VOL. 3 (2019) / ISSUE 2
ISSN 2703—240X

The Journal of Sport & Exercise Science

THE OFFICIAL JOURNAL OF SESNZ

SESNZ
SPORT & EXERCISE SCIENCE
NEW ZEALAND

SESNZ.ORG.NZ/JOURNAL

SPORT & EXERCISE SCIENCE

NEW ZEALAND

PUBLISHER

Sport and Exercise Science New Zealand

Address: SESNZ, PO Box 37415, Christchurch, 8245

Tel: 03 369 3878

natmanager@sesnz.org.nz

www.sesnz.org.nz/

ISSN 2703-240X

Contents

SESNZ
SPORT & EXERCISE SCIENCE
NEW ZEALAND

The Journal of Sport and Exercise Science, Vol. 3, Issue 2, 1-7 (2019)

www.sesnz.org.nz

JSES
ISSN: 2703-240X

The relationship between on-water performance and physical characteristics in elite and sub-elite outrigger canoe paddlers

Tupuria King[1], Joseph A. McQuillan[1], Nicholas D. Gill[1, 2], Matthew W. Driller[1 *]

[1]*Te Huataki Waiora School of Health, University of Waikato, New Zealand*
[2]*New Zealand Rugby Union*

ARTICLE INFO

Received: 06.11.2018
Accepted: 15.12.2018
Online: 26.11.2019

Keywords:
Waka Ama
Canoeing
VO_{2max}
Water sports

ABSTRACT

The aim of the present study was to compare and investigate the relationship between 500 m on-water performance and physical characteristics in elite and sub-elite outrigger canoe paddlers. A total of 16 males participated in the study including eight elite paddlers (age: 24.8 ± 10.5 yrs., total paddling experience: 12.5 ± 5.2 yrs.) and eight sub-elite paddlers (age: 34.4 ± 15.4 yrs., total paddling experience: 6.8 ± 5.2 yrs.). Body mass, height, sitting height, arm span, arm length, body fat percentage, 50 kg muscular endurance (bench press and bench pull), peak oxygen uptake (VO_2peak) and Wingate performance (30 sec maximal effort) were assessed and subsequently correlated with 500 m outrigger canoeing performance at a national championship's regatta. When group data were combined, moderate to strong correlations were found between 500 m outrigger canoeing performance and absolute VO_2peak (r = -0.61), upper limb length (r = -0.60) 50 kg bench press (r = -0.56), total paddling experience (r = -0.53), body mass (r = -0.51), sitting height (r = -0.51), singles paddling experience (r = -0.49), height (r = -0.48) and Wingate distance (r = -0.42). When groups were compared, elite paddlers showed significantly greater Wingate mean power and distance, paddling experience and 500 m on-water performance times than sub-elite paddlers ($p < 0.05$). However, there were no significant differences in anthropometrical measures, muscular endurance and VO_2peak between the two groups ($p < 0.05$). VO_2peak and upper limb length were the best predictors of performance over the 500 m sprint distance across the entire group. Thirty-second Wingate mean power and distance, years of paddling experience and subsequent 500 m on-water performance differentiated elite from sub-elite paddlers.

1. Introduction

Outrigger canoe racing has become a popular sport around the globe and in 2016, outrigger canoeing appeared as an official sport at the Rio Paralympic Games. Outrigger canoes consist of a hull with an attachment (ama) that extends out from the port side via two booms (kiato) to keep it afloat. The most common sprint distance in the singles division is 500 m, which takes between two-three minutes to complete (West, 2006). According to Gastin (2001), maximal efforts of up to 75 seconds derives approximately equal energy contribution from the anaerobic and aerobic energy systems, with increasing reliance placed on the aerobic energy system beyond this point in time. Based on the duration, the energy contribution during maximal intensity ranges between 27-37% anaerobic and 63-73% aerobic (Gastin, 2001) for the 500 m sprint distance.

Optimal outrigger canoe performance requires a complex combination of anthropometric, physiological and biomechanical factors (Humphries et al., 2000; LaBreche, 2001; Yamada et al., 2001; Dascombe et al., 2002; Stanton et al., 2002; Sealey, 2010). Finding the relationship between these characteristics and performance may be valuable for crew selection and fitness assessment (Sealey, 2010). In relation to 250 m outrigger canoeing performance, Humpries et al. (2000) found *moderate* correlations for height, sitting height, arm span, VO_2max, humerus and femur widths and *strong* correlations for one

*Corresponding Author: Matthew W. Driller, The Huataki Waiora School of Health, University of Waikato, New Zealand, mdriller@waikato.ac.nz

repetition max bench press, acromial width and both right and left peak paddle force in 21 amateur outrigger canoe paddlers. A more recent study by Sealey (2010) found *moderate* to *strong* correlations between 1000 m ergometer performance and mean and peak power, VO_2peak, mean heart rate, and peak lactate in 17 trained female outrigger canoeists. Sealey (2010) reported VO_2peak values of ~3.17 $L.min.^{-1}$ in the female paddlers, and 1000 m ergometer times ranged between 5-7 minutes. In elite flat-water kayakers, Fry and Morton (1991) found *moderate* correlations between VO_2max and 500 m performance. In their study, they reported absolute and relative VO_2peak scores of ~4.78 L.min-1 and ~59.22 $mL.kg.^{-1}min.^{-1}$, respectively. The time to complete 500 m in the flat-water kayak in this cohort was ~2 minutes and just over 4 minutes for the 1000 m distance. Furthermore, a study on competitive canoe and kayak paddlers demonstrated high correlations between two-minute time trial performance and absolute VO_2max, Wingate mean power, Wingate peak power and bench press strength (Hamano et al., 2015).

Despite being the most competitive event in outrigger canoeing World Championship level, to our knowledge, there is no published research that has specifically focused on the 500 m sprint distance. Furthermore, participants employed in earlier outrigger canoe studies have been classified as amateur (Humpries et al., 2000), trained (Sealey, 2010), experienced (LaBreche, 2001), competitive (Stanton et. al., 2002) or state level (Dascombe et al., 2002), therefore, researchers are yet to report on the characteristics of elite level paddlers. The aim of the present study was to compare and investigate the relationship between physical characteristics and 500 m on-water performance in elite and sub-elite outrigger canoe paddlers.

2. Methods

2.1. Participants

A total of 16 male participants volunteered to take part in the current study. For analysis, participants were split into two groups; elite paddlers (n = 8, age: 24.8 ± 10.5 yrs, total paddling experience: 12.5 ± 5.2 yrs) and sub-elite paddlers (n = 8, age: 34.4 ± 15.4 yrs, total paddling experience: 6.8 ± 5.2 yrs). Inclusion criteria for ‘elite’ paddlers included participation in the elite division at a World Championship campaign within the past two years. The criteria for ‘sub-elite’ was nationally competitive outrigger canoeists who have not competed in the elite division at a World Championship campaign. All participants qualified to compete at the 2018 New Zealand Waka Ama Sprint Championships in the 500 m sprint distance event in either the master’s, premier or junior men singles division. Each participant signed written informed consent prior to any testing being completed. Ethical approval was provided by the institutions Human Research Ethics Committee.

2.2. Procedures

Physiological/physical testing took place in a temperature-controlled sport science laboratory (21 ± 1ºC), where two testing sessions were separated by a 24-hour period to allow for adequate recovery. The 500 m on-water performance times were taken from publicly available results at the New Zealand National Championships regatta. Physical testing took place within two weeks prior to the National Championships regatta in order to align with the paddlers peak physical performance. The timeline of the study design is shown in Figure 1.

