trunk side-strains have also been reported to have a recurrence rate of 30% and has been cited as a common risk factor for injury amongst fast bowlers (Nealon & Cook, 2018). Till date, most reports on abdominal/trunk side-strains have suggested it may be an increased workload-related overuse injury. As the current study was designed as an observational study, we could not conclude on the possibility of workload related aetiology being behind the abdominal/trunk side-strain prevalence of fast bowlers. Future research could be directed into investigating cricket-related abdominal/trunk side-strain injuries. While most cricket injury surveillance studies have reported a high lumbar injury prevalence amongst fast bowlers, surprisingly no lower back injuries were reported amongst fast bowlers.

In the current study, as shown in Table 5, bowling during matches was one of the most common activities the players were undertaking at the time of injury onset. Of the 69 matches missed due to injuries, fast bowlers missed 31 matches which is the highest proportion among all player positions. While fast bowlers encountered 12 match time-loss injuries and missed 31 matches, the batsmen missed 23 matches due to 11 match time-loss injuries. Estimating injury severity using time-loss is suggested according to the international injury surveillance consensus (Orchard et al., 2005). Therefore analysing the results of the current study, it could be concluded that although the number of match time-loss injuries between fast bowlers and batsmen was similar, fast bowlers may have been affected the most due to injuries.

Even though the current study's report of 29 new injuries was collected through media reports, all the injury reports were checked across multiple sources before and after a match. Another method used to verify the reported injury was to double-check if the injured player missed the next match after the reported injury. In the current study, only four non-time-loss injuries were recorded. The low number of non-time-loss injuries recorded in the current study may have been due to these less severe injuries being less newsworthy. This is acknowledged as a limitation in the current study, as many non-time loss injuries potentially were not reported and hence not recorded. As all injury reports were media injury reports associated with the matches missed by players, there was a high percentage of 85% (23/27) of time-loss injuries recorded. It must be noted that many injuries during international cricket competitions may not be reported to the media and it reinforces the recommendation by the international cricket injury surveillance consensus that prospective longitudinal study supported by the tournament organisers and team management is necessary.

5. Conclusion

Despite this study design being based on media reports of cricket injuries, this is the only study to our knowledge to report on the injury patterns for the 2015 CWC tournament. This study has reported that fast bowlers were the most injury-prone, hamstrings as the most injured body part and bowling as the most common activity at the time of an injury. This current study also reinforces the appeal made by the international cricket injury surveillance consensus group (Orchard et al., 2005, 2016 b) to implement effective cricket injury surveillance across cricket playing nations and during major cricket tournaments.

Conflict of Interest

The authors declare no conflict of interests.

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Physiological and perceptual responses to a five-week pre-event taper in professional mixed martial arts athletes

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ABSTRACT

The purpose of this study was to evaluate changes in markers of endocrine, immune and mood status among Mixed Martial Arts (MMA) athletes during different stages of fight preparation camps. Six professional MMA athletes were observed across the final five weeks (W4 – W0); including the final seven days (D6 – D0) of fight camp, and were tested for salivary immunoglobin-A (sIgA), salivary cortisol (SC), plasma creatine kinase (CK), urine osmolality (UO), body mass (BM), training load (TL), reported fluid intake and profile of mood state (POMS) scores. Magnitude-based decisions revealed large, very likely decreases in sIgA concentrations in W1 relative to all previous weeks, and large, very likely reductions in CK concentrations within W0 in relation to W2 and W4. POMS scores increased in W0 and W1 compared to W4 (moderate, very likely), despite a reduction in training load in W0 relative to all previous weeks (large, very likely). In W0, reported fluid intake decreased as UO increased at D1 and D2, in comparison to all previous days (large, very likely). Elevated POMS and SC (moderate to large, very likely) were also observed at D1, in comparison to D2 to D6. While 8% of BM was lost over the 5-week period, 5% was lost within the final 4 days. Across a 5-week fight camp, mood states are negatively affected, alongside increased markers of muscle damage and immune status, which can be partially offset with a pre-event taper. Owing to the weight cutting practices of these professional MMA athletes, ~ 5% of BM is lost in the final 4 days, which coincides with poorer mood states and increased stress-hormone responses in the final few days of the fight camp. Coaches should consider the implications of taper length and RWL strategies in the recovery process of MMA athletes.

1. Introduction

Mixed Martial Arts (MMA) is a combat sport, which combines various fighting techniques found in traditional martial arts, such as kickboxing, boxing, muay-thai, wrestling and Brazilian Jiu-Jitsu. Athletes within MMA are generally deemed to be in an 'off-camp' or 'fight-camp' phase, the latter of which is used to target specific adaptations in the final 4-10 weeks prior to a competitive event (UFCPI, 2018). As a result of training for multiple disciplines and in the event of agreeing a bout at short notice (< 4 weeks), training load can often be mismanaged within the fight camp, contributing to inadequate recovery and suboptimal performance (Amtmann, 2004). High training loads may lead to excessive muscle damage, kidney dysfunction (via rhabdomyolysis) and fluid or electrolyte imbalances (Mashiko et al., 2004), leading to chronic states of overreaching and subsequent development of over-training syndrome (Coutts et al 2007).

After repeated, strenuous bouts of prolonged training sessions, a window of 3-72 h of reduced immunity has been observed, referred to as the 'open window' (Walsh et al., 2011), leaving athletes at a greater risk to infections, particularly those of the upper respiratory tract (URTIs) (Budgett, 1998). Salivary proteins, such as IgA (sIgA) play an integral role in mucosal immunity and can serve as an indicator of URTI risk (Mackinnon, Ginn, & Seymour, 1993). Indeed, reductions in sIgA secretion during

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prolonged training camps have been reported, and sIgA secretion is inversely related to URTI risk (Gleeson et al., 1995). In addition, higher cortisol, mood disturbances and muscle soreness are associated with decreased mucosal immunity, which can be elicited during a period of increased training loads (Papacosta, Nassis, & Gleeson, 2016).

Progressive reductions in training load (tapers) are typically incorporated into pre-competition training programmes to minimise training-induced fatigue, maximize physiological adaptations and optimise performance (Mujika, 2010). Pre-competition tapering is more complicated in combat sports (in comparison to non-weight classification sports), owing to the potential use of rapid weight loss (RWL) strategies in the days leading up to a competitive event. Such strategies aim to reduce body mass (primarily water mass) within the final days preceding an event and are used in order to gain a competitive advantage (against a lighter athlete). During intensive training, this may be detrimental to the athlete's health, compromising immune function and reducing salivary flow rate (Ford et al., 1997; Tsai et al., 2009). Therefore, it is suggested that the practices of MMA fighters towards the end of a fight camp may compromise their health status, in turn, leading to suboptimal performance.

Athletes dehydrating for the purpose of RWL typically have inadequate time to rehydrate before MMA events e.g. restoring 5% of body mass within 24 hours (Jetton et al., 2013). With inadequate fluid intake and physical recovery, athletes are more susceptible to renal injury, due to the high levels of plasma creatine kinase concentrations observed in MMA fighters and reductions in myoglobin solubility (Weichmann et al., 2016). The resulting hypo-hydration and severe energy restrictions from RWL have also been reported to lead to an increased perception of fatigue, tension, anxiety and impaired short-term memory (Steen & Brownell, 1990; Choma, Sforzo, & Keller, 1998). Furthermore, hypo-hydration has been reported to impair muscle excitability and reduce muscular endurance, irrespective of fluid replacement (Bigard et al., 2001; Bowtell et al., 2013). Therefore, hypo-hydration is likely to contribute to neuromuscular fatigue before and during competition.

It is likely that the cumulative demands of pre-competition preparation for combat sports athletes induce physical and mental fatigue, which can lead to chronic overreaching and subsequently over-training syndrome, unless adequate recovery is provided (Urhausen & Kindermann, 2002). Those with OTS report disrupted mood, sleep and behaviour (Meeusen et al., 2013), as well as neuroendocrine dysregulation (Cadegiani & Kater, 2017). Indeed, some hormones secreted from the hypothalamic pituitary adrenal axis have been related to immunosuppression (Ford et al., 1997) and could be used to monitor the health status of combat sports athletes. Presently, there has been no investigation of combat athletes' well-being and endocrine response to an MMA fight camp. It is therefore necessary to evaluate the fight preparation period of professional MMA athletes, as this information could be used to inform future preparations.

The purpose of the study was to evaluate the change in physiological (hydration, endocrine and immune) and perceptual markers (mood state) of professional MMA athletes within the final 5-weeks (minimum fight camp time frame + period of RWL) of an uninterrupted fight camp.

2. Methods

Participants provided written informed consent to participate in a prospective observational study across five weeks. Institutional ethical approval was given for this study, which was conducted in accordance with the 1964 Helsinki declaration. Prior to initial testing, participants arrived at the laboratory, completed a physical activity readiness questionnaire (PAR-Q) and were familiarised with methods for obtaining and storing urine and saliva samples. In addition, they were familiarised to the Profile of Mood State (POMS) questionnaire.

On each testing day, participants were instructed to obtain urine and saliva samples at home within 30-min of waking up. Upon arrival at the laboratory in the morning (~0900 h) in a fasted state before training, they were requested to empty their bladders, followed by measurements of body mass, POMS and capillary blood samples (from the ear) to assess plasma creatine kinase (Figure 1). Each testing day was identical except for the final week (excluding fight day), wherein daily measurements of POMS, urine, saliva and body mass were taken. Weeks and days are expressed as n where n = number of weeks/days from fight day (Figure 1).

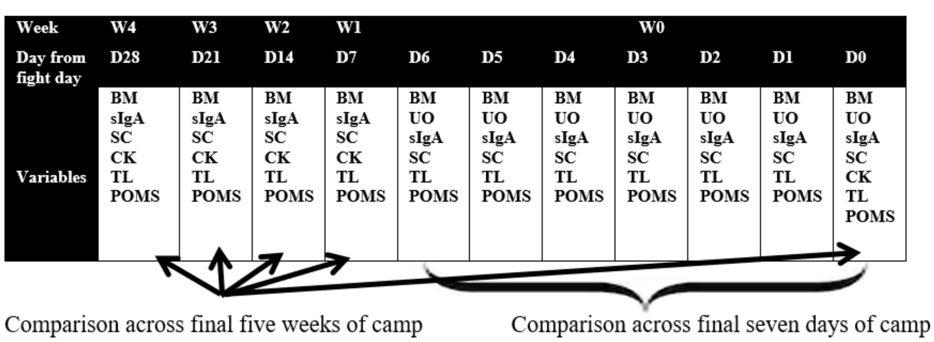

Figure 1: Research Design. 11 testing points across 5 weeks.
Body Mass (BM); Urine Osmolality (UO); Salivary Immunoglobin-A (sIgA); Salivary Cortisol (SC); Creatine Kinase (CK); Training Load (TL); Profile of Moods State (POMS).

2.1. Participants

Six male (age: 27 ± 7 years, stature: 1.71 ± 0.08 m, body mass: 78.1 ± 10.3 kg, training age: 6 ± 4 years, counter-movement jump height: 0.39 ± 0.10 m) professional MMA athletes with no underlying health conditions, consented to take part in this study. Inclusion criterion necessitated that the athletes were injury free and competing within a regulated MMA organization.

2.2. Methods

2.2.1. Body mass

Following, urination and prior to any fluid and energy intake the mean of three nude body mass measurements were taken using a portable scale (MPMS-230, Marsden Weighing Group, Oxfordshire, UK).

2.2.2. Urine Osmolality

Participants were instructed to collect midstream samples of first urine (within 30-min of waking up) (50 ml collection pots)) and return them to the laboratory on each testing day. Pre-fight (weigh-in) day urine was assessed in the final 30-min prior to stepping on the scale at the event. Fight day urine was assessed ~ 6-h prior to the bout, before consumption of a lunch meal and a minimum of 1-h post water consumption. Urine osmolality (mOsml·kg^{-1}H_2O) was measured using a thermally compensated refractometer (Osmocheck refractometer, Vitech Scientific Ltd, West Sussex, UK) with a manufacturer's reported testing accuracy of ± 20 mOsml·kg^{-1}H_2O and a between run coefficient of variation (CV) of 0.3%. Participants were asked to report fluid intake (L) on a daily basis in the final week.