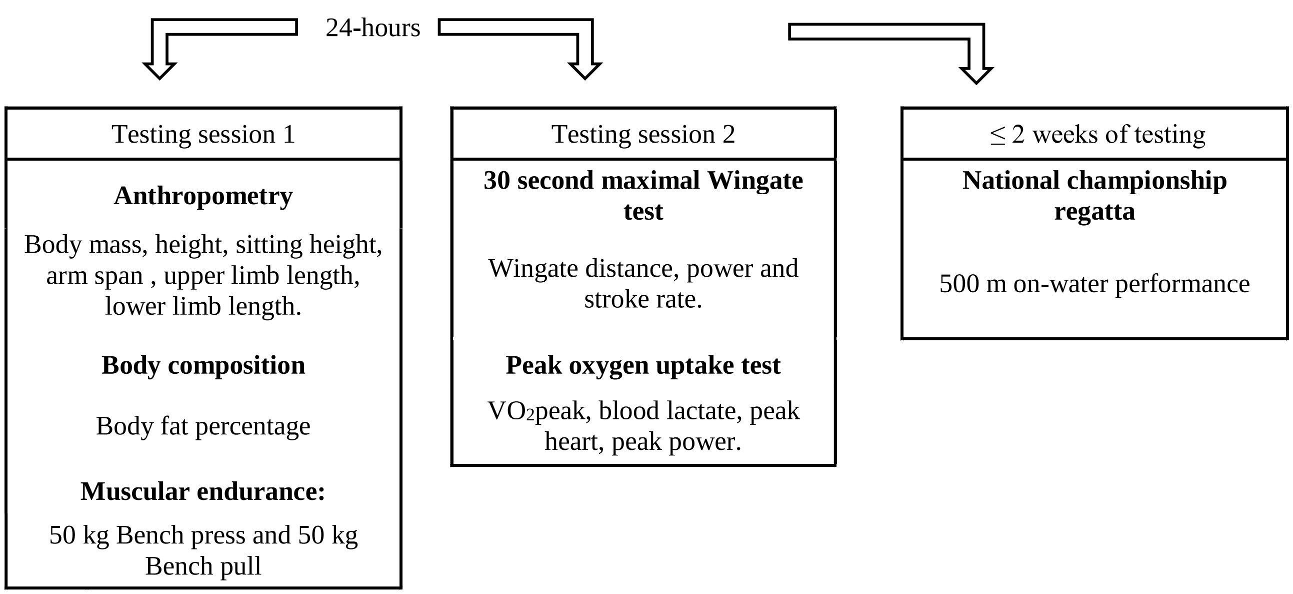

Figure 1: Timeline of the study design

2.3. Anthropometry and Body Composition

Body composition and anthropometric measurements including body mass, body fat %, height, sitting height, arm span, upper limb length and lower limb length were obtained prior to the muscular endurance test protocols and were measured to the nearest 0.1 kg, 0.1 % and 0.1 cm, respectively, using a Tanita TBF-215 body composition analyser and anthropometric steel tape measure (Lufkin, Apex, AC). The body composition scales used in the current study have been previously validated for body fat % against the gold standard measure of DXA-derived body composition (Boneva-Asiova & Boyanov, 2008).

2.4. Muscular Endurance Test

Upper-body muscular endurance was determined using a bench press and bench pull test using a standardized load of 50 kg for each test. Given the relatively homogenous group of athletes, we opted for an absolute load rather than a weight relative to body mass. In an attempt to synchronize the speed of each repetition we used a metronome set at 30 repetitions per minute. Participants began with a 10 min active warm-up including dynamic stretching followed by some low to moderate intensity lifts on the bench press and bench pull prior to the test. Each participant performed practice lifts on both exercises with the 20 kg bar unloaded.

2.5. 50 kg Bench Press

Participants began the bench press test by lying in a supine position on the bench with their feet flat on the floor and the head rested on the bench. The starting position of the bar for the bench press was with arms at full extension and the beep of the metronome would signal the commencement of each repetition. One repetition was counted as the bar touching the chest at the bottom of the repetition and the arms were fully extended at the top of the repetition. Failure to touch the chest at the bottom of a rep during the bench press was not counted as a rep. The recorded score was the number of successful repetitions completed. The test was terminated by the researcher when the participant failed to keep in time with the metronome or the participant voluntarily stopped.

2.6. 50 kg Bench Pull

Participants began the bench pull by lying in a prone position with their chin touching the edge of the bench. The legs were kept in a relaxed position on top of the bench in a flexed or extended knee position. The starting position of the bar for the bench pull was with arms in full extension and the beep of the metronome would signal the start of each repetition. The bar was required to touch the bottom of the bench during flexion of the bench pull and arms were to achieve full extension at the bottom of the repetition. If a participant failed to touch the bench with the bar the repetition was not counted. The recorded score was the number of successful repetitions completed. The test was terminated by the researcher when the participant failed to keep in time with the metronome, or the participant stopped voluntarily.

2.7. Wingate Test

Anaerobic power was assessed using a 30 second Wingate test on an outrigger canoe ergometer (MultiStroke O1-M, Kayak Pro, Florida, USA). The Wingate test was performed as described by Bar-or (1987). The Wingate test consisted of a five-minute warm-up on the ergometer at a self-selected intensity, followed by minimum five-minute rest period before the 30 second all-out effort. During the five-minute warm-up, participants were instructed to perform a 10-15 second maximal sprint, to familiarise them with the effort required during the Wingate test. Participants were verbally instructed to paddle as hard as possible for the 30 second effort. All participants were required to change stroke sides after 15 seconds but could self-select the side that they started on. During the test participants were able to view (time, distance and power). Mean power (W), distance (m) and mean stroke rate (strokes.min^{-1}) were recorded at the end of the 30 second effort for analysis. A five-minute active recovery at self- selected intensity was then performed after the Wingate test with an additional five-minute passive rest period prior to starting the next maximal oxygen uptake test.

2.8. Peak Oxygen Uptake Test

A peak oxygen uptake test was performed on the same outrigger canoe ergometer (MultiStroke O1-M, Kayak Pro, Florida, USA) to determine VO_2peak,VO_2 peak power, peak heart rate (HR), and peak blood lactate concentration. Cardiorespiratory-metabolic variables were measured throughout the peak oxygen uptake test using the Parvo Medics TrueOne 2400 metabolic analyser (Parvo Medics, Inc., Salt Lake City, UT). The analyzer was calibrated before each test using alpha gases of known concentration according to the manufacturer's instructions. VO_2peak was taken as the highest VO_2 value recorded during a 1-min period of the final stage in the test. Heart rate was measured continuously using a heart rate monitor with chest strap (Polar Electro Oy., Finland). The maximal oxygen uptake test began approximately ten minutes after the completion of the Wingate test. Participants performed the test against a resistance set at level one on the resistance lever (maximum=10). The peak oxygen uptake test started at 25 W for one-minute increasing by 15 W.min^{-1} incrementally thereafter until volitional exhaustion. Participants were encouraged to complete as many stages as possible before they could no longer maintain the target power output. A blood lactate sample was taken via the earlobe three minutes after the completion of the test using the Lactate Pro analyser (Lactate Pro, Akray, Japan). The test–retest reliability of the Lactate Pro has been previously reported, with technical error of measurement results ranging from 0.1 to 0.4 mmol. L^{-1} at blood lactate concentrations of 1 to 18 mmol. L^{-1} (Tanner et al., 2010). Previous research has shown that peak blood lactate concentrations occur between 3-9 minutes following maximal exercise (Weinstein et al, 1998), and blood lactate taken 3-minutes following a maximal exercise bout has shown good test-retest reliability, with a typical error of measurement of ~0.48mmol.L. $^{-1}$ (Driller et al., 2013).

2.9. 500 m On-water Performance

On-water performance times for the 500 m distance were obtained from the 2018 New Zealand Waka Ama Sprint Championship regattas official timing (www.wakaama.co.nz). The times were taken from each participant's first race in their heat since not all participants progressed to the finals. All participants were instructed to give a maximal effort during their first heat, regardless of where their competitors were in the race. While participants were spread across heats, all heats were held at 10 am (± 1 hr). Temperature was ~20°C and humidity ~80% with light headwinds (<11 km /h).

2.10. Statistical Analyses

Descriptive statistics and data are expressed as a means ± standard deviations (SD) and with ranges where appropriate. Pearson correlation coefficients (r) were used to determine the relationship between selected variables. Positive values denote positive linear correlation. Negative values denote negative linear correlation. The size of each correlation is described using an r value of 0.0-0.19; "very weak", 0.20-0.39; "weak", 0.40-0.59; "moderate", 0.60-0.79; "strong", 0.80-1.0; "very strong. An unpaired Students T-test was used to determine the difference between elite and sub-elite participants, with statistical significance set at $p < 0.05$. All statistical analyses were performed using Statistical Package for Social Science (V. 25.0, SPSS Inc., Chicago, IL).

3. Results

Physical characteristics and 500 m on-water performance in elite and sub-elite outrigger canoeists are displayed in Table 1.

Table 1: Comparison of physical characteristics and 500 m performance in elite and sub-elite outrigger canoeists. * significant difference between groups ($p < 0.05$)

	Mean (± SD)		
	elite *(n = 8)*	**sub-elite *(n = 8)***	**p-value**
Age (yrs.)	24.8 ± 10.5	34.4 ± 15.4	0.166
Total paddling experience (yrs)	12.5 ± 5.2	6.8 ± 5.2	0.020*
Singles paddling experience (yrs)	8.9 ± 4.9	3.4 ± 3.2	0.047*
Anthropometry and body composition			
Body mass (kg)	94.4 ± 8.5	85 ± 13.7	0.120
Height (cm)	181.6 ± 5.0	179.9 ± 7.3	0.583
Sitting Height (cm)	94.4 ± 3.3	93.2 ± 3.8	0.509
Arm span (cm)	189.4 ± 6.9	188.5 ± 9.1	0.827
Upper limb length (cm)	78.7 ± 2.1	76.9 ± 3.1	0.196
Lower limb length (cm)	112.8 ± 3.3	112.8 ± 5.1	0.977
Body fat (%)	21.0 ± 4.9	19.6 ± 2.8	0.528
Muscular endurance test			
50 kg Bench press (reps)	34.8 ± 12.4	28.0 ± 11.0	0.268
50 kg Bench pull (reps)	29.1 ± 8.4	22.5 ± 3.9	0.061
Wingate test			
Wingate mean power (W)	323.8 ± 55.7	240.1 ± 32.6	0.003*
Wingate distance (m)	148.7 ± 7.8	134.7 ± 6.5	0.002*
Stroke rate (spm)	86.8 ± 12.6	78.8 ± 8.5	0.159
Peak oxygen uptake test			
VO_2peak ($L.min^{-1}$)	4.1 ± 0.7	3.7 ± 0.6	0.166
VO_2peak ($mL. kg.^{-1}min^{-1}$)	45.6 ± 8.1	44.5 ± 2.0	0.719
Blood lactate ($mmol. L^{-1}$)	7.8 ± 3.4	7.8 ± 2.6	0.968
VO_2 peak heart rate (bpm)	187.8 ± 17.4	177.8 ± 9.1	0.183
VO_2 peak power (W)	207.2 ± 38.7	175.4 ± 29.5	0.086
National championship regatta			
500 m on-water performance (s)	144.9 ± 4.9	154.2 ± 6.8	0.007*

No significant differences were found between groups for anthropometry and body composition measures ($p > 0.05$). Significant differences were found between groups for total paddling experience and singles paddling experience ($p < 0.05$). Elite paddlers showed significantly higher Wingate mean power (323.8 ± 55.7 W vs. 240.1 ± 32.6 W, $p < 0.05$) and Wingate distance (148.7 ± 7.8 m vs. 134.7 ± 6.5 m, $p < 0.05$) when compared to sub-elite paddlers. Elite paddlers also showed significantly faster 500 m on-water performance times (144.9 ± 4.9 vs. 154.2 ± 6.8 s, p =.007) compared to sub-elite paddlers.

When data was pooled (Table 2), a *strong* correlation was found between 500 m on-water performance and absolute VO_2peak (3.9 ± 0.5 $L.min^{-1}$, r = -0.61). 50 kg bench press (31.4 ± 9.8 reps, r = -0.56) had a *moderate* correlation to 500 m outrigger canoeing performance.

Table 2: Correlations between physical characteristics and 500 m on-water performance (n=16)

Variable	Correlation	Strength
VO_2peak ($L.min^{-1}$)	-0.61	Strong
Upper limb length (cm)	-0.60	Strong
50 kg bench press (reps)	-0.56	Moderate
Total paddling experience (yrs)	-0.53	Moderate
Body mass (kg)	-0.51	Moderate
Sitting height (cm)	-0.51	Moderate
Singles paddling experience (yrs)	-0.49	Moderate
Height (cm)	-0.48	Moderate
Wingate distance (m)	-0.42	Moderate
Wingate mean power (W)	-0.38	Weak
VO2 peak power (W)	-0.38	Weak
Arm span (cm)	-0.37	Weak
VO_2 peak heart rate (bpm)	-0.35	Weak
Blood lactate (mmol. L^{-1})	0.25	Weak
Lower limb length (cm)	-0.22	Weak
50 kg bench pull (reps)	-0.21	Weak
Wingate stroke rate (spm)	-0.21	Weak
VO_2peak (mL. kg. $^{-1}$min^{-1})	-0.18	Very weak
Body fat (%)	-0.09	Very weak

4. Discussion

The current study is the first to assess the physical characteristics of elite outrigger canoe paddlers in comparison to sub-elite paddlers. Furthermore, to our knowledge, this is the first study to look at the relationship between different lab-based test measures and on-water performance at a National Championship regatta. The key findings from the current study showed that elite paddlers demonstrated significantly greater Wingate mean power and distance, paddling experience and 500 m on-water performance times than sub-elite paddlers. Additionally, absolute VO_2peak expressed as $L.min^{-1}$ was the single best predictor of 500 m on-water performance (r = -0.61).

Our results are consistent with other canoe studies that have shown correlations between paddling performance and VO_2peak (Humphries et al., 2000; Sealey, 2010; Fry & Morton, 1991; Hamano et al., 2015). Humpries et al. (2000) found a lower (*moderate*) correlation, between 250 m outrigger canoeing performance and VO_2max (r = -0.59), than our current study. While Sealey et al. (2010) found a higher (*moderate*) correlation between 1000m ergometer performance and VO_2peak (r = -0.69). Furthermore, in a study by Fry and Morton, (1991) multiple performance distances were correlated with VO_2max whereby a *moderate* correlation was found for 500 m performance (r = -0.56) and an even *stronger* correlation for 1000 m performance (r = -0.71) in elite flat-water kayakers. These results suggest that the VO_2peak becomes progressively more important as the distance of the event increases. Indeed, previous research on track runners has shown that the aerobic energy system contribution to events over 200 m, 400 m, 800 m and 1500 m was 29%, 43%, 66% and 84%, respectively (Spencer & Gastin, 2001). This would highlight the need for athletes to possess a greater VO_2peak, as event duration increases. In the current study, the 500 m performance test was completed in ~2.5 minutes, slightly longer than the duration of an 800 m run reported by Spencer and Gastin (2001), which was just under 2 minutes. Given the aerobic contribution was 66% in their study for this distance, it is reasonable to assume that the aerobic contribution in our study would be similar, taking into account less muscle mass required in paddling vs. running. Given the likely larger contributions of the aerobic energy system, it is somewhat unsurprising that VO_2peak was one of the best predictors of on-water 500 m paddling performance in the current study.

The absolute aerobic values attained by elite paddlers were higher than several previous outrigger canoe studies (for review, see Canyon & Sealey, 2016) including Malaysian (2.86 ± 0.5 $L.min^{-1}$; Singh et al., 1995), Great Britain (3.56 ± 0.6 $L.min^{-1}$; Marrin and Pout, 2005) and Japanese dragon boaters (3.8 $L.min^{-1}$; Ho et al., 2013) and competitive sprint canoe and kayak paddlers (Canoe: 3.83 ± 0.3 $L.min^{-1}$, Kayak: 3.81 ± 0.3 $L.min^{-1}$; Hamano et al., 2015). In contrast, our participants presented VO_2peak values slightly lower than elite flat-water kayakers (4.4 ± 0.5 $L.min^{-1}$; Pickett et al., 2017) which could be due to greater rotation and activation of the legs, causing greater muscle mass activation and higher stroke rate during kayak paddling.