2.2.3. Whole-blood Creatine Kinase concentration

Approximately 300 µl of capillary whole-blood (from the ear) was collected (Microcuvette®CB300, Sarstedt, Numbrecht, Germany), placed in a refrigerated centrifuge (Mikro 220R D-78532, Tuttlingen, Germany) and spun at 3500 rev/min for 6-min at 4 ◦C. All samples were then stored and analysed using an automated analyser (Clinical Analyser Rx Daytona – Randox Teoranta, Co. Donegal, Republic of Ireland) with a between run CV of 2.0%.

2.2.4. Saliva Variables (sIgA & Cortisol)

An IPRO Lateral Flow Device reader (IPRO Interactive Ltd, Wallingford, UK) was used to analyse salivary cortisol and sIgA. Saliva swab testing kits with instructions were administered for participants to obtain morning saliva within the first 30 min of waking up, prior to arrival at the laboratory. Approximately 0.5 ml of saliva was collected via an oral swab and placed into a buffer solution. Two drops of the buffer/saliva mixture were then placed on to a lateral flow indicator test strip, allowing the mixture to flow laterally across the conjugated pad and the nitrocellulose membrane. Test strips were left for a 15-min incubation period before analysis. Between run mean CV were 8.5% and 6.8% for sIgA and cortisol respectively.

2.2.5. Training Load

Participants were asked to provide a rate of perceived exertion (RPE) using a 10-point rating scale. The intensity of all training sessions (technique drilling, grading, sparring, strength and conditioning) were recorded within 30-min of completion. A typical weekly training schedule is shown in Table 1.

The RPE value was multiplied by training time to calculate session RPE (sRPE) as a measure of training load (Lambert & Borresen, 2010). Intended taper length was also requested to indicate when and how training load reduction was expected. Athletes within this study underwent a taper length between six and ten days, which was preceded by a final 'maximal' sparring session and utilizing the days within the taper to reduce load via mobility, conditioning and 'drilling' sessions.

2.2.6. Profile of Mood States Questionnaire (POMS)

POMS was administered to assess transient disturbances in 6 different moods: anger, confusion, tension, fatigue, depression and vigour. The questionnaire consisted of 65 questions assessed through a 5-point likert scale ranging between 'not at all' and 'extremely' and resulted in an total mood disturbance score. Participants were asked to complete an online version of the POMS questionnaire while isolated in a quiet area of the laboratory at the start of each testing day (~ 9 am) (Morgan et al., 1987).

Table 1: Typical weekly training schedule of a single MMA fighter. MA – martial arts, MMA – mixed martial arts, S&C – strength & condition, D&S – drills and sparring, S – sparring.

	Mon	**Tues**	**Wed**	**Thurs**	**Fri**	**Sat**	**Sun**
AM	MA specific – D&S (120 min)	Rest	MMA – S (90 min)	MA specific – D&S (120 min)	Rest	MMA – S (90 min)	MA specific – D&S (150 min)
PM	S&C (90 min)	MA specific – D&S (120 min)	S&C (90 min)	MA specific – D&S (120 min)	Rest	S&C (60 min)	Rest

2.3. Statistical Analysis

Magnitude-based decisions (MBD) were used to determine whether observed effects were unlikely or likely, allowing practical inferences to be drawn from the approach described by Batterham & Hopkins (Batterham & Hopkins, 2006). Effect sizes (ES) and MBD identified likelihood of effects of time on each dependant variable (BM, UO, sIgA, CK, SC, TL, POMS total score and sub-scores) across the final five weeks. ES were defined as; *trivial* = 0.2; *small* = 0.21 – 0.6; *moderate* = 0.61 – 1.2; *large* = 1.21 – 1.99; *very large* > 2.0. Raw data were log-transformed to account for uniformity of effects. Threshold probabilities for a substantial effect based on the 90% confidence limits were: <0.5% *most unlikely*, 0.5 – 5% *very unlikely*, 5.1 – 25% *unlikely*, 25.1 – 75% *possibly*, 75.1 – 95% *likely*, 95.1 – 99.5% *very likely*, > 99.5% *most likely*. Thresholds for the magnitude of the observed change in the dependant variables were determined as the within-participant standard deviation x 0.2 (*small*), 0.6 (*moderate*) and 1.2 (*large*). Effects with confidence limits across a *likely, small* positive or negative change were classified as unclear. The uncertainty of effects were based on 90% confidence limits for all variables. A custom spreadsheet designed for cross-over trials was used to perform all of the calculations (http://www.sportsci.org/).

3. Results

3.1. Changes across final five weeks

Large, very likely reductions in TL were observed between week 0 and all other weeks. There were *large, very likely* reductions in sIgA between week 1 and weeks 2, 3 & 4. CK reductions were *large, very* or *most likely* between week 0 and weeks 1, 2 & 4, and also between weeks 1 & 3. POMS depression score reductions were *large, very likely* between week 4 and weeks 3 & 2 while POMS confusion score reductions were *large, very* or *most likely* between week 4 and weeks 2 & 1 (Table 2).

3.2. Changes across final seven days

There were *large, very* or *most likely* reductions in UO and increases in fluid intake between all days (Table 3). There were *large, very likely* increases in POMS scores between day 1 and days 4, 5 & 6, and reductions between day 4 and days 0 & 2. *Large, very likely* increases in POMS depression scores were found between day 1 and days 2, 3 & 4. *Large, very* or *most likely* increases in POMS confusion scores were found between day 1 and days 3, 4, 5 & 6. *Large, very likely* reductions in POMS fatigue scores were found between day 1 and days 4, 5 & 6. There were also *large, very likely* reductions in POMS vigour scores between day 1 and days 4, 5 & 6 (Table 4).

4. Discussion

The aim of this study was to evaluate changes in physiological and mood state across the final five weeks of a fight camp amongst professional MMA fighters. The main observations within this study include a reduction in BM of ~ 8% within the final five weeks, with ~ 5% occurring within the final four days of the weight cut. Mood state worsened across the five weeks, particularly due to the increase in POMS sub-scores of confusion, depression and tension. *Very large* plasma CK reductions were observed in the final week relative to all weeks, however a *large* reduction in sIgA secretion was observed within the penultimate week. Though sIgA also improved with TL reduction (taper), it did not return to baseline concentrations. Finally, a *large* increase in SC was observed within the final two days (weigh-in and fight day), yet overall change was *trivial* across the five weeks. Collectively, the results provide novel evidence of the undesirable changes in immunoendocrine and mood status in professional MMA athletes across the final five weeks of a fight preparation camp.

Participants within the present study achieved a total BM loss of ~10.0% across the final four weeks, with 4.7-5.7% of BM reduction occurring within the final week. A similar magnitude of change across time has been observed in MMA (Jetton et al., 2013; Kasper et al., 2018), judo (Pallares et al., 2016), wrestling (Roemmich & Sinning, 1997) and boxing (Reljic, Hassler, & Jost, 2013). However, athletes within the current study decreased BM by 1.8 kg within the final 24-h, which is lower than previously reported losses of 3.4 and 9.8 kg within 24-h and 27 days respectively (Barley, Chapman, & Abbiss, 2017). Five of the six athletes were hyper-hydrated before gradually dehydrating to a hypo-hydrated state during weigh-in day. With reported fluid intake as high as 8.5 L at D6 but as low as 0.2 L at D1, patterns follow a typical weight-cutting method reported amongst MMA athletes, known as 'water-loading' (Reale et al., 2018). It is possible that methods of water loading within this study differed from others, as most did not reach a state of severe hypo-hydration (> 1200 $mOsml \cdot kg^{-1} H_2O$) that has been reported (Kasper et al., 2018). Though final UO was not measured immediately prior to the fight (~ 6-h), the current findings confirm that fluid balance is manipulated by MMA athletes to control body mass losses but suggest that magnitude/method of water loading may vary between individuals. It is also possible that the changes in BM were influenced by calorie restriction; however, this was not monitored and is a limitation of the study.

TL was *largely* reduced in W0 to facilitate at least a one-week taper, in order to minimise training induced fatigue and maximise physiological adaptations prior to the fight. However, irrespective of TL periodisation strategies, a reduction in sIgA secretion and increase in mood scores remained evident in the final two weeks of the preparation camp. Acute reductions in TL have been strongly associated with improved mood state (Saw, Main, & Gastin, 2016), yet peak disturbances in total mood scores were observed in the penultimate day (weigh-in) and penultimate week within this study, indicating that the athletes' psychological state was not solely dependent on load reduction and may have been attributed to fluid restriction levels. This has been observed in participants regardless of whether fluid restriction was involuntary (Ely et al., 2013) or voluntary and when sleep, diet and caffeine were controlled (Mundel, Hill, & Legg, 2015). With increased POMS sub-scores of confusion, depression, anger alongside decreased plasma CK and sIgA concentration, it is possible that mood disturbances were also reflective of pre-fight stressors, along with the recovery process from training-induced fatigue. This suggests that POMS provides a useful global indicator of mood state but may not consistently coincide with adjustments in TL, due to a multitude of factors involved in subjective scoring.

Plasma CK concentrations increased across the pre-competition fight camp, with peak values occurring within W1. However, this was reduced in W0, in accordance with a programmed decrease in TL. CK concentrations were larger than anticipated in the current sample, with fight day concentrations almost resembling CK values 24-h post-fight and 3 times the observed values pre-event (Weichmann et al., 2016). The reasons for this are unclear but could be related to muscle damage

Table 2: Magnitude-based decisions for dependant variables across week 4 to 0.

	Week from fight					**Direction and qualitative inference [ES] (log transformed ± 90 % CL)**
Variable	**4**	**3**	**2**	**1**	**0**	
BM (kg)	77.12 ± 7.61	76.42 ± 7.44	76.2 ± 8.55	75.48 ± 8.21	75.6 ± 8.19	**P + :** 4 v 1 [0.19] (± 0.13), 4 v 0 [0.18] (± 0.15)
TL (AI)	3852 ± 738	4028 ± 817	4635 ± 1067	3969 ± 1097	2871 ± 433	**L +** : 4 v 3 [0.86] (± 0.97), 4 v 1 [1.05] (± 1.22) **VL +** : 3 v 0 [1.83] (± 0.94), 1 v 0 [1.63] (± 1.28) **ML +** : 4 v 0 [2.68] (± 0.70), 2 v 0 [2.6] (± 1.03)
CK (u/L)	1473 ± 453	1171 ± 487	1285 ± 738	1489 ± 1288	713 ± 667	**L +** : 4 v 3 [0.56] (± 0.40) **VL +** : 4 v 0 [3.24] (± 1.95), 3 v 0 [2.69] (± 1.92), 2 v 0 [2.69] (± 1.28) **ML +** : 1 v 0 [2.44] (± 0.53)
SC (ug/ml)	14.61 ± 4.49	15.7 ± 4.91	18.97 ± 9.11	16.76 ± 9.16	20.76 ± 13.48	**P - :** 4 v 3 [0.13] (± 0.24)
sIgA (ug/ml)	474 ± 202	532 ± 180	499 ± 110	240 ± 164	364 ± 157	**L + :** 2 v 0 [0.64] (± 0.63) **VL +** : 4 v 1 [1.39] (± 1.08), 3 v 1 [1.66] (± 1.21), 3 v 0 [0.71] (± 0.48), 2 v 1 [1.59] (± 0.89)
POMS (total score)	16.2 ± 10.6	31.3 ± 15.5	33.8 ± 18.1	45.5 ± 22.0	35.3 ± 17.2	**P - :** 2 v 1 [0.32] (± 0.45) **L -** : 4 v 2 [0.85] (± 0.76), 3 v 1 [0.53] (± 0.68) **VL -** : 4 v 1 [1.17] (± 0.88), 4 v 0 [0.93] (± 0.71)
Depression	2.0 ± 1.0	3.1 ± 2.6	2.0 ± 1.8	8.0 ± 11.2	7.7 ± 6.3	**VL - :** 4 v 3 [1.57] (± 1.11), 4 v 1 [2.87] (± 2.51) **L +** : 3 v 2 [0.85] (± 0.70) **VL +** : 1 v 0 [0.7] (± 0.37)
Confusion	3.3 ± 1.0	5 ± 2.4	7.7 ± 1.9	7.6 ± 1.9	6.2 ± 4.8	**VL - :** 4 v 3 [0.86] (± 0.60), 4 v 2 [2.02] (± 1.13), 3 v 1 [1.16] (± 0.56) **ML -** : 4 v 1 [2.02] (± 0.74) **L -** : 3 v 2 [1.16] (± 1.16)
Tension	6.3 ± 5.4	8.3 ± 3.2	8.8 ± 4.9	13 ± 6.8	13.5 ± 5.5	**L - :** 4 v 2 [0.47] (± 0.39), 4 v 1 [0.82] (± 0.92), 3 v 1 [0.36] (± 0.41) **P +** : 1 v 0 [0.35] (± 0.47)
Fatigue	11 ± 7.9	13 ± 2.4	14.2 ± 5.1	10.7 ± 2.0	8.5 ± 5.5	**P + :** 3 v 0 [0.27] (± 0.32), 2 v 1 [0.22] (± 0.41)
Anger	8.3 ± 4.5	13.7 ± 8.5	10.8 ± 7.1	13.8 ± 5.7	10.7 ± 2.7	**L - :** 4 v 1 [0.7] (± 0.58), 4 v 0 [0.49] (± 0.53), 2 v 1 [0.63] (± 0.74)
Vigour	15.2 ± 5.4	12 ± 6.9	9.7 ± 6.3	9.7 ± 4.6	11.7 ± 7.5	**L + :** 4 v 2 [0.77] (± 0.67), 4 v 1 [1.01] (± 0.91)

Qualtitative inferences: L = Likely; VL = Very likely; ML = Most likely; P = Possibly; + = Increase; - = Decrease.