The correlation between upper limb length and 500 m on-water performance was consistent with a similar study on canoe and kayak paddlers (Hamano et al., 2015). The upper limb length of elite paddlers (78.7 ± 2.1 cm) in this study were similar to both canoe (78.3 ± 2.8 cm) and kayak paddlers (78.0 ± 3.2 cm) (Hamano et al., 2015) while sub-elite paddler's measures displayed lower upper limb lengths than both canoe and kayak paddlers (Hamano et al., 2015). Larger upper limb length may help the paddler to reach further forward during a stroke increasing stroke length. Stroke length is inversely proportional to stroke rate (Stanton et al., 2002) which means paddlers with longer could employ a slower stroke rate for the same given velocity. The use of a slower stroke rate (≤55 strokes. min^{-1}) during a 1000 m ergometer time trial has shown to be less physiologically demanding than a faster stroke rate (≥ 65 strokes. min^{-1}) despite no significant difference in performance time (Sealey, 2010). Specific on-water stroke length or stroke rate was not measured in this study therefore, future research should quantify the relationship between arm length, stroke length and stroke rate during specific on-water outrigger canoeing in elite paddlers to assess any difference in efficiency.

Anaerobic capacity is also important over the 500 m distance as it accounts for approximately 32% of the energetic demand for an event of this duration (Gastin, 2001). Elite paddlers mean power (W) and distance (m) during the 30 second Wingate test were 26% and 9% greater, respectively, than sub-elite paddlers in the current study. Furthermore, their mean 500 m on-water performance times were 9.3 seconds faster than sub-elite performances. The ability to produce high power output during the first 30 seconds of a 500 m distance event may contribute to the superior 500 m performance times displayed by elite paddlers. The on-water performance measures were limited therefore future research may consider including video analysis, boat speed GPS and stroke rate technology such as a cadence sensor in order to further assess outrigger canoe performance. Limitation of the current study was that the athletes did not partake in the same heat at National Championships. Although the conditions did not vary between races, it is possible that conditions and race tactics employed by others in the heat may have affected the performance times. Future research should aim to mitigate these factors by considering an on-water individual time-trial outside of a competition setting. However, as mentioned, participants were instructed to perform a maximal effort in their first heat, regardless of what their opponents were doing. To minimise the possible change in environmental conditions, we only took times from the heats which occurred within ± 1 hour of 10am.

5. Conclusion

Our findings suggest that elite paddlers possess greater Wingate mean power and distance during an anaerobic Wingate test, overall paddling experience and 500 m on-water performance times than sub-elite paddlers. Furthermore, we found VO_2peak to be the best predictor of 500 m performance when groups were combined. Therefore, a peak oxygen uptake and anaerobic Wingate test on an outrigger canoeing ergometer may serve as effective methods for assessing and monitoring a paddlers aerobic and anaerobic capacity which may aid in talent identification, crew selection or physical fitness assessment.

6. Practical Application

Results from the current study may be used to guide coaches and practitioners working in the sport of outrigger canoeing when it comes to talent identification of young athletes entering the sport. We would suggest that VO_2peak, upper limb length and upper-body strength (50kg bench-press) tests may serve as appropriate measures for identifying athletes, as they were the most closely related to on-water 500m performance.

Conflict of Interest

The authors declare no conflict of interest.

References

Bar-Or, O. (1987). The Wingate anaerobic test. An update on methodology, reliability and validity. *Sports Medicine, 4*(6), 381-94.

Boneva-Asiova, Z., & Boyanov, M. J. D. (2008). Body composition analysis by leg-to-leg bioelectrical impedance and dual-energy X–ray absorptiometry in non-obese and obese individuals. *Obesity and Metabolism*, *10*, 1012-18.

Canyon, D. V., & Sealey, R. (2016). A Systematic Review of Research on Outrigger Canoe Paddling and Racing. *Annals of Sports Medicine Research*, 3(5), 1076.

Dascombe, B., Stanton, R., Peddle, M., Evans, G., & Coutts, A. (2002). Force production in outrigger canoeing. *Journal of Science and Medicine in Sport*, *5*(4): 37.

Driller, M., Argus, C., & Shing, C. (2013). The reliability of a 30 second sprint test on the Wattbike cycle ergometer. *International Journal of Sports Physiology and Performance*, *8*(4), 379-383.

Fry, R. W., & Morton, A. R. (1991). Physiological and Kinanthropometric attributes of elite flatwater kayakists. *Medicine and Science in Sports and Exercise, 23*(11), 1297-1301.

Gastin, P. B. (2001). Energy system interaction and relative contribution during maximal exercise. *Sports Medicine*, *31*(10), 725-741.

Hamano, S., Ochi, E., Tsuchiya, Y., Muramatsu, E., Suzukawa, K., & Igawa, S. (2015). Relationship between performance test and body composition/physical strength characteristic in sprint canoe and kayak paddlers. *Open Access Journal of Sports Medicine, 6*, 191-199.

Ho, S. R., Smith, R. M., Chapman, P. G., Sinclair, P. J., & Funato, K. (2013). Physiological and physical characteristics of elite dragon boat paddlers. *Journal of Strength and Conditioning Research*, 27(1), 137-145.

Humphries, B., Abt, G. A., Stanton, R., & Sly, N. (2000). Kinanthropometric and physiological characteristics of outrigger canoe paddlers. *Journal of Sports Sciences, 18*(6), 395-399.

LaBreche, J. M. (2001). Metabolic specificity in outrigger canoe paddlers. Masters thesis. The University of Columbia.

Marrin, K., & Pout, M. J. (2005). Anthropometric and physiological characteristics of elite male dragon boat paddlers. *Journal of Sports Sciences, 23*(11-12), 1204.

Pickett, C. W., Nosaka, K., Zois, J., Hopkins, W. G., & Blazevich, J. A. (2017). Maximal Upper Body Strength and Oxygen Uptake are Associated with Performance in High-Level 200-M Sprint Kayakers. *Journal of Strength and Conditioning Research, 32*(11), 3186-3192.

Sealey, R. M. (2010). Determinants of maximal outrigger canoe paddling performance. PhD thesis. James Cook University, Australia.

Singh, R., Singh, H.J., & Sirisinghe, R. G. (1995). Physical and physiological profiles of Malaysian dragon boat rowers. *British Journal of Sports Medicine, 29*(1), 13-15.

Spencer, M. R., & Gastin, P. B. (2001). Energy system contribution during 200- to 1500-m running in highly trained athletes. *Medicine and Science in Sport and Exercise, 33*(1), 157-162.

Stanton, R., Evans, G., Dascombe, B., & Peddle, M. (2002). Biometric and biomechanical correlates to outrigger canoe paddling. *Strength and Conditioning Coach, 10*, 19-26.

Tanner, R. K., Fuller, K. L., & Ross, M. L. R. (2010). Evaluation of three portable blood lactate analysers: Lactate Pro, Lactate Scout and Lactate Plus. *European Journal of Applied Physiology, 109*(3), 551-559.

Weinstein, Y., Bediz, C., Dotan, R., & Falk, B. J. M. (1998). Reliability of peak-lactate, heart rate, and plasma volume following the Wingate test. *Medicine and Science in Sport and Exercise, 30*(9), 1456-1460.

West, S. (2006). *The paddler's guide to outrigger canoeing*. Maroochydore, Australia: Batini Books & KC Publishing.

Yamada, D. S., Dierenfield, L. M., Hiller, W. D. B., Pinkert, T. P., Nielsen, G. R., & Crisanti, A. S. (2001). Physical and physiological profile characteristics of female world champion long distance outrigger canoe paddlers. *Medicine and Science in Sport and Exercise, 33*(5), 342.

SESNZ
SPORT & EXERCISE SCIENCE
NEW ZEALAND

The Journal of Sport and Exercise Science, Vol. 3, Issue 2, 8-13 (2019)

www.sesnz.org.nz

JSES
ISSN: 2703-240X

Melatonin and sleep responses following exercise in elite female athletes

Shannon O'Donnell[1 *], Christopher M. Beaven[1], Gregory M. Jacobson[2], Steve Bird[2], Matthew W. Driller[1]

[1]*Te Huataki Waiora School of Health, University of Waikato, New Zealand*
[2]*School of Science and Engineering, University of Waikato, New Zealand*

ARTICLE INFO

Article history:
Received: 06.03.2019
Accepted: 18.06.2019
Online:26.11.2019

Keywords:
Actigraphy
Female
Sports

ABSTRACT

To determine the melatonin concentrations and subsequent sleep indices of elite netball athletes following a training day when compared to a control day. Ten elite female netball athletes (mean ± SD; age = 23 ± 6 yrs) provided saliva samples PRE (17:15h) and POST (22:00h) a training session, and a day with no training (CONTROL). Sleep monitoring was performed using wrist actigraphy to assess total time in bed (TTB), total sleep time (TST), sleep efficiency (SE) and sleep latency (SL). Melatonin levels were significantly lower (p < 0.05), both PRE and POST the training condition (6.2 and 17.6 pg/mL, respectively) when compared to the CONTROL (14.8 and 24.3 pg/mL, respectively). There were no significant differences observed between conditions for any of the sleep variables. However, a small reduction in TST could be observed following the training session condition compared to the CONTROL condition. The scheduling of netball training in the evening is shown to suppress salivary melatonin levels. This may have an influence on subsequent sleep following night-time exercise.

1. Introduction

Athletes experience high training load demands and stress (Tuomilehto et al., 2016) with sleep widely regarded as important for performance and recovery (Halson, 2013). Athletes often experience poorer sleep quantity in comparison to non-athletes (Driller et al., 2017a) and reports have shown that sleep is often impaired on nights following training or competition (O'Donnell et al., 2018). Several contributing factors may cause sleep disruption, including social/media requirements (Romyn et al., 2015), competition scheduling (Fullagar et al., 2016), and increases in muscle pain and core temperature following training or competition (Oda & Shirakawa, 2014). An additional contributing factor that may impair sleep could be the suppression of melatonin following evening exercise (Monteleone et al., 1990).

Previous research has reported, disturbances to both sleep quantity and quality has implications for psychological, cognitive and physical recovery following training sessions (Fullagar et al., 2015). Given the restorative benefits provided through sleep for athletes, such as hormonal responses and cognitive performance (Davenne, 2009), disruptions in sleep indices may consequently have a negative effect on recovery and performance, which is an important consideration for those athletes that need to perform to a high standard on a weekly basis (Skein et al., 2013). Furthermore, sleep is proposed to be one of the most effective recovery strategies for elite athletes following exercise (O'Donnell et al., 2018), and previous research has shown that athletes may face unique issues that can impair their sleep, including training or competing late at night (Driller et al., 2018).

Previous research on the effect of melatonin levels following exercise has shown polarized results, with both increases (Buxton et al., 2003, Carr et al., 1981) and decreases (Buxton et al., 1997, Monteleone et al., 1990) being reported. Carr and colleagues (1981) had reported increased plasma melatonin levels in seven women following serial acute submaximal exercise. Whereas Monteleone and colleagues (1990) demonstrated reduced melatonin levels in seven male participants following nocturnal physical activity. Melatonin is a hormone that is synchronized from environmental cues, contributing to the initiation of sleep in the circadian system (Escames et al., 2012). Due to the importance of melatonin in the circadian system, its contribution to sleep initiation, and the changes in expression seen after exercise, there is a need for more investigation. In addition, the impact of exercise on biorhythms and sleep is becoming increasingly more important to understand with the increase of evening competitions and training occurring for both athletes and non-athletes.

Therefore, the aims of this study was to measure the effects of training on melatonin levels in elite female netball athletes and

*Corresponding Author: Shannon O'Donnell, The Huataki Waiora School of Health, University of Waikato, New Zealand, shannonleaodonnell@gmail.com

determine if there was any effect between melatonin levels and subsequent sleep indices.

2. Methods

2.1. Participants

A total of 10 elite female netball athletes (mean ± SD; age = 23 ± 6 y; body mass = 79.8 ± 8.9 kg) volunteered to participate in the study. Athletes were from the same team and were of international representative standard. The study took place during the in-season competition phase of the netball season. The athletes were free from any sleep disorders, as assessed through the Pittsburgh Sleep Quality Index (PSQI), with a global score of <5 indicating 'good sleepers' (Buysse et al., 1989). All participants provided informed written consent before taking part in this study. Ethical approval for the study was obtained through the institution's Human Research Ethics Committee (HREC#3).

2.2. Design

The current study took place over a seven-day period, whereby athletes completed one netball training session, and one rest day (CONTROL). Individual intensity for the training session was assessed through the athlete's average heart rate (Polar Electro Oy, Finland) and Rate of Perceived Exertion (RPE – Borg's 6-20 scale) (Borg, 1982, Alexiou and Coutts, 2008, Foster et al., 2001, Gaudino et al., 2015). The training session's total duration was two hours, taking place at 18:00h and concluding at 20:00h in the evening.

Saliva samples were obtained at two time points from each athlete for the training session and CONTROL days; immediately PRE (17:15h), and POST (22:00h). Athletes were instructed to collect the saliva samples in the same room, under the same lighting conditions between the two conditions. Sleep was monitored on the nights following the training session and CONTROL to assess total sleep time (TST), sleep efficiency (SE%), sleep latency (SL), and total time in bed (TTB). To control for dietary variables, athletes recorded the meals using a smartphone application (MealLogger App, Wellness Foundry, USA) for the training session and were instructed to replicate their diet for the subsequent CONTROL day.

2.3. Sleep Monitoring

Athletes were required to wear an actigraph (Readiband, Fatigue Science, Vancouver, Canada) over the duration of the study period to monitor sleep patterns. The Readiband device has been shown to have an acceptable inter-device reliability (ICC = >0.90) in a healthy adult population (Driller et al., 2016) and is commonly used in sporting teams as it is more practical and less intrusive compared to polysomnography. Athletes were instructed to wear the actigraph on the wrist they felt most comfortable (Driller et al., 2017b) continuously for the monitoring period, with the exception of time spent during on-court training sessions, or when in contact with water (e.g. showering or swimming). The raw activity scores were translated to sleep-wake scores based on computerized scoring algorithms. Sleep indices were quantified via the Fatigue Science software (Readiband, Fatigue Science, Vancouver, Canada) at a sampling rate of 16Hz.

2.4. Hormone Assessment

At each of the two time points during the two trials, athletes provided a 5 mL saliva sample by passive drool into a sterile plastic tube, with saliva samples stored at -20°C, until analysed. On the day of testing, saliva samples were thawed to room temperature and centrifuged at 3000 rpm for 15 minutes to precipitate mucins. Saliva samples were assayed using a highly sensitive Enzyme Linked Immunosorbent Assay (ELISA) for melatonin (Salimetrics, NSW, Australia), following the manufacturer's instructions. Samples were analysed in duplicate, using 100 µL of saliva per determination, with the ELISA having a lower limit of sensitivity of 1.37 pg/mL. The standard curve ranged from 0.78 pg/mL to 50.00 pg/mL, had an average intra-assay coefficient of variation (CV) of 5.7%, and an average inter-assay CV of 7.5%.

2.5. Statistical Analysis

Descriptive group statistics are shown as mean ± standard deviation unless otherwise stated. A Microsoft Excel spreadsheet was used to estimate the mean effects and 90% confidence intervals (90% CI) of all measured variables between trials (Hopkins, 2006). Magnitudes of the standardized effects were calculated using Cohen's d and interpreted using thresholds of 0.2, 0.6, 1.2 and 2.0 for *small, moderate, large and very large*, respectively (Hopkins et al., 2009). An effect size of < 0.2 was considered to be *trivial* and the effect was deemed *unclear* if its 90% confidence interval overlapped the thresholds for *small* positive and *small* negative effects (Batterham and Hopkins, 2006). A student's paired t-test was used to compare the training session and CONTROL conditions for sleep measures, and a two-way analysis of variance (ANOVA) was performed to compare the time points (PRE and POST) and the effect of conditions on salivary melatonin levels using a Statistical Package for Social Science (V.22.0, SPSS Inc., Chicago, IL), with significance set at $p \leq 0.05$.