Table 3: Magnitude-based decisions for dependant variables across final seven days.

	Day from fight							**Direction and qualitative inference [ES] (log transformed ± 90 % CL)**
Variable	**6**	**5**	**4**	**3**	**2**	**1**	**0**	
BM (kg)	75.6 ± 9	75.8 ± 8	75.6 ± 8	74.9 ± 8	73.4 ± 7	71.8 ± 6	75.6 ± 8	**VL + :** 5 v 1 [0.38] (± 0.17), 4 v 1 [0.36] (± 0.16) **P -** : 2 v 0 [0.21] (± 0.13) **P +** : 5 v 2 [0.22] (± 0.13) **L +** : 6 v 1 [0.36] (± 0.17) **VL -** : 1 v 0 [0.37] (± 0.16)
UO (mOsml·kg-1H2O)	252 ± 133	153 ± 147	215 ± 148	524 ± 129	733 ± 158	1024 ± 176	506 ± 388	**VL - :** 6 v 3 [1.01] (± 0.52), 6 v 2 [1.4] (± 0.66), 5 v 0 [1.19] (± 0.81), 2 v 1 [0.39] (± 0.12) **ML -** : 6 v 1 [1.78] (± 0.70), 5 v 3 [1.65] (± 0.50), 5 v 2 [2.03] (± 0.65), 5 v 1 [2.42] (± 0.58), 4 v 3 [1.21] (± 0.45), 4 v 2 [1.6] (± 0.54), 4 v 1 [1.99] (± 0.82), 3 v 1 [0.77] (± 0.21) **L +** : 6 v 5 [0.64] (± 0.68), 2 v 0 [0.84] (± 1.01), 1 v 0 [1.23] (± 1.03) **L -** : 6 v 0 [0.56] (± 0.42), 5 v 4 [0.43] (± 0.52), 4 v 0 [0.76] (± 0.82), 3 v 2 [0.39] (± 0.24)
Fluid intake (L)	5.2 ± 2.4	5.8 ± 1.7	5.2 ± 1.4	2.5 ± 0.5	1.8 ± 0.7	0.6 ± 0.3	3.4 ± 1.3	**VL + :** 6 v 0 [0.78] (± 0.43), 4 v 0 [0.87] (± 0.39) **VL - :** 2 v 0 [1.15] (± 0.72) **ML - :** 1 v 0 [3.4] (± 1.03) **ML + :** 6 v 3 [1.26] (± 0.48), 6 v 2 [1.92] (± 0.61), 6 v 1 [4.18] (± 0.97), 5 v 3 [1.55] (± 0.39), 5 v 2 [2.21] (± 0.78), 5 v 1 [4.46] (± 0.87), 5 v 0 [1.06] (± 0.41), 4 v 3 [1.35] (± 0.39), 4 v 2 [2.01] (± 0.59), 4 v 1 [4.27] (± 0.72), 3 v 1 [2.92] (± 0.92), 2 v 1 [2.25] (± 0.76) **L + :** 3 v 2 [0.66] (± 0.6) **L - :** 3 v 0 [0.48] (± 0.53)
SC (ug/ml)	15 ± 7	11 ± 5	11 ± 4	10 ± 3	12 ± 5	23 ± 12	21 ± 13	**VL + :** 6 v 5 [0.47] (± 0.15) **VL -** : 4 v 1 [0.93] (± 0.38), 2 v 1 [0.91] (± 0.50) **ML -** : 5 v 1 [0.99] (± 0.38), 3 v 1 [1.1] (± 0.34) **L +** : 6 v 4 [0.41] (± 0.29), 6 v 3 [0.57] (± 0.38), 6 v 2 [0.39] (± 0.22) **L -** : 6 v 1 [0.52] (± 0.22)
sIgA (ug/ml)	555 ± 221	476 ± 298	507 ± 162	400 ± 142	324 ± 192	400 ± 294	364 ± 157	**L + :** 6 v 3 [0.46] (± 0.37), 6 v 2 [0.87] (± 0.71), 6 v 1 [0.87] (± 0.98), 4 v 3 [0.37] (± 0.25), 4 v 1 [0.78] (± 0.95), 3 v 2 [0.41] (± 0.41) **VL +** : 4 v 2 [0.78] (± 0.52)

Qualitative inferences: L = Likely; VL = Very likely; ML = Most likely; P = Possibly; + = Increase; - = Decrease.

Table 4: Magnitude-based decisions for POMS variables across final seven days.

	Day from fight							**Direction and qualitative inference [ES] (log transformed ± 90 % CL)**
Variable	**6**	**5**	**4**	**3**	**2**	**1**	**0**	
POMS (total score)	22.8 ± 7.5	23.3 ± 7.1	20.2 ± 11.6	32.5 ± 21.5	40.8 ± 18.1	51.8 ± 12.4	35 ± 16.7	**L +** : 1 v 0 [0.87] (± 0.72) **VL -** : 6 v 1 [1.63] (± 0.75), 5 v 1 [1.55] (± 0.60), 4 v 2 [1.61] (± 1.26), 4 v 1 [2.21] (± 1.34), 4 v 0 [1.35] (± 1.04) **L -** : 6 v 2 [1.02] (± 0.88), 6 v 0 [0.77] (± 0.65), 5 v 2 [0.94] (± 0.89), 5 v 0 [0.68] (± 0.63), 3 v 2 [0.8] (± 0.79), 3 v 1 [1.41] (± 1.27), 2 v 1 [0.61] (± 0.57)
Depression	5.5 ± 3.2	5.5 ± 2.8	5 ± 3.4	6.3 ± 5.9	8.5 ± 7.3	12.3 ± 7.5	8.2 ± 6.3	**L - :** 6 v 1 [1.63] (± 1.81), 5 v 1 [1.56] (± 1.67) , 3 v 2 [0.45] (± 0.43) , 5 v 1 [1.56] (± 1.67) **VL -** : 4 v 1 [2.06] (± 1.35), 3 v 1 [1.97] (± 1.09), 2 v 1 [1.65] (± 1.16) **VL +** : 1 v 0 [1.53] (± 1.16)
Confusion	3.5 ± 0.8	4.2 ± 1.7	4.7 ± 1.9	7 ± 2.7	8.5 ± 4.6	10.2 ± 3.8	6.2 ± 4.8	**L - :** 6 v 4 [0.75] (± 0.69), 3 v 2 [0.4] (± 0.40), 2 v 1 [0.73] (± 0.63) **VL -** : 6 v 3 [1.94] (± 1.29), 6 v 2 [2.34] (± 1.52), 5 v 3 [1.72] (± 1.47), 5 v 2 [2.12] (± 1.63), 5 v 1 [2.86] (± 1.62), 4 v 3 [1.19] (± 0.93), 4 v 2 [1.59] (± 1.05) **ML -** : 6 v 1 [3.08] (± 1.09), 4 v 1 [2.32] (± 0.88), 3 v 1 [1.13] (± 0.44) **VL +** : 1 v 0 [2.23] (± 1.55) **L +** : 2 v 0 [1.49] (± 1.29)
Tension	9.2 ± 3.3	10.3 ± 2.1	11.2 ± 3.1	10.8 ± 3.1	11.5 ± 3.0	12.5 ± 4.2	13.5 ± 5.5	**L - :** 6 v 5 [0.37] (± 0.36), 6 v 3 [0.41] (± 0.57), 6 v 2 [0.6] (± 0.53), 6 v 0 [0.84] (± 0.81), 3 v 0 [0.43] (± 0.58) **VL -** : 6 v 4 [0.53] (± 0.32)
Fatigue	7.5 ± 2.0	6.8 ± 1.9	5.2 ± 2.9	10.7 ± 5.3	9.8 ± 3.7	11.5 ± 2.7	8.5 ± 5.5	**VL - :** 6 v 1 [1.25] (± 0.91), 6 v 0 [0.93] (± 0.62), 5 v 1 [1.54] (± 0.86), 5 v 0 [1.2] (± 0.71), 4 v 1 [2.81] (± 1.79), 4 v 0 [2.57] (± 1.65) **P +** : 6 v 5 [0.28] (± 0.28) **L +** : 5 v 4 [1.28] (± 1.39) **VL +** : 6 v 4 [1.56] (± 1.35)
Anger	9.5 ± 5.1	9 ± 4.5	9 ± 4.8	8.5 ± 6.3	10.8 ± 6.0	12.5 ± 6.8	10.7 ± 2.7	**P - :** 3 v 2 [0.3] (± 0.37)
Vigour	12.3 ± 3.1	12.5 ± 3.0	7.5 ± 1.9	7.9 ± 2.7	8.1 ± 4.5	8.8 ± 3.8	7.7 ± 4.8	**L - : 6** v 4 [0.47] (± 0.63), 5 v 4 [0.42] (± 0.57) **VL -** : 1 v 0 [1.66] (± 1.34) **L +** : 5 v 3 [0.64] (± 0.73) **VL +** : 6 v 2 [1.57] (± 1.21), 6 v 1 [2.41] (± 2.01), 5 v 2 [1.61] (± 1.28), 5 v 1 [2.45] (± 2.03), 4 v 3 [1.06] (± 0.6), 4 v 2 [2.04] (± 1.38), 4 v 1 [2.88] (± 1.61)

Qualitative inferences: L = Likely; VL = Very likely; ML = Most likely; P = Possibly; + = Increase; - = Decrease.

induced by MMA bouts, which include repetitive eccentric contractions (e.g. kicking decelerations) and blunt trauma associated with strikes (Baird et al., 2012; Weichmann et al., 2016), which were not specifically monitored during the fight camp. Nevertheless, these data indicate a progression in indirect muscle damage markers during fight camp, which suggests that the participants in this study may have entered their fights with a higher level of muscle damage than previously reported (Weichmann et al., 2016), further highlighting the importance of TL management to optimise recovery within the correct time frame.

SC and sIgA concentrations were monitored across the 5-week tapering period, as an indication of the hypothalamic pituitary axis stress response and mucosal immunity, respectively. Peak reduction of sIgA concentrations were observed in W1, indicating potential increased URTI risk due to a reduced mucosal immunity[5]. It was speculated that this steep decline in sIgA concentration is representative of the 'open window' phenomenon, whereby athletes have been reported to have lower salivary immunoglobins and peripheral blood immune cells following prolonged and intensified training (Walsh et al., 2011). Similarly, the athletes examined here were recovering from training-induced fatigue, following a period of high TL. Interestingly, there was a *moderate* reduction in sIgA concentration in W0 (compared to W3 & W2), which occurred alongside reductions in TL and plasma CK concentration, indicating a partially successful tapering strategy. sIgA concentrations observed in the initial weeks were not restored in the final stages of the taper, suggesting higher risk of illness and infection near to the day of the fight. In addition to physical exertion, cortisol secretion can be induced by non-physical stimuli, such as anxiety and psychological stress (Kunz-Ebrecht et al., 2003). This is supported by similar trends observed in total mood and sub-scores of confusion and depression reported in the current study. These findings indicate that some professional MMA athletes might experience higher levels of anticipatory psychological stress or arousal particularly at weigh-in and fight days. Further research is required to understand the way in which this can be managed to facilitate optimal performance.