3. Results

The athletes' mean heart rate during the training session was 145 ± 10 bpm with a mean rating of perceived exertion of 14 ± 1.

The values for the comparison between the training session and CONTROL conditions for sleep can be observed in Table 1. There was a significant interaction between time (PRE and POST) and condition (training session and CONTROL) for melatonin concentration ($p < 0.05$). A significant difference of 8.7 ± 10.4 pg/mL in melatonin was observed immediately PRE the training session compared to PRE CONTROL (d = -0.69, $p < 0.05$, Figure 1). There was a significant difference in melatonin levels POST the training session compared to POST CONTROL (7.4 ± 7.1, d = -0.74, $p < 0.05$, Figure 1).

There were no statistically significant differences observed between conditions for any of the sleep variables. However, a *small* reduction in TST could be observed following the training session condition compared to the CONTROL condition (-45 minutes, d = 0.21, $p > 0.05$, Table 1).

Table 1: Mean ± SD values for the measured sleep variables in a training and control environment, including the difference between training and control, P-values and Effect Sizes (±90% confidence intervals).

	Control	Training	Raw Difference (Control - Training)	Control - Training Effect Size
Total Sleep Time (TST) (h:mm)	8:46 ± 1:03	8:01 ± 1:17	0:45 ± 0:31	0.21 ±0.25 *Small*
Sleep Efficiency (SE) (%)	82.1 ± 8.9	85.3 ± 7.2	-3.4 ± 11.9	-0.35 ±0.90 *Unclear*
Total Time in Bed (TTB) (h:mm)	10:36 ± 2:09	9:56 ± 1:48	0:40 ± 1:56	0.19 ±0.60 *Unclear*
Sleep Latency (SL) (min)	27.5 ± 34.7	38.5 ± 29.3	-10.8 ± 33.8	-0.34 ±0.71 *Unclear*

Significant difference between conditions ($p < 0.05$)

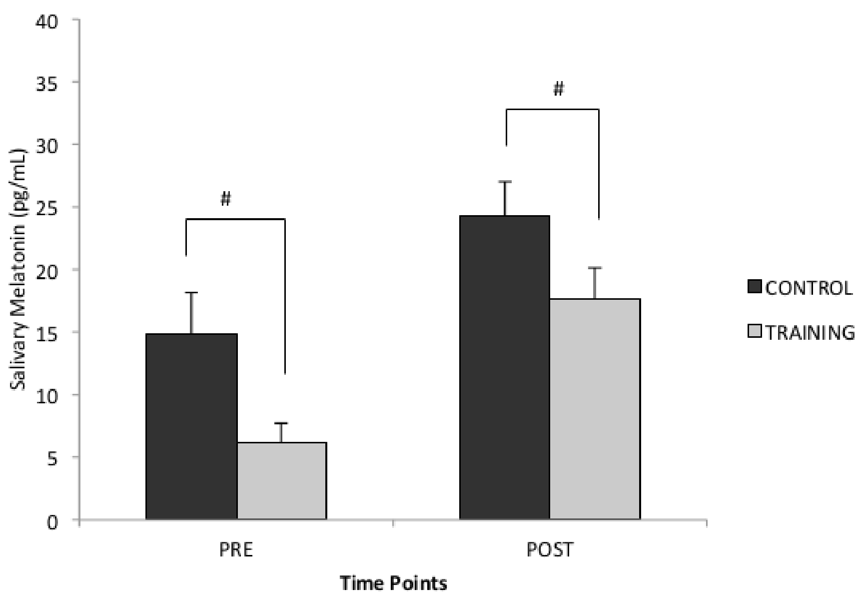

Figure 1: Salivary melatonin concentrations (pg/mL) PRE and POST a training and control day. # indicates a significant difference between conditions ($p < 0.05$).

4. Discussion

This study presents novel findings on the melatonin response to training and rest days and examines the subsequent sleep indices in an elite female athlete population. The main findings from the study were significantly lower salivary melatonin levels on a training day, both PRE and POST, when compared to the same time points on a rest day. Whist there was no significant differences for the sleep indices, a general trend towards impaired SL and TST in the training session trial when compared to the control was observed. These findings provide the first evidence that female athletes express lower levels of melatonin both PRE and POST training, when compared to a rest day, which contribute to the *small* trend in impaired sleep that was seen.

The results of the current study are consistent with previous investigations that have examined the suppressed melatonin response following exercise (Monteleone et al., 1990, Buxton et al., 1997). A study in healthy male participants (n=7) assessed the melatonin response following nocturnal physical activity (Monteleone et al., 1990), reporting plasma melatonin levels were significantly suppressed at 23:00 pm ($p < 0.02$), 1:00 am ($p < 0.01$), and at 2:00 am ($p < 0.03$) following a 22:40pm exercise session compared to the control condition. Similarly, a study in moderately trained males (n=8) assessing the melatonin response following differing intensity and durations of nocturnal exercise

(Buxton et al., 1997), reported a phase delay of plasma melatonin secretion following both a three hour low intensity exercise session (63 min) and a one hour high intensity exercise session (-55 minutes) compared to a baseline non-exercising condition. Whilst our study offers support of these findings, with similarities in suppressed melatonin following exercise, it should be noted there are several differences between the protocols of the studies. Both Buxton et al. (1997) and Monteleone et al. (1990) measured melatonin in plasma, in comparison to the current study where melatonin was measured through saliva. In addition, the time where exercise was initiated, differs substantially between all three studies; 1:00 am (Buxton et al., 1997), 22:40 pm (Monteleone et al., 1990), and 18:00 pm in the current study. Lastly, the duration and intensity of the exercise in each study is variable. Each of these factors make it difficult to draw decisive conclusions between the three studies. However, it is clear, from each study that exercise does have a major impact upon melatonin levels, which in turn will affect human biorhythms and physiological processes related to sleep regulation.

In regards to objective sleep metrics, the results of the current study support previous research that has assessed sleep following evening competition (Shearer et al., 2015, Juliff et al., 2018). Although not statistically significant, a *small* difference was observed following training compared to control for TST (-45 minutes), which was similar to the TST reductions from an evening game observed by Juliff and colleagues (2018) in 42 netball athletes. The physical exertion that occurs from late night training and competition may cause disruptions to circadian rhythms, in turn causing a phase delay in melatonin production, and delayed sleep onset (Shearer et al., 2015). It is positive to observe that the *small* reduction in TST (8:01 h:min) observed following the training session compared to CONTROL remained within the recommended 7 – 9 hours of sleep duration for the general population (Hirshkowitz et al., 2015). Indeed, it is somewhat surprising that the sleep duration in both conditions in the current study (8:01 and 8:46 for the training session and CONTROL) is higher than that described in previous research in elite netballers (O'Donnell et al., 2018, Juliff et al. 2018). O'Donnell et al. (2018) reported sleep durations of 6:46 the night of a netball match and 7:23 the next night following a match. Similarly, Juliff et al. (2018) reported total sleep durations of ~7:20 in the week leading up to a netball tournament. While not statistically significant, a *small* trend was also observed for delayed SL in the current study following training (38.5 minutes) compared to control (27.5 minutes). Interestingly, the athletes SE showed a *small* trend to better sleep following the training compared to the control (3.4%). These findings demonstrate that the impact of exercise (and anticipation of exercise) on the melatonin biorhythm does appear to elicit changes in sleep duration and sleep latency.

Considering the continuous level of training demands athletes' experience, any disruption they face regarding sleep would be disadvantageous. Previous research has highlighted the importance of implementing sleep hygiene education and strategies (Fullagar et al., 2016, O'Donnell & Driller, 2017) into athlete's routines, as an aid to maintain or improve sleep indices specifically during and following competition. A strategy that may be beneficial to elite athletes is the implementation of meditation following nocturnal exercise. A study by Tooley et al. (2000) investigated the melatonin response in 17 male and female participants following a meditation period. Results reported that the participants' plasma melatonin levels were significantly higher post the meditation period compared to the same time on the control night. Other studies investigating melatonin and health (Szewczyk-Golec et al., 2015) has highlighted the implications of suppressed melatonin on general well being. These studies highlight the need to better understand the effects of nocturnal exercise and its interaction with melatonin, especially given the suppression of melatonin levels seen in our studies and their potential effect on sleep quality.

There were a number of limitations with this study, which may have influenced the results. Exposure to artificial light was not controlled, which has been shown to suppress melatonin levels (Anisimov et al., 2012) and cannot be discounted as having an influence on the results. However, the data was collected in the athletes' home environment(s) during the CONTROL trial, therefore it would have detracted from the ecological validity of the results if this was performed in a laboratory. A further limitation of the current study was the lack of control for the menstrual cycle phases for each individual athlete. This may have influenced melatonin levels by the change in body temperature that occurs across the different phases (Cagnacci et al., 1996). Other limitations were the small sample size and the small number of measured time points where saliva was collected, meaning the persistence of the effects of exercise cannot be extrapolated. Regardless of this, a significant impact of exercise on melatonin levels was shown and highlights the need for more research in this area with highly trained athletes.

5. Conclusion

The results of the current study indicate that the training environment resulted in significantly suppressed melatonin levels with a trend towards impaired sleep indices when compared to a control day in female athletes. Given adequate sleep is crucial for aiding in the psychological and physiological recovery of an athlete, as well as the potential health implications of the disrupted melatonin biorhythms, the findings from this study highlight the importance for future research on the interactions of nocturnal exercise and subsequent melatonin levels.

6. Practical Applications

Results from the current study may be used by coaching staff and practitioners working with elite athletes to incorporate adequate recovery time into training schedules to account for the impaired sleep indices experienced following evening exercise. This may include scheduling longer sleep-in time following evening training sessions.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgment

The authors would like to thank each of the athletes for their time and participation during this study. Funding for the hormonal analysis was provided by the University of Waikato.

References

Alexiou, H., & Coutts, A. (2008). A comparison of methods used for quantifying internal load in women soccer players. *International Journal of Sports Physiology and Performance, 3***,** 320-330.

Anisimov, V., Vinogradova, I., Panchenko, A., Popovich, I., & Zabezhinski, M. (2012). Light-at-night-induced circadian disruption, cancer and aging. *Current Aging Science, 5***,** 170-177.

Batterham, A., & Hopkins, W. (2006). Making meaningful inferences about magnitudes. *International Journal of Sports Physiology and Performance, 1***,** 50-57.

Borg, G. (1982). Physical bases of perceived exertion. *Medicine and Science in Sports and Exercise, 14***,** 377-381.

Buxton, O., Frank, S., L'Hermite-Baleriaux, M., Leproult, R., Turek, F., & van Cauter, E. (1997). Roles of intensity and duration of nocturnal exercise in causing phase delays of human circadian rhythms. *American Journal of Physiology, 273***,** 536-542.

Buxton, O., Lee, C., L'Hermite-Baleriaux, M., Turek, F., & van Cauter, E. (2003). Exercise elicits phase shifts and acute alterations of melatonin that vary with circadian phase. *American Journal of Physiology Regulatory, Integrative and Comparative Physiology, 284***,** R714-724.

Buysse, D., Reynolds, C., Monk, T., Berman, S., & Kupfer, D. (1989). The Pittsburg Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Research, 28***,** 193-213.

Cagnacci, A., Soldani, R., Laughlin, G., & Yen, S. (1996). Modification of circadian body temperature rhythm during the luteal menstrual phase: role of melatonin. *Journal of Applied Physiology, 8***,** 25-29.

Carr, D., Reppert, S., Bullen, B., Skrinar, G., Beitins, I., Arnold, M., Rosenblatt, M., Martin, J., & McArthur, J. (1981). Plasma melatonin increases during exercise in women. *The Journal of Clinical Endocrinology & Metabolism, 53***,** 224-225.

Davenne, D. (2009). Sleep of athletes - problems and possible solutions. *Biological Rhythm Research, 40***,** 45-52.

Driller, M., Dixon, Z., & Clark, M. (2017a). Accelerometer-based sleep behavior and activity levels in student athletes in comparison to student non-athletes. *Sport Sciences for Health, 13,* 411-418.

Driller, M., Mah, C., & Halson, S. (2018). Development of the Athlete Sleep Behavior Questionnaire: A tool for identifying maladaptive sleep practices in elite athletes. *Sleep Science, 11,* 37-44.

Driller, M., McQuillan, J., & O'Donnell, S. (2016). Inter-device reliability of an automatic-scoring actigraph for measuring sleep in healthy adults. *Sleep Science***,** 9, 198-201.

Driller, M., O'Donnell, S., & Tavares, F. (2017b). What wrist should you wear your actigraphy device on? Analysis of dominant vs. non-dominant wrist actigraphy for measuring sleep in healthy adults. *Sleep Science, 10,* 132-135.

Escames, G., Ozturk, G., Baño-Otálora, B., Pozo, M., Madrid, J., Reiter, R., Serrano, E., Concepción, M., & Acuña-Castroviejo, D. (2012). Exercise and melatonin in humans: reciprocal benefits. *Journal of Pineal Research, 52,* 1-11.

Foster, C., Florhaug, J., Franklin, J., Gottschall, L., Hrovatin, L., Parker, S., Doleshal, P., & Dodge, C. (2001). A new approach to monitoring exercise training *Journal of Strength and Conditioning Research, 15***,** 109-115.

Fullagar, H., Skorski, S., Duffield, R., Hammes, D., Coutts, A., & Meyer, T. (2015). Sleep and athletic performance: the effects of sleep loss on exercise performance, and phyiological and cognitive responses to exercise. *Sports Medicine, 45***,** 161-186.

Fullagar, H., Skorski, S., Duffield, R., & Meyer, T. (2016). The effect of an acute sleep hygiene strategy following a late-night soccer match on recovery of players. *Chronobiology international, 33***,** 1-16.

Gaudino, P., Marcello Iaia, F., Strudwick, A., Hawkins, R., Alberti, G., Atkinson, G., & Gregson, W. (2015). Factors influencing perception of effort (session rating of perceived exertion) during elite soccer training. *International Journal of Sports Physiology and Performance, 10***,** 860-864.

Halson, S. (2013). Sleep and the elite athlete. *Sports Science Exchange, 26***,** 1-4.

Hirshkowitz, M., Whiton, K., Albert, S., Alessi, C., Bruni, O., Doncarlos, L., ... Hillard, P. (2015). National sleep foundation's sleep time duration recommendations: methodology and results summary. *Sleep Health, 1***,** 40-43.

Hopkins, W. (2006). *Analysis of a post-only crossover trial (excel spreadsheet)* [Online]. Available: http://www.sportsci.org/resource/stats/ [Accessed].

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science *Medicine & Science in Sports & Exercise, 41***,** 3-12.

Juliff, L., Halson, S., Hebert, J., Forsyth, P., & Peiffer, J. (2018). Longer sleep durations are positively associated with finishing place during a national mulit-day netball competition. *Journal of Strength and Conditioning Research, 32,* 189-194.

Monteleone, P., Maj, M., Fusco, M., Orazzo, C., & Kemali, D. (1990). Physical exercise at night blunts the nocturnal increase of plasma melatonin levels in healthy humans. *Life Sciences, 47***,** 1989-1995.

O'Donnell, S., Beaven, C., & Driller, M. (2018). Sleep/wake behavior prior to and following competition in elite female athletes. *Sport Sciences for Health, 14,* 289-295.

O'Donnell, S., Beaven, C., & Driller, M. (2018). From Pillow to Podium: A review on understanding sleep for elite athletes. *Nature and Science of Sleep, 10,* 243-253.