Changes in sub sections of mood state may have also been associated with factors other than SC. For example, in the final week of the taper, scores of confusion, depression and anger increased as BM reduced, but decreased again as BM increased within the final day. Such a trend suggests that the mood state of an MMA athlete may be influenced by the magnitude or method of BM reduction within the final week of fight preparation. Hypo-hydration has been reported to impair visuomotor performance (Wittbrodt et al., 2018), short-term memory (Choma, Sforzo, & Keller, 1998) and brain metabolism (Kempton et al., 2011), suggesting acute altered brain function. As cortisol is a glucocorticoid, which can be elevated due to euphorigenic or neuro-stimulatory causes (Kunz-Ebrecht et al., 2003), it is hypothesised that rises in cortisol, tension and fatigue may also be attributed to neuroendocrine and corticospinal responses to hypo-hydration. It is also important to note that though participants returned to baseline BM, UO did not, suggesting blood volume may have not increased and reached baseline values. The reduction in blood volume and increase in UO results in a shift of sodium uptake, leading to altered excitation-contraction capabilities (Hackney et al., 2012; Bowtell et al., 2013). As a result, though athletes may have achieved initial BM, this may not be reflective of restored performance, tolerance to fatigue and sarcolemmal breakdown (within bouts), as has been reported previously (Bigard et al., 2001) and could have major implications upon brain morphology (e.g. ventricular enlargement) (Wittbrodt et al., 2018), increased oxygen metabolism (Kempton et al., 2011) and neuromuscular function (e.g. time to fatigue in skeletal muscle) (Bigard et al., 2001; Hackney et al., 2012; Bowtell et al., 2013).

Data presented here suggest MMA athletes may enter competitive events with significant muscle damage due to sub-optimal tapering strategies, which should be monitored in accordance to individual load and type of session. Rehydration strategies should be considered (i.e. bolus vs metered drinking, % of BM lost vs total litres of fluid ingested, electrolyte and glucose content) for effective recovery of blood volume and BM. Furthermore, it is recommended that coaches look towards alternative and additional methods of subjective mood/stress scoring, specific to overreaching and/or discriminating between psychosocial stressors and TL.

The authors acknowledge that a larger sample size with a wider weight-class range are needed to further examine the immunoendocrine and mood status of MMA athletes undergoing a fight preparation camp. It is possible that heavyweight athletes may not engage in RWL strategies and therefore present a different physiological and mood profile during a fight preparation camp.

In conclusion, the mood state of professional fighters appears to deteriorate across the five-week fight camp, leading to increased feelings of confusion, depression and tension. Indirect markers of muscle damage and mucosal immunity are also negatively affected during the five-weeks, but can partially recover with a de-loading taper strategy in the pre-fight period. Professional MMA athletes practice pre-fight fluid restriction as a method of RWL, which appears to coincide with negative mood states. Increased cortisol in the final few days of the fight camp may also be related to increased pre-fight stress/anxiety, while salivary IgA decreased >70% 1 week out from fight day, potentially increasing risk of MMA athletes to URTIs towards or after competition date. Practitioners and coaches within MMA should consider refining methods related to the monitoring of load management and mood states while looking to optimise the rehydration process for their athletes during fight preparation camps.

Conflict of Interest

The authors declare no conflicts of interest.

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Validity and reliability of the Beast™ sensor to measure movement velocity during the back squat exercise

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ABSTRACT

The purpose of this study was to analyze the validity and reliability of the BEAST™ wearable device to measure movement velocity during the back squat exercise. Eleven national-level female field-hockey players (age: 18.4 ± 1.7 y; back squat 1-RM: 92.7 ± 14.1 kg; height: 158.4 ± 4.6 cm; weight: 54.5 ± 5.5 kg) performed 3 repetitions of the back squat exercise with four loads on a power rack. Movement velocity for each repetition was simultaneously recorded using a linear position transducer (LPT) and the BEAST™ sensor. Results showed excellent agreement between the LPT and the BEAST™ for mean movement velocity and power, with intra-class correlation coefficient (ICC) values of 0.966 and 0.957, respectively; however, a systematic bias was observed with the BEAST™ sensor compared to the LPT device with greater mean velocity (+0.098 m·s-1, p < 0.001, 14.3%) and power (+51.8 W, p < 0.001, 21.9%). For repetitions at a given workload, mean velocity and power measures were highly reproducible for both the BEAST™ (velocity: ICC = 0.935, CV = 7.4%, power: ICC = 0.962, CV = 8.4%) and the LPT (velocity: ICC = 0.929, CV = 8.7%; power: ICC = 0.923, CV = 10.2%). The results support the use of the BEAST™ as a reliable low-cost wearable device to track velocity and power outputs during back squat training. Comparisons between data from the BEAST™ sensor and the LPT device should be made with caution due to the significant systematic bias observed. Wearable devices, such as the one used in this study, have valuable practical applications for athletes, strength and conditioning coaches, and sport scientists attempting to optimize training via feedback or monitor adaptations resultant from the manipulation of training micro-cycles and periodised plans.

1. Introduction

Resistance training is a fundamental part of an athlete's conditioning program with clear benefits on health (Shaw, Shaw, & Brown, 2015) and performance (Crewther, Cronin, & Keogh, 2005; Harries, Lubans, & Callister, 2012). Prescribing the proper training intensity to optimize gains requires adequate assessment of muscle strength, which is typically quantified using direct measurements of 1-repetition maximum (Baechle & Earle, 2008) or estimated using predictive equations (LeSuer, McCormick, Mayhew, Wasserstein, & Arnold, 1997). Both methods have limitations as they can be time-consuming and have the potential to expose individuals to an increased injury risk, particularly for inexperienced athletes with little to no experience in lifting relatively heavy loads (Hooper et al., 2014; Sánchez-Medina & González-Badillo, 2011). Furthermore, 1-RM values can change after only a few training sessions (González-Badillo & Sánchez-Medina, 2010). Therefore, there is a cogent argument for conducting strength assessments frequently to ensure that the optimal training intensities are prescribed across a range of muscle groups and exercises. Although recurring assessments of 1-RM over a short period of time for individual sport athletes may be feasible, doing so with team sport athletes is a challenge given

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the number of athletes involved and their differing functional abilities.

Over the past few years, there is a growing scientific and practical interest in the use of movement velocity for assessing and monitoring resistance training. González-Badillo and Sánchez-Medina (2010) demonstrated the existence of an "inextricable relationship" between the relative load and mean velocity. This relationship allows maximal strength assessment using the mean concentric velocity of movement without the need to perform a 1-RM test once the minimal velocity threshold for a specific resistance exercise is identified. In the past, movement velocity has been tracked using Linear Position Transducers (LPT). These devices typically involve a central processing unit that is attached to the resistance training equipment (such as a barbell) via a retractable measuring cable to yield the displacement, velocity, and acceleration of an object with respect to time. The literature regarding the use of position transducer technology in strength and conditioning practice has been reported previously (Harris, Cronin, Taylor, Boris, & Sheppard, 2010), and validity and reliability with respect to force plates (O'Donnell, Tavares, McMaster, Chambers, & Driller, 2018) and an isoinertial dynamometer (Garnacho-Castaño, López-Lastra, & Maté-Muñoz, 2015) has also been reported.

Unfortunately, LPT are costly (over $3,200 NZD) and not affordable for most strength and conditioning specialists, especially those dealing with teams where multiple units would be required. However, in recent years, devices equipped with an accelerometer have been validated against LPT for measuring bar velocity by integrating the acceleration data with respect to time (Balsalobre-Fernandez, Kuzdub, Poveda-Ortiz, & Campo-Vecino, 2016; Balsalobre-Fernandez et al., 2017; Banyard, Nosaka, & Haff, 2017; Comstock et al., 2011). In a training environment, such devices are often attached to the barbell or affixed directly to the weight plates to collect movement data in real-time. The BEAST™ sensor (Beast Technologies, Brescia, Italy) is a device specifically designed to be worn on the wrist to track velocity (m·s-1) and power (W), and provide real-time data through a smartphone application, that costs ~$420 NZD. The sensor weighs 38 g with dimensions of 20 x 19 x 40 mm. However, despite the increasing popularity of the BEAST™ technology in strength and conditioning, the validity and reliability of the device have not been reported in team sport athletes with minimal resistance training history.

2. Methods

This study aimed to analyze the validity and reliability of the BEAST™ sensor to measure bar movement velocity and power during the commonly prescribed back squat exercise, using a LPT as reference for comparison.

2.1. Participants

Eleven female field-hockey players ([mean ± standard deviation] age: 18.4 ± 1.7 y, height: 158.4 ± 4.6 cm, body mass: 54.5 ± 5.5 kg, back squat 1-RM: 92.7 ± 14.1 kg or 1.7 ± 0.3 kg/kgBM, resistance training history 1.2 ± 1.0 y) from the Malaysian national women's development squad performed 3 repetitions of the back squat exercise on a power rack with four different loads. Movement velocity for each of the total 132 repetitions (i.e., 11 players x 3 repetitions x 4 loads) was simultaneously recorded using the CHRONOJUMP™ linear position transducer (CHRONOJUMP™, Barcelona, Spain) and the BEAST™ sensor. The players were informed of the risks and benefits of participation in the study and provided informed consent to participate. Ethical approval was attained from the institutional ethics committee of the National Sports Institute.

2.2. Procedures

The back squat test was performed in a gymnasium using a squat rack, a 20 kg barbell, and free weights. The test procedure started with a standard warm up involving 5-min of cycling on a stationary bike, 5-min of dynamic stretching, 10 repetitions of bodyweight squats, and 10 repetitions of the back squat exercise with the unloaded 20 kg barbell. The players then rested for five minutes. After the warm up, each athlete completed three repetitions of the back squat to parallel with the unloaded to standardize the squat depth with a 5 s rest between repetitions. The athletes were instructed to maintain a shoulder width stance, and to perform the concentric phase of the back squat movement as fast as possible. The process was repeated with four absolute submaximal loads: 20, 30, 40, and 60 kg, with 5 min passive rest between sets. The players did not perform any heavy training the day prior to the test, and were informed to attend the test session well rested, hydrated, and in a non-fasted state. All testing was conducted by the team's physiologist in a single testing session.

2.3. Apparatus

The BEAST™ sensor unit consists of a 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer with an acquisition frequency of 50 Hz. The BEAST™ sensor was placed on the dorsal aspect of the player's left wrist, approximately 2 cm proximal to joint line, and connected to an android-based smartphone Samsung™ S6 (Samsung Electronics Co. Ltd, Seoul, South Korea) via Bluetooth 4.0 LE running the BEAST™ application for android (version 1.9.11).

A CHRONOJUMP™ Bosco-system Linear Position Transducer (CHRONOJUMP™, Barcelona, Spain), which had previously been demonstrated to be valid (ICC range 0.925 to 0.988) and reliable in assessing average velocity (mean bias 0.018%) and average power (mean bias 0.024%) (Vivancos et al., 2014) when compared to the T-Force system (Ergotech, Murcia, Spain), was considered the criterion in this study. The LPT was placed in an inverted position on top of the squat rack and the retractable cable was attached to the left extremity of the barbell. Bar velocity was measured using the LPT at a sample rate of 1000 Hz and the data was smoothed using nonlinear spline adaptive filtering. The LPT was connected via USB to a laptop running

Windows 7 Professional and the CHRONOJUMP™ Software (version 1.5.6). For each back squat repetition, the mean velocity (m·s-1) and power (W) values were extracted from the BEAST™ sensor (in the Z direction) and LPT device, and recorded for further analysis.

2.4. Statistical Approach

Descriptive statistics (mean, standard deviation (SD), and range values) were calculated for the total sum of the four submaximal loads (20, 30, 40 & 60 kg). Normality of distribution was assessed using z-scores for skewness and kurtosis before performing further statistical analyses (Kim, 2013). As the data were normally distributed, parametric tests were used. The within-subject reliability of measures was assessed using intra-class correlation coefficients (ICC) with 95% confidence intervals [upper, lower].

The relative reproducibility of measures was considered poor, good, and excellent when the corresponding ICC values were < 0.4, 0.4 – 0.75, and > 0.75 (Shrout & Fleiss, 1979). The absolute reliability was quantified using the coefficient of variation (CV) as outlined by Hopkins (Hopkins, 2000), and deemed adequate when < 10% (Harper, Morin, Carling, & Kiely, 2020; Rogers et al., 2019).

The concurrent validity of mean velocity and power measures from the BEAST™ and LPT was also quantified using ICC with 95% confidence intervals [upper, lower], and the qualitative thresholds describe above. Independent paired t-tests and Bland-Altman plots with mean differences (± 1.96 SD) were employed to identify any potential systematic bias between recording devices. All statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) version 21.0 (IBM Corporation; Armonk, New York, USA) unless stated otherwise. The level of significance was set at $p \leq 0.05$.

3. Results

3.1. Reliability

Descriptive and reliability statistics for mean velocity and power of the BEAST™ sensor and LPT device are presented in Table 1. Mean velocity was measured at 20 kg (BEAST™ sensor: 0.95 $m \cdot s^{-1}$ / LPT: 0.84 $m \cdot s^{-1}$), 30 kg (0.77 / 0.67 $m \cdot s^{-1}$), 40 kg (0.73 / 0.65 $m \cdot s^{-1}$), 60 kg (0.66 / 0.53 $m \cdot s^{-1}$). Mean power was calculated at 20 kg (BEAST™ sensor: 201 W / LPT: 168 W), 30 kg (246 / 203 W), 40 kg (308 / 266 W), 60 kg (415 / 318 W). Note that the current data set only enables an estimation of the concurrent error within the testing session, as opposed to a true within-subject variation.

Table 1: Descriptive and within-subject reliability statistics for mean velocity and power values from BEAST™ sensor and LPT device.

Parameter	Mean ± SD	ICC [upper, lower]	CV (%)
BEAST™ mean velocity ($m \cdot s^{-1}$)	0.765 ± 0.148	0.935	7.4
Trial 1	0.737 ± 0.154	[0.872, 0.968]	
Trial 2	0.762 ± 0.154		
Trial 3	0.798 ± 0.133		
LPT mean velocity ($m \cdot s^{-1}$)	0.668 ± 0.149	0.929	10.0
Trial 1	0.638 ± 0.150	[0.863, 0.965]	
Trial 2	0.674 ± 0.152		
Trial 3	0.690 ± 0.143		
BEAST™ mean power (W)	287.4 ± 88.6	0.962	8.4
Trial 1	275.4 ± 83.3	[0.927, 0.981]	
Trial 2	291.5 ± 94.7		
Trial 3	295.0 ± 87.8		
LPT mean power (W)	235.5 ± 70.7	0.923	12.3
Trial 1	223.2 ± 64.6	[0.856, 0.961]	
Trial 2	242.9 ± 76.3		
Trial 3	239.6 ± 70.3		

Values are mean ± standard deviation (SD), intra-class correlation coefficient (ICC) with 95% confidence limits [upper, lower], and coefficient of variation (CV).

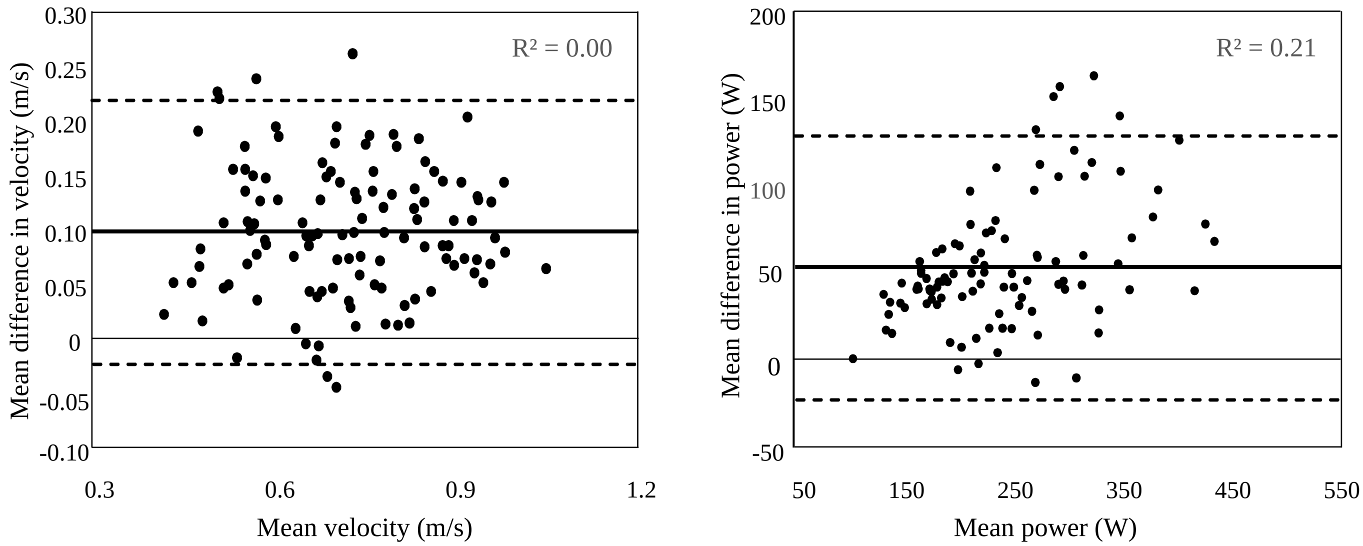

Figure 1: Bland-Altman plots between BEAST™ and LPT metrics, A: mean velocity; B: mean power
The central line represents the systematic bias between instruments (positive values mean higher velocity obtained with the BEAST™, while negative values mean higher velocity obtained with the LPT), while the upper and lower dotted lines represent ±1.96 SD.

3.2. Validity

There was an excellent agreement (ICC = 0.966 [range 0.943 to 0.982]) between the mean velocity measured by the LPT and the BEAST™ sensor. However, there was a systematic bias between the mean velocity from the two devices (p < 0.001), with the BEAST™ sensor providing values 14.3% higher than the LPT device (0.098 m·s^{-1} [0.058 to 0.137], refer Figure 1A). Similarly, there was an excellent agreement (ICC = 0.931 [0.873 to 0.965]) between mean power measured by the LPT and the BEAST™. However, there was a systematic bias between the two devices (p < 0.001), with the BEAST™ sensor providing values 21.9% higher than the LPT (51.8 W [30.7 to 73.0], Figure 1B).

4. Discussion

This study determined that the BEAST™ sensor is a reliable tool to measure mean movement velocity and power during the back squat exercise when compared to a validated LPT device. Both systems exhibited excellent relative reliability (ICC > 0.75) while the BEAST™ sensor actually outperformed the LPT in terms of absolute reliability (CV) for velocity and power measures. The absolute reliability is similar to the 5.0 ± 4.1% CV reported for the PUSH™ wearable device (Balsalobre-Fernandez et al., 2016). A very large correlation and excellent agreement was found between the BEAST™ sensor and the LPT for both mean velocity and power data collected during the back squat exercise. The resultant smallest worthwhile effect derived from the between-subject standard deviation is 19 W and 0.03 m·s-1 for the BEAST™ sensor, with values of 16 W and 0.03 m·s-1 for the LPT.

It should be noted that a systematic bias was observed, whereby readings were larger from the BEAST™ sensor than the LPT in the squat movement pattern (mean velocity: 0.098 m·s-1; mean power: 51.8 W). Therefore, data from the BEAST™ sensor cannot be used interchangeably with a LPT without accounting for the systematic bias demonstrated herein. Specifically, this brings in to question the validity of the BEAST™ sensor when compared to the LPT. The observed bias is consistent with previous work that showed a 0.11 m·s-1 difference between an accelerometer-based technology and a LPT (Balsalobre-Fernandez et al., 2016). Noteworthy is that the Bland-Altman Figures suggest a more or less consistent absolute bias across the velocities observed (R^2 = 0.00); however, there was a tendency for a greater absolute mean difference between technologies as power output increased (R^2 = 0.21). We acknowledge that the use of a force platform may have provided a superior criterion measure for power data; however, the direct measurement of displacement and time establishes an LPT as an ideal criterion for movement velocity.

The cost of the BEAST™ sensor (~$420 NZD) along with the BEAST™ smartphone application has important implications for strength and conditioning coaches. The sensor allows assessment of strength and power capabilities, monitoring resistance training in real-time, and tracking changes in squat performance over time in a reliable manner. The BEAST™ sensor's online platform provides a summary of the training sessions, including relevant information such as a session's total volume, average intensity, and average power; data that coaches can use to effectively monitor training load. In addition, all resistance exercises performed during a training session are recorded, and data from the best repetition for each exercise are highlighted. This feature facilitates the monitoring of 1-RM changes over time given that changes in lifting velocities at a given load correlate with an athlete's strength capacity (González-Badillo & Sánchez-Medina, 2010). Further, the ability to assess 1-RM using previously established load-velocity relationships, also has the advantage of eliminating the need for dedicated strength testing sessions. In addition, the sensor can and provide strength and conditioning practitioners with a dynamic indication of the training status of an athlete.

The provision of real-time objective performance measures during training and testing of athletes has shown to be effective in eliciting higher performance outputs and desirable adaptations than in non-feedback conditions (Randell, Cronin, Keogh, Gill, & Pedersen, 2011). Although previously such training methods were mostly only accessible in elite sporting environments or research facilities, the ease-of-use and affordability of sensors and smartphone applications such as the BEAST™ is permitting a wider use of sensor technology across performance levels. Wearable sensors combined with smartphone applications are an easy-to-use and affordable system, eliciting a paradigm shift in the way strength and conditioning coaches and sport scientists approach resistance training and monitoring.

The data demonstrate that the BEAST™ sensor is a reliable tool to assess the lower-limb neuromuscular capacity of well-trained athletes performing a parallel back squat. As a result, exercise prescription, monitoring, and feedback can be enhanced. The reduced requirement for dedicated assessment sessions and the ability to dynamically monitor changes in neuromuscular capacity provides valuable information for practitioners, with respect to manipulation of periodised plans, training micro-cycles, and individual session goals.

Conflict of Interest

The authors declare no conflict of interests.

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the number of athletes involved and their differing functional abilities.

Over the past few years, there is a growing scientific and practical interest in the use of movement velocity for assessing and monitoring resistance training. González-Badillo and Sánchez-Medina (2010) demonstrated the existence of an "inextricable relationship" between the relative load and mean velocity. This relationship allows maximal strength assessment using the mean concentric velocity of movement without the need to perform a 1-RM test once the minimal velocity threshold for a specific resistance exercise is identified. In the past, movement velocity has been tracked using Linear Position Transducers (LPT). These devices typically involve a central processing unit that is attached to the resistance training equipment (such as a barbell) via a retractable measuring cable to yield the displacement, velocity, and acceleration of an object with respect to time. The literature regarding the use of position transducer technology in strength and conditioning practice has been reported previously (Harris, Cronin, Taylor, Boris, & Sheppard, 2010), and validity and reliability with respect to force plates (O'Donnell, Tavares, McMaster, Chambers, & Driller, 2018) and an isoinertial dynamometer (Garnacho-Castaño, López-Lastra, & Maté-Muñoz, 2015) has also been reported.

Unfortunately, LPT are costly (over $3,200 NZD) and not affordable for most strength and conditioning specialists, especially those dealing with teams where multiple units would be required. However, in recent years, devices equipped with an accelerometer have been validated against LPT for measuring bar velocity by integrating the acceleration data with respect to time (Balsalobre-Fernandez, Kuzdub, Poveda-Ortiz, & Campo-Vecino, 2016; Balsalobre-Fernandez et al., 2017; Banyard, Nosaka, & Haff, 2017; Comstock et al., 2011). In a training environment, such devices are often attached to the barbell or affixed directly to the weight plates to collect movement data in real-time. The BEAST™ sensor (Beast Technologies, Brescia, Italy) is a device specifically designed to be worn on the wrist to track velocity (m·s-1) and power (W), and provide real-time data through a smartphone application, that costs ~$420 NZD. The sensor weighs 38 g with dimensions of 20 x 19 x 40 mm. However, despite the increasing popularity of the BEAST™ technology in strength and conditioning, the validity and reliability of the device have not been reported in team sport athletes with minimal resistance training history.

2. Methods

This study aimed to analyze the validity and reliability of the BEAST™ sensor to measure bar movement velocity and power during the commonly prescribed back squat exercise, using a LPT as reference for comparison.

2.1. Participants

Eleven female field-hockey players ([mean ± standard deviation] age: 18.4 ± 1.7 y, height: 158.4 ± 4.6 cm, body mass: 54.5 ± 5.5 kg, back squat 1-RM: 92.7 ± 14.1 kg or 1.7 ± 0.3 kg/kgBM, resistance training history 1.2 ± 1.0 y) from the Malaysian national women's development squad performed 3 repetitions of the back squat exercise on a power rack with four different loads. Movement velocity for each of the total 132 repetitions (i.e., 11 players x 3 repetitions x 4 loads) was simultaneously recorded using the CHRONOJUMP™ linear position transducer (CHRONOJUMP™, Barcelona, Spain) and the BEAST™ sensor. The players were informed of the risks and benefits of participation in the study and provided informed consent to participate. Ethical approval was attained from the institutional ethics committee of the National Sports Institute.

2.2. Procedures

The back squat test was performed in a gymnasium using a squat rack, a 20 kg barbell, and free weights. The test procedure started with a standard warm up involving 5-min of cycling on a stationary bike, 5-min of dynamic stretching, 10 repetitions of bodyweight squats, and 10 repetitions of the back squat exercise with the unloaded 20 kg barbell. The players then rested for five minutes. After the warm up, each athlete completed three repetitions of the back squat to parallel with the unloaded to standardize the squat depth with a 5 s rest between repetitions. The athletes were instructed to maintain a shoulder width stance, and to perform the concentric phase of the back squat movement as fast as possible. The process was repeated with four absolute submaximal loads: 20, 30, 40, and 60 kg, with 5 min passive rest between sets. The players did not perform any heavy training the day prior to the test, and were informed to attend the test session well rested, hydrated, and in a non-fasted state. All testing was conducted by the team's physiologist in a single testing session.

2.3. Apparatus

The BEAST™ sensor unit consists of a 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer with an acquisition frequency of 50 Hz. The BEAST™ sensor was placed on the dorsal aspect of the player's left wrist, approximately 2 cm proximal to joint line, and connected to an android-based smartphone Samsung™ S6 (Samsung Electronics Co. Ltd, Seoul, South Korea) via Bluetooth 4.0 LE running the BEAST™ application for android (version 1.9.11).

A CHRONOJUMP™ Bosco-system Linear Position Transducer (CHRONOJUMP™, Barcelona, Spain), which had previously been demonstrated to be valid (ICC range 0.925 to 0.988) and reliable in assessing average velocity (mean bias 0.018%) and average power (mean bias 0.024%) (Vivancos et al., 2014) when compared to the T-Force system (Ergotech, Murcia, Spain), was considered the criterion in this study. The LPT was placed in an inverted position on top of the squat rack and the retractable cable was attached to the left extremity of the barbell. Bar velocity was measured using the LPT at a sample rate of 1000 Hz and the data was smoothed using nonlinear spline adaptive filtering. The LPT was connected via USB to a laptop running

Windows 7 Professional and the CHRONOJUMP™ Software (version 1.5.6). For each back squat repetition, the mean velocity (m·s-1) and power (W) values were extracted from the BEAST™ sensor (in the Z direction) and LPT device, and recorded for further analysis.

2.4. Statistical Approach

Descriptive statistics (mean, standard deviation (SD), and range values) were calculated for the total sum of the four submaximal loads (20, 30, 40 & 60 kg). Normality of distribution was assessed using z-scores for skewness and kurtosis before performing further statistical analyses (Kim, 2013). As the data were normally distributed, parametric tests were used. The within-subject reliability of measures was assessed using intra-class correlation coefficients (ICC) with 95% confidence intervals [upper, lower].

The relative reproducibility of measures was considered poor, good, and excellent when the corresponding ICC values were < 0.4, 0.4 – 0.75, and > 0.75 (Shrout & Fleiss, 1979). The absolute reliability was quantified using the coefficient of variation (CV) as outlined by Hopkins (Hopkins, 2000), and deemed adequate when < 10% (Harper, Morin, Carling, & Kiely, 2020; Rogers et al., 2019).

The concurrent validity of mean velocity and power measures from the BEAST™ and LPT was also quantified using ICC with 95% confidence intervals [upper, lower], and the qualitative thresholds describe above. Independent paired t-tests and Bland-Altman plots with mean differences (± 1.96 SD) were employed to identify any potential systematic bias between recording devices. All statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) version 21.0 (IBM Corporation; Armonk, New York, USA) unless stated otherwise. The level of significance was set at $p \leq 0.05$.

3. Results

3.1. Reliability

Descriptive and reliability statistics for mean velocity and power of the BEAST™ sensor and LPT device are presented in Table 1. Mean velocity was measured at 20 kg (BEAST™ sensor: 0.95 $m \cdot s^{-1}$ / LPT: 0.84 $m \cdot s^{-1}$), 30 kg (0.77 / 0.67 $m \cdot s^{-1}$), 40 kg (0.73 / 0.65 $m \cdot s^{-1}$), 60 kg (0.66 / 0.53 $m \cdot s^{-1}$). Mean power was calculated at 20 kg (BEAST™ sensor: 201 W / LPT: 168 W), 30 kg (246 / 203 W), 40 kg (308 / 266 W), 60 kg (415 / 318 W). Note that the current data set only enables an estimation of the concurrent error within the testing session, as opposed to a true within-subject variation.

Table 1: Descriptive and within-subject reliability statistics for mean velocity and power values from BEAST™ sensor and LPT device.

Parameter	Mean ± SD	ICC [upper, lower]	CV (%)
BEAST™ mean velocity ($m \cdot s^{-1}$)	0.765 ± 0.148	0.935	7.4
Trial 1	0.737 ± 0.154	[0.872, 0.968]	
Trial 2	0.762 ± 0.154		
Trial 3	0.798 ± 0.133		
LPT mean velocity ($m \cdot s^{-1}$)	0.668 ± 0.149	0.929	10.0
Trial 1	0.638 ± 0.150	[0.863, 0.965]	
Trial 2	0.674 ± 0.152		
Trial 3	0.690 ± 0.143		
BEAST™ mean power (W)	287.4 ± 88.6	0.962	8.4
Trial 1	275.4 ± 83.3	[0.927, 0.981]	
Trial 2	291.5 ± 94.7		
Trial 3	295.0 ± 87.8		
LPT mean power (W)	235.5 ± 70.7	0.923	12.3
Trial 1	223.2 ± 64.6	[0.856, 0.961]	
Trial 2	242.9 ± 76.3		
Trial 3	239.6 ± 70.3		

Values are mean ± standard deviation (SD), intra-class correlation coefficient (ICC) with 95% confidence limits [upper, lower], and coefficient of variation (CV).

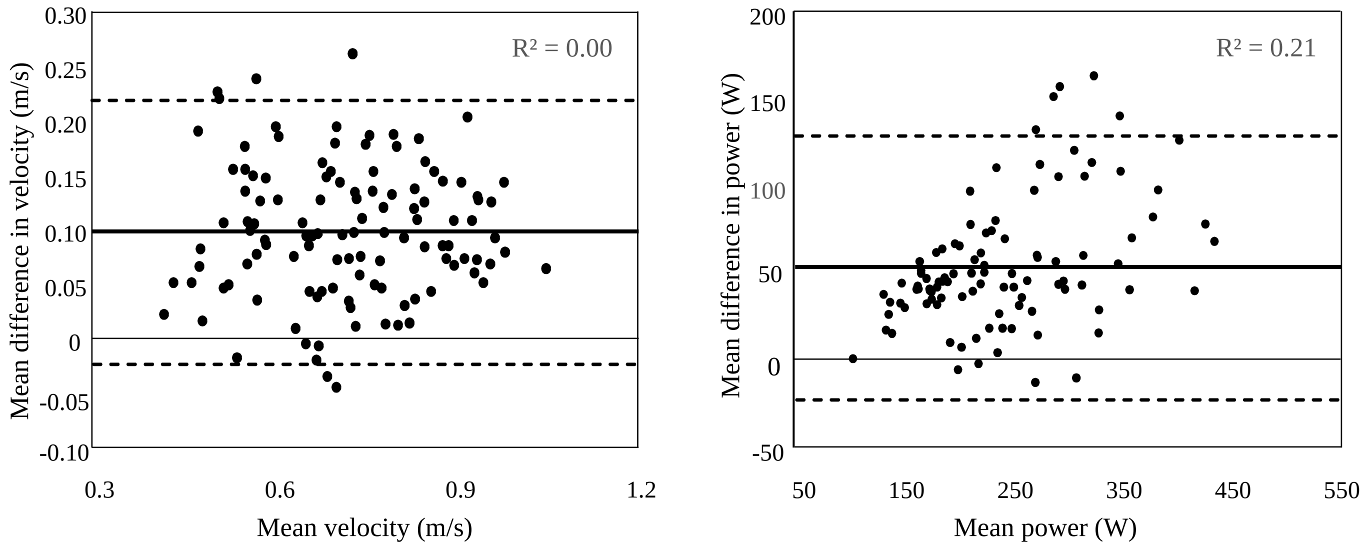

Figure 1: Bland-Altman plots between BEAST™ and LPT metrics, A: mean velocity; B: mean power
The central line represents the systematic bias between instruments (positive values mean higher velocity obtained with the BEAST™, while negative values mean higher velocity obtained with the LPT), while the upper and lower dotted lines represent ±1.96 SD.

3.2. Validity

There was an excellent agreement (ICC = 0.966 [range 0.943 to 0.982]) between the mean velocity measured by the LPT and the BEAST™ sensor. However, there was a systematic bias between the mean velocity from the two devices ($p < 0.001$), with the BEAST™ sensor providing values 14.3% higher than the LPT device (0.098 m·s^{-1} [0.058 to 0.137], refer Figure 1A). Similarly, there was an excellent agreement (ICC = 0.931 [0.873 to 0.965]) between mean power measured by the LPT and the BEAST™. However, there was a systematic bias between the two devices ($p < 0.001$), with the BEAST™ sensor providing values 21.9% higher than the LPT (51.8 W [30.7 to 73.0], Figure 1B).

4. Discussion

This study determined that the BEAST™ sensor is a reliable tool to measure mean movement velocity and power during the back squat exercise when compared to a validated LPT device. Both systems exhibited excellent relative reliability (ICC > 0.75) while the BEAST™ sensor actually outperformed the LPT in terms of absolute reliability (CV) for velocity and power measures. The absolute reliability is similar to the 5.0 ± 4.1% CV reported for the PUSH™ wearable device (Balsalobre-Fernandez et al., 2016). A very large correlation and excellent agreement was found between the BEAST™ sensor and the LPT for both mean velocity and power data collected during the back squat exercise. The resultant smallest worthwhile effect derived from the between-subject standard deviation is 19 W and 0.03 m·s-1 for the BEAST™ sensor, with values of 16 W and 0.03 m·s-1 for the LPT.

It should be noted that a systematic bias was observed, whereby readings were larger from the BEAST™ sensor than the LPT in the squat movement pattern (mean velocity: 0.098 m·s-1; mean power: 51.8 W). Therefore, data from the BEAST™ sensor cannot be used interchangeably with a LPT without accounting for the systematic bias demonstrated herein. Specifically, this brings in to question the validity of the BEAST™ sensor when compared to the LPT. The observed bias is consistent with previous work that showed a 0.11 m·s-1 difference between an accelerometer-based technology and a LPT (Balsalobre-Fernandez et al., 2016). Noteworthy is that the Bland-Altman Figures suggest a more or less consistent absolute bias across the velocities observed ($R^2 = 0.00$); however, there was a tendency for a greater absolute mean difference between technologies as power output increased ($R^2 = 0.21$). We acknowledge that the use of a force platform may have provided a superior criterion measure for power data; however, the direct measurement of displacement and time establishes an LPT as an ideal criterion for movement velocity.

The cost of the BEAST™ sensor (~$420 NZD) along with the BEAST™ smartphone application has important implications for strength and conditioning coaches. The sensor allows assessment of strength and power capabilities, monitoring resistance training in real-time, and tracking changes in squat performance over time in a reliable manner. The BEAST™ sensor's online platform provides a summary of the training sessions, including relevant information such as a session's total volume, average intensity, and average power; data that coaches can use to effectively monitor training load. In addition, all resistance exercises performed during a training session are recorded, and data from the best repetition for each exercise are highlighted. This feature facilitates the monitoring of 1-RM changes over time given that changes in lifting velocities at a given load correlate with an athlete's strength capacity (González-Badillo & Sánchez-Medina, 2010). Further, the ability to assess 1-RM using previously established load-velocity relationships, also has the advantage of eliminating the need for dedicated strength testing sessions. In addition, the sensor can and provide strength and conditioning practitioners with a dynamic indication of the training status of an athlete.

The provision of real-time objective performance measures during training and testing of athletes has shown to be effective in eliciting higher performance outputs and desirable adaptations than in non-feedback conditions (Randell, Cronin, Keogh, Gill, & Pedersen, 2011). Although previously such training methods were mostly only accessible in elite sporting environments or research facilities, the ease-of-use and affordability of sensors and smartphone applications such as the BEAST™ is permitting a wider use of sensor technology across performance levels. Wearable sensors combined with smartphone applications are an easy-to-use and affordable system, eliciting a paradigm shift in the way strength and conditioning coaches and sport scientists approach resistance training and monitoring.

The data demonstrate that the BEAST™ sensor is a reliable tool to assess the lower-limb neuromuscular capacity of well-trained athletes performing a parallel back squat. As a result, exercise prescription, monitoring, and feedback can be enhanced. The reduced requirement for dedicated assessment sessions and the ability to dynamically monitor changes in neuromuscular capacity provides valuable information for practitioners, with respect to manipulation of periodised plans, training micro-cycles, and individual session goals.

Conflict of Interest

The authors declare no conflict of interests.

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Effect of chronic exposure to height on the psychophysiological responses to a climbing task

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A B S T R A C T

Rock climbing offers a potential therapeutic intervention for trainee firefighters, construction workers or for those with acrophobia. To examine the therapeutic potential of climbing we examined the extent of differences in psychophysiological responses between climbers and non-climbers. Responses of 15 climbers and 14 non-climbing matched controls to a 20-metre ladder climb were assessed. Climbers ascended the ladder more quickly ($p < 0.0005$; $d = 1.15$) than non-climbers without significant differences in peak heart rate ($p = 0.906$; $d = 0.05$) or peak oxygen uptake ($p = 0.136$; $d = 0.83$). The climbers demonstrated a blunted psychophysiological response, reporting lower levels of cognitive anxiety ($p = 0.036$; $d = 0.84$), lower peak cortisol concentrations ($p = 0.010$; $d = 1.04$), a decreased relative anticipatory heart rate rise ($p = 0.008$; $d = 1.06$) as well as reporting a higher mean level of self-confidence ($p = 0.007$; $d = 1.10$). Physiological and psychological responses were lower for climbers when compared with non-climbers. Consequently, the climbers in this study appeared to demonstrate a degree of habituation to working at height, most likely due to chronic exposure. In a climbing context coaches should consider the potential effects of elevated anxiety for beginner climbers and its impact on their learning. Climbing appears to represent a potential therapeutic intervention for those with height-induced elevations in anxiety.

1. Introduction

For those beginning a career in the construction industry or as a fire-fighter, any anxiety associated with working at height can be debilitating such that it interferes with on the job training (Ting, Palminteri, Lebreton, & Engelmann, 2020). To date, research focused on the demands of fire-fighting has tended to concentrate on the environmental demands of the profession, and consequently there appear to be gaps in the literature in regard to fear of height in fire-fighting trainees (Horn, Stewart, Kesler, DeBlois, Kerber, Fent et al., 2019). In recent years for those with acrophobia there has been a growing interest in the use of virtual reality to form part of therapeutic interventions for patients (Diemer, Lohkamp, Mühlberger, & Zwanzger, 2015). There has been a lesser focus on the potential of climbing in the real-world as a therapeutic intervention for people with acrophobia.

In a climbing context, performance is underpinned by a significant psychophysiological component (Draper, Dickson, Fryer, & Blackwell, 2011; Draper, Jones, Fryer, Hodgson, & Blackwell, 2008; Draper, Jones, Fryer, Hodgson, & Blackwell, 2010; Giles et al., 2014). A growing number of studies have assessed the psychological and physiological responses of elite and advanced level rock climbers to a variety of factors, including but not limited to: route knowledge (Draper et al., 2008), potential fall distance (Baláš et al., 2017) and, climber protection (Dickson, Fryer, Blackwell, Draper, & Stoner, 2012; Fryer, Dickson, Draper, Blackwell, & Hillier, 2013). These studies found that higher stress trials negatively affect performance: resulting in slower climbing time, greater cognitive anxiety, and lower self-confidence (Dickson et al., 2012; Fryer et al., 2013), increased catecholamine concentrations (Baláš et al., 2017), and an elevated cortisol response (Draper et al., 2008).

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As for fire-fighters and construction workers who work at height regularly and for those with acrophobia, research with those new to climbing or for non-climbers is limited. To date, only the work of Pijpers and colleagues provides findings for novices (e.g., Pijpers, Oudejans, Holsheimer, & Bakker, 2003). In this research, Pijpers et al. (2003) found that novices demonstrated significant elevations in anxiety and heart rate (HR), when compared with climbers. However, Pijpers and colleagues work was conducted using low level traverses (moving sideways along a wall) rather than ascending to height which is the more common style in rock climbing (Pijpers et al., 2003). Currently there is no known research investigating the psychophysiological responses to climbing to height for novice or non-climbers. Such work would be of relevance not only in a climbing context, but also for those who have to work at height in their work or for those suffering with acrophobia, where climbing might represent a therapeutic intervention.

It is most likely that psychophysiological responses of non-climbers have not been reported due to the technical and safety concerns associated with the sport. Free-hanging wire ladder climbs are often used as a training tool for climbers, but also offer a non-sport-specific task that could enable non-climbers to easily ascend to height. The purpose of this study was to examine psychophysiological responses of climbers and non-climbers to a 20-meter wire ladder climbing task. Given the possible effects of habituation for climbers, our expectation was that, in comparison to the non-climbers, the climbers would (i) ascend the ladder more quickly; (ii) be less cognitively and somatically anxious; (iii) have greater self-confidence; (iv) while showing a lower anticipatory rise in HR and (v) lower cortisol concentrations.

2. Methods

2.1. Study Design

This cross-sectional study was designed following the STROBE guidelines for cross-sectional observational studies and were followed for the reporting of the results (Poorolajal, Cheraghi, Irani, & Rezaeian, 2011; Vandenbroucke, von Elm, Altman, Gøtzsche, Mulrow, Pocock, et al., 2007).

2.2. Participants

Fifteen experienced climbers (herein referred to as ‘climbers’), who were all regularly exposed to ascending at height, and 14 non-climbing matched controls who were unaccustomed to rock climbing or height exposure, participated in the current study (described in Table 1). Climbers were recruited from local climbing walls on the basis that they took part in sport climbing, and regularly ascended walls 15 – 20 meters in height at least twice a week (self-reported 6 month redpoint grade of 15.2 ± 2.9: Draper et al., 2016). Non-climbers had no prior experience of rock climbing and did not participate in any other activities or work that required them to ascend to height. Groups were matched for height, mass, and physical activity status. Exclusion criteria included current or recent smoker, a diagnosis of, or receiving medications for, cardiac or cardiovascular disease, anxiety, depression or acrophobia. Written informed consent was obtained and medical health questionnaires (PAR-Q and novel study form) were completed prior to participation. Institutional ethical approval, which conformed to the principles of the Declaration of Helsinki, was granted prior to data collection.

Table 1: Participants anthropometric and physiological data (mean ± SD)

	NON-CLIMBERS		**EXPERIENCED CLIMBERS**	
	Female (n= 4)	Male (n = 10)	Female (n = 3)	Male (n = 12)
Age (y)	38.7 ± 12.6	32.9 ± 9.8	37.9 ± 2.0	26.7 ± 8.7
Height (m)	1.63 ± 0.03	1.76 ± 0.07	1.67 ± 0.06	1.77 ± 0.07
Mass (Kg)	59.3 ± 9.0	71.4 ± 10.8	61.8 ± 2.4	73.1 ± 9.5

Note: y, years; m, meters; Kg, kilograms

2.3. Procedure

Participants attended a single session in order to complete an ascent of a 20-meter high indoor wire ladder (Figure 1). To reduce the impact of circadian rhythm, particularly on salivary cortisol concentrations, sessions were completed between the hours of 3 and 8 PM. Participants were asked not to alter their training regime in the run-up to the study, and to choose a session that allowed for adequate rest, avoiding strenuous exercise for 24 hours prior. Finally, to avoid sample contamination and ergogenic effects, participants were asked to refrain from consuming food and any caffeinated beverages within two hours of the visit.

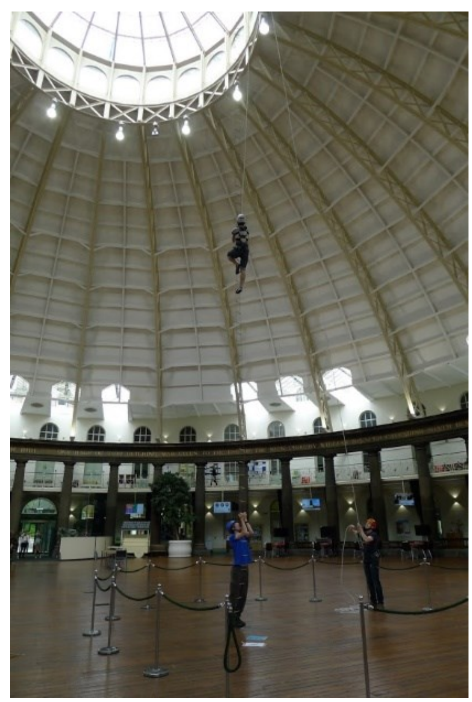

Figure 1: Illustration of the ladder, belay and climbing set-up for the 20m wire ladder climb

As shown in Figure 1, the ladder climbing session took place in a large indoor space, allowing for a moveable, flexible, 20-meter high free-hanging wire ladder (150 mm rung width, 4 rungs per meter: Lyon Equipment, France) to be suspended from the ceiling, along with a semi-static safety rope. Safety gear included helmet, harness and a top rope used with belayer. Participants were instructed to wear comfortable trainers and loose fitting clothing. The flexible wire ladder climbing task was chosen as it was unfamiliar to all participants. In keeping with previous rock climbing studies, the participants completed a standardised warm-up consisting of 5-minutes light jogging (free running) at 60% of maximal HR (HR_{MAX}), and 5-minutes of stretching and mobilising (Dickson et al., 2012; Draper et al., 2011). Following the warm-up, all participants were given instruction on how to climb the wire ladder (taking one rung at a time and climbing at a comfortable self-paced speed). The $K4b^2$ was air, gas, turbine, and delay calibrated between participants. Finally, the pre-climb salivary samples were collected. Oxygen uptake and HR were measured for the duration of the test using a portable metalizer ($K4b^2$, Cosmed, Rome, Italy), and $\dot{V}O_2$ data were averaged at 15-second intervals. Participants began climbing in their own time. Heart rate and $\dot{V}O_2$ were measured continuously using the Polar V800 and $K4b^2$, respectively. Salivary cortisol was sampled as soon as the participant returned to the ground. A 20-minute passive recovery period then commenced, with salivary cortisol collected at 5-minute intervals.

2.4. Measures

2.4.1. State Anxiety

The revised competitive state anxiety inventory (CSAI-2R) was used to measure state anxiety (Cox, Martens, & Russell, 2003). The CSAI-2R is a 17-item inventory, with each item scored on a Likert scale ranging from 1 (“not at all”) to 4 (“very much so”). The scores for each participant were combined to create a score on each of the three subscales: (1) somatic anxiety (e.g., my heart is racing), (2) cognitive anxiety (e.g., I am concerned about performing poorly), and (3) self-confidence (e.g., I am confident because I can mentally picture myself reaching my goal). Cronbach’s alpha was calculated for the CSAI-2R sub-scales and all appeared to have good internal consistency: somatic ($\alpha = 0.91$), cognitive ($\alpha = 0.88$), and self-confidence ($\alpha = 0.88$). State anxiety was assessed using the CSAI-2R inventory between the warm-up and starting the climb.

2.4.2. Heart Rate

Heart rate was recorded using a Polar H7 chest strap and V800 HR monitor (HRM; Polar, Finland). Anticipatory HR response was calculated as the percentage change from seated rest (for 5 min) to one minute prior to climbing. Peak HR (HR_{PEAK}) was taken as the highest HR observed during the ascent. Pulmonary gas exchange was measured using on-line breath by breath (b^2) analysis throughout each test using the $K4b^2$. Data were smoothed (5 breath moving average), and $\dot{V}O_{2PEAK}$ was determined as the highest 15-second average.

2.4.3. Salivary Cortisol

All saliva samples were collected using salivettes (Sarstedt AG & Co, Germany). In accordance with previous research (Gonzalez, Del Mar Bibiloni, Pons, Llompart, & Tur, 2012), participants were instructed not to brush their teeth 30-minutes before attendance, not to consume water 5-minutes before any sample, and not to consume food 2-hours before arrival. Following the method set out by Westermann, Demir, and Herbst (2004), saliva samples were analysed for cortisol concentration using an enzyme-linked immunosorbent assay (ELISA) Kit (Saliva RE52611, IBL International, Germany). Intra-assay coefficients of variation were 3.95% and 4.68% for the low and high saliva controls, respectively. Salivary cortisol response was calculated as the percentage change from pre-climb cortisol concentration. Cortisol concentrations were expressed as nmol/L or percentage.

2.5. Statistical Analyses

Normal distributions were ascertained, and homogeneity of variance was confirmed after visual assessment of the frequency histogram and a Shapiro–Wilk’s test, respectively. All descriptives are reported as mean ± SD. For meaningfulness, mean differences (MD) and 95% confidence intervals ($CI_{95\%}$) were used. Gender differences in all variables were considered using a series of independent samples t-tests – no significant differences were apparent in any variables other than height and body-mass; consequently, male and female data were considered together. The magnitude of the group difference was calculated by independent samples *t*-tests. A two-way ANOVA (group*sampling time) was used to investigate change from pre-climb in saliva cortisol concentrations between groups. Pairwise differences were examined using paired and independent samples *t*-test. Corrections for multiple comparisons were made using the Benjamini and Hochberg (1995) false-discovery rate (FDR) method (Glickman, Rao, & Schultz, 2014). The magnitude of the difference was determined using η_p^2 for multiple comparisons and Cohen’s *d* for comparisons between two groups. All data were analysed using SPSS (Version 25).

3. Results

Mean (±SD) ascent time, $\dot{V}O_2$, HR and CSAI-2R for the non-climbers and climbers during the ladder ascent are shown in Table 2. Independent samples *t*-test demonstrated that the non-climber group climbed significantly slower than the climbers ($t_{(27)} = 3.08$ $p < 0.0005$; MD = 60.25 sec, $CI_{95\%}$ 19.92, 100.58; $d = 1.15$). There was no statistical difference in HR_{PEAK} ($t_{(27)} = 0.12$, $p = 0.906$; MD = 0.66 $b \cdot min^{-1}$, $CI_{95\%}$ -10.75, 12.07; $d = 0.05$) or $\dot{V}O_{2PEAK}$ ($t_{(26)} = 1.58$, $p = 0.136$; MD = 4.15 $mL \cdot kg^{-1} \cdot min^{-1}$, $CI_{95\%}$ -1.47, 9.78; $d = 0.83$).

As shown in Table 2, the non-climbers reported significantly greater cognitive anxiety ($t_{(27)} = 2.21$, $p = 0.036$; MD = 3.05, $CI_{95\%}$ 0.22, 5.88; $d = 0.84$), and lower self-confidence ($t_{(27)} = 2.94$, $p = 0.007$; MD = -4.95, $CI_{95\%}$ -1.49, -8.41; $d = 1.10$), when compared to the climbers (Table 2). There was no significant difference in somatic anxiety ($t_{(27)} = 1.74$, $p = 0.093$; MD = 1.96, $CI_{95\%}$ -0.35, 4.29; $d = 0.66$). The non-climbers had a significantly greater percentage rise in anticipatory HR response ($t_{(27)} = 2.85$, $p = 0.008$; MD = 14%, $CI_{95\%}$ 4, 24; $d = 1.06$).

Table 2: Climb time, $\dot{V}O_2$ and HR, state anxiety, self-confidence and anticipatory heart responses (mean ± SD)

	NON-CLIMBERS	**EXPERIENCED CLIMBERS**	***ES (d)***	***Significance***
CLIMB TIME *(seconds)*	172.9 ± 71.6	112.7 ± 23.2	1.15	p < 0.0005*
HR (b·min^{-1}) peak	162.1 ± 10.9	162.8 ± 15.2	0.05	p = 0.906
$\dot{V}O_2$ (mL·kg^{-1}·min^{-1}) peak	32.3 ± 4.6	36.5 ± 5.5	0.83	p = 0.136
CSAI-2R				
Somatic anxiety	14.3 ± 3.8	12.3 ± 2.1	0.66	p = 0.093
Cognitive anxiety	15.9 ± 4.8	12.8 ± 2.2	0.84	p = 0.036*
Self-confidence	27.7 ± 5.1	32.7 ± 4.0	1.10	p = 0.007*
Anticipatory rise in HR (%) *(Percentage difference from rest to 1 minute pre-climb)*	33 ± 14	19 ± 13	1.06	p = 0.008*

*Notes: HR heart rate; b.min^{-1} beats per minute; $\dot{V}O_2$ volume of oxygen; mL·kg^{-1}·min^{-1} millilitres per minute per kilogram; CSAI-2R competitive state anxiety inventory; * significant following FDR correction.*

A mixed model ANOVA (group*sampling time) revealed a significant interaction for salivary cortisol ($F_{(5,135)}$ = 4.29, p = 0.001; η_p^2 = 0.137). Post-hoc FDR corrected paired samples t-tests demonstrated a statistically significant increase from pre-climb salivary cortisol only for the non-climbers 15-minutes after the climb ($t_{(13)}$ = 5.57, p < 0.0005; MD = 2.49 nmol/L, $CI_{95\%}$ 1.53, 3.47; d = 0.84). As shown in Figure 2, a post-hoc FDR corrected independent samples t-tests demonstrated statistically greater salivary cortisol concentrations for the non-climbers than the climbers at 0, 5, 10, 15 and 20 minutes post climb, but not pre-climb, with the greatest difference observed 15-minutes' after the climb ($t_{(27)}$ = 2.78, p = 0.010; MD = 3.50 nmol/L, $CI_{95\%}$ 0.92, 6.07; d = 1.04).

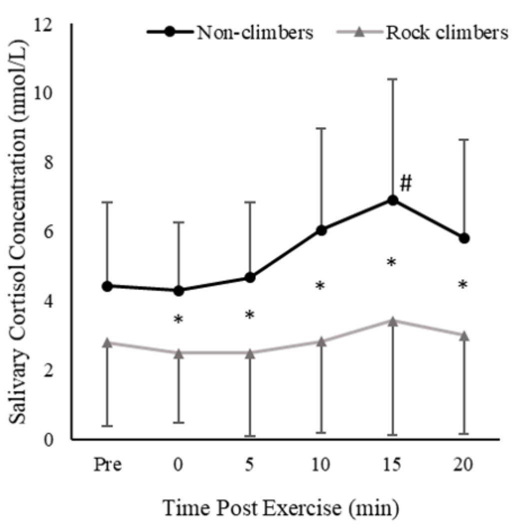

Figure 2: Salivary cortisol pre- and post-exercise (nmol/L). *statistical difference between groups, # statistical difference from pre-climb values.

4. Discussion

As a risk management sport which involves participants ascending to heights where potential harm is significant, rock climbing could offer a therapeutic intervention for trainee firefighters, construction workers or for those with acrophobia. As an initial investigation in this area, our aim was to examine psychophysiological responses of climbers and non-climbers to a 20-meter wire ladder climbing task. The main findings of the study were that: (a) non-climbers ascended at a significantly slower rate without any significant differences in HR_{PEAK} or $\dot{V}O_{2PEAK}$; (b) the non-climbers reported significantly greater cognitive anxiety and lower self-confidence, and (c) anticipatory HR rise and peak saliva cortisol concentrations were significantly higher than those sampled at baseline only for the non-climbers.

The free-hanging ladder climbing task was novel to all participants, non-climbers and climbers alike. Despite the climber's ability there were no significant differences in average or peak HR or $\dot{V}O_2$ between groups (Table 2). The lack of difference in cardiovascular measures between groups is unsurprising as many studies have also found no difference between ability groups of experienced climbers (Bertuzzi, Franchini, Kokubun, & Kiss, 2007; Draper et al., 2010; España-Romero et al., 2009); furthermore, it's known that it is not the systemic cardiovascular measures that separate climbing ability groups but the smaller changes inside small muscle groups, like the forearms, that are more important in determining performance (Fryer, Giles, Palomino, de la O Puerta, & España-Romero, 2018). However, despite this there were significant differences in the rate of ascent, with non-climbers taking ~ 60 seconds longer to ascend the ladder. It is conceivable that differences in pace of locomotion resulted because of climbing experience and/or elevated anxiety resulting in the conscious control and slowing of movements (Nieuwenhuys & Oudejans, 2012). The latter explanation is more likely, as differences in climbing pace between groups were also accompanied by a significantly greater psychophysiological response (Table 2 & Figure 2) in the non-climbers, due to anxiety in response to the ladder climbing task. Furthermore, while it is impossible to eliminate the former, its contribution is likely to be less significant as the task was novel to all, and all were instructed to ascend in the same way with a supinated grip (atypical for climbers). In support of the anxious disruption of movement, differences in climbing pace with anxiety have also been demonstrated in a climbing task by Pijpers et al. (2003), who reported significant alterations in movement behaviour when anxious novice climbers traversed a route at height, leading to slower and less fluent movement. Similarly, in a more typical climbing context, Draper et al. (2011) found unsuccessful intermediate climbers ascended a route significantly slower than successful climbers. Therefore, the slowing of the pace of ascent likely represents the anxious disruption of the non-climbers' movements, although further research would be necessary to confirm this (Nieuwenhuys & Oudejans, 2012).

The non-climbers displayed a significantly greater cortisol response (Figure 2), anticipatory rise in pre-climb HR, cognitive anxiety and lower self-confidence (Table 2) in comparison to the climbers, suggesting an increased nervous response to the ladder climbing task. More specifically, it is conceivable that the non-climbers elevated cortisol response occurred due to elevated hypothalamic-pituitary-adrenal axis activation, stimulated by increased anxiety due to the ladder task or even anticipation of the task (Kirschbaum & Hellhammer, 2000). This proposal is further supported by the non-climbers' greater self-reported cognitive anxiety and pre-climb anticipatory rise in HR from rest (Tables 2 and 3). Conversely, despite the novelty of the ladder climbing task, the blunting of the climbers' cortisol response may have resulted from familiarity with ascending to height or through self-selection into the sport as a result of predisposition for working at height (Kirschbaum et al., 1995), the most likely explanation is one of habituation. Pre-climb heart rate and self-reported state anxiety would appear to provide a means of tracking stress response over time, although further research will be necessary to establish if this is the case; possibly through assessing the responses of novice climber to repeated ladder ascents.

The results of previous climbing psychophysiology research are discordant having failed to identify significant differences in either cortisol or anticipatory HR between abilities groups or in response to different tasks (Dickson et al., 2012; Fryer et al., 2013), for a review of this research see Giles et al. (2014). In contrast, the findings of the current study lend support for climbers having a sport specific blunted psychophysiological response. Whilst it could be speculated that some of the increased peak cortisol response in non-climbers might have been due to the greater exercise duration (Hill et al., 2008) and greater anaerobic energy system contribution (Bertuzzi et al., 2007). However, it is unlikely that exercise intensity solely affected peak cortisol response, as (a) HR and $\dot{V}O_2$ were similar between the groups; (b) there was no relationship between climb time and cortisol (p = 0.179; r = -0.266); and (c) excess post-exercise oxygen consumption was similar between groups ($p < 0.0005$).

Given the non-climbers' increased level of anxiety in response to the task, coaches and instructors should be aware of the implications arising because of the need to ascend to height when working with novices or when training people to work at height, particularly considering anxieties implications for performance and learning, most likely associated with brain-stem activation as a part of the flight or fight response. While anxiety is known to have implications for climbing performance (Pijpers et al., 2003), it is also associated with interference in learning and discontinuation of sport participation and less pleasure while participating (Crane & Temple, 2015). Future research should consider the implications of anxiety when ascending to height for the learning of technical movement skills in climbers; research should also consider the role of anxiety towards ascending to height for sport progression and enjoyment. Finally, the potential for health-based studies where climbing could be used to modify or help with anxiety disorders should be explored.

5. Conclusion

In order to explore the psychophysiological responses to ascending to height for climbers and non-climbers a low skill ladder climbing task was selected for our study. Consequently, this study appears to be the first to compare psychophysiological responses of non-climbers and climbers, providing insight into habituation, and consequential blunting of psychophysiological responses through involvement in rock climbing. Our data suggest that climbers display an attenuated psychophysiological response to ascending to height when compared with non-climbers. Based on the results of the present study, if not due to self-selection to the sport, it is possible that climbers are habituated to ascending to height. We would speculate, given our findings, that the most likely explanation is one of habituation. Given these findings, rock climbing may offer a distracting therapeutic intervention for trainee firefighters, construction workers or for those with acrophobia which affords a blunting of the fear of height response.

Conflict of Interest

No potential conflict of interest was reported by the authors

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