O'Donnell, S., & Driller, M. (2017). Sleep-hygiene education improves sleep indices in elite female athletes. *International Journal of Exercise Science, 10,* 522-530.

Oda, S., & Shirakawa, K. (2014). Sleep onset is disrupted following pre-sleep exercise that causes large physiological excitement at bedtime. *European Journal of Applied Physiology, 114***,** 1789-1799.

Romyn, G., Robey, E., Dimmock, J., Halson, S., & Peeling, P. (2015). Sleep, anxiety and electronic device use by athletes in the training and competition environments. *European Journal of Sport Science***,** *16,* 301-308.

Shearer, D., Jones, R., Kilduff, L., & Cook, C. (2015). Effects of competition on the sleep patterns of elite rugby union players. *European Journal of Sport Science, 15***,** 681-686.

Skein, M., Duffield, R., Minett, G., Snape, A., & Murphy, A. (2013). The effect of overnight sleep deprivation after competitive rugby league matches on postmatch physiological and perceptual recovery. *International Journal of Sports Physiology and Performance, 8***,** 556-564.

Szewczyk-Golec, K., Woźniak, A., & Reiter, R. (2015). Inter-relationships of the chronobiotic, melatonin, with leptin and adiponectin: implications for obesity. *Journal of Pineal Research, 59***,** 277-291.

Tuomilehto, H., Vuorinen, V., Penttilä, E., Kivimäki, M., Vuorenmaa, M., Venojärvi, M., Airaksinen, O., & Pihlajamäki, J. (2016). Sleep of professional athletes: underexploited potential to improve health and performance. *Journal of Sports Sciences***,** *35,* 704-710.

SESNZ
SPORT & EXERCISE SCIENCE NEW ZEALAND

The Journal of Sport and Exercise Science, Vol. 3, Issue 2, 14-20 (2019)

www.sesnz.org.nz

JSES
ISSN: 2703-240X

Anticipating deceptive movements in rugby union: The role of reinvestment

Sebastian M. Sherwood[1, 2 *], Tiaki B. Smith[1, 2], Rich S. W. Masters[1, 3]

[1]Te Huataki Waiora School of Health, University of Waikato, New Zealand
[2]Chiefs Super Rugby Club, Ruakura, Hamilton, New Zealand
[3]School of Public Health, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Hong Kong SAR

ARTICLE INFO

Received: 13.05.2019
Accepted: 11.09.2019
Online: 26.11.2019

Keywords:
Decision making
Anticipation
Virtual reality
Consciousness

ABSTRACT

The ability to quickly and accurately anticipate deceptive and non-deceptive movements is crucial in many sports. In the current investigation, novice (N=10), intermediate (N=10) and professional (N=10) rugby players anticipated the final running direction of an opponent changing direction (with or without deception). The study aimed to better understand (1) the effect skill level has on anticipation of deceptive and non-deceptive movements and (2) whether the propensity for reinvestment plays a role in anticipatory performance. Reinvestment is an individual predisposition to consciously monitor and control decisions (measured using the Decision Specific Reinvestment Scale) or movements (measured using the Movement Specific Reinvestment Scale). Much research has shown that the tendency to reinvest detrimentally affects performance under pressure. Our results showed that expert players took significantly longer to respond than novices but were significantly more accurate than novices when anticipating deceptive and non-deceptive changes of direction. Furthermore, Conscious Motor Processing (a subscale of the Movement Specific Reinvestment Scale) scores were associated with poorer response accuracy for deceptive changes of direction.

1. Introduction

In fast paced sports, decisions are seldom made on the basis of reliable (high certainty) information alone. Performers therefore need to make decisions based upon anticipation of what is likely to occur. For example, Chang and Yang (2010) calculated that when facing a fast serve in tennis (over 200km/h) players have 500-700ms before they attempt to return the ball. They have a very small window in which to judge the ball's direction and speed, decide on an appropriate shot, move into the right position and prepare and execute the required shot. Responding based purely on the flight of the ball (reliable information) is insufficient because human sensory processing speeds are too slow (Loffing & Cañal-Bruland, 2017). Consequently, expert performers utilise advanced information from the server's kinematics to anticipate the shot direction or location (Farrow, Abernethy, & Jackson, 2005).

The ability to anticipate the behaviours of an opponent has been shown to discriminate between experts and non-experts in many sports, including squash (Howarth, Walsh, Abernethy, & Snyder, 1984), tennis (Singer, Cauraugh, Chen, Steinberg, & Frehlich, 1996), rugby (Jackson, Warren, & Abernethy, 2006) and badminton (Wright, Bishop, Jackson, & Abernethy, 2011). To measure an individual's ability to anticipate effectively, temporal occlusion methodologies are often utilised. These involve termination of observed sequences of movement at various times to remove advanced and/or reliable information. Occlusion before reliable information is available (e.g., racket contact in tennis) forces performers to make decisions based on advanced information only.

Anticipation is further complicated when a player uses deception to mislead an opponent into making an incorrect decision (see Güldenpenning, Kunde, & Weigelt, 2017, for a review). Research has shown that anticipation is poorer for deceptive compared to non-deceptive movements (e.g., Mori & Shimada, 2013; Dicks, Button, & Davids, 2010; Jackson et al., 2006). Both Mori and Shimada (2013) and Jackson et al (2006) demonstrated that novices were more susceptible to deceptive movements than experts, showing significant decreases in the accuracy of their responses. Anticipation of deceptive actions by

*Corresponding Author: Sebastian M. Sherwood, The Huataki Waiora School of Health, University of Waikato, New Zealand, sms548@students.waikato.ac.nz

experts is thought to be superior to novices because they have greater experience in both perceiving and performing the observed actions (Cañal-Bruland, van der Kamp, & van Kesteren, 2010). Aglioti, Cesari, Romani, and Urgesi (2008), for instance, found that experienced basketball players could predict the outcome of a shot when they only saw body kinematics, whereas, journalists with experience of watching, but not playing, basketball needed to see the ball trajectory to successfully anticipate shot outcome.

Anticipation may also be affected by mental functions. The theory of reinvestment (Masters, 1992; Masters & Maxwell, 2008) proposes that there are individual differences in the extent to which people consciously or non-consciously monitor and control their behaviours. Movement specific reinvestment (Masters, 1992; Masters, Eves, & Maxwell, 2005) refers to an individual's propensity to draw upon (and reinvest) previously acquired explicit, rule-based knowledge to consciously control movements. Decision specific reinvestment (Kinrade, Jackson, Ashford, & Bishop, 2010) refers to an individual's propensity to consciously monitor and control decision making processes. Research in the motor domain has generally shown that individuals with a high disposition for movement specific reinvestment (measured using the Reinvestment Scale or the Movement Specific Reinvestment Scale; (MSRS), see Masters & Maxwell, 2008) are more likely to experience performance breakdown under pressure (e.g., Law, Masters, Bray, Eves, & Bardswell, 2003; Liao & Masters, 2001; Masters, Polman, & Hammond, 1993; Schücker, Ebbing, & Hagemann, 2010). Research has also shown that high decision reinvestors (measured using the Decision Specific Reinvestment Scale (DSRS), Kinrade et al., 2010) make slower and/or less accurate decisions under pressure. This has been shown in sports such as basketball (Kinrade, Jackson, & Ashford, 2015), netball (Jackson, Kinrade, Hicks, & Wills, 2013) and korfball (Kinrade et al., 2010). For example, Jackson et al (2013) found DSRS score to be a significant predictor of poorer passing completion under pressure, in a real-life netball matches. It has been suggested that reinvestment causes performance decrements under pressure because previously automated processes are broken down into separate units, as in the early stages of learning, which increases the opportunities for disruption (Beilock & Carr, 2001; Masters, 1992).

In rugby, a ball carrier will often perform a side-step to mislead a defensive counterpart into making an ineffective tackle. For example, Wheeler, Askew, and Sayers (2010) showed that 72% of tackle breaks resulted from an attacker side-stepping the defensive player. To date, the association between propensity for reinvestment and anticipation of deceptive movements has not been examined. We therefore asked whether a higher propensity for reinvestment (movement or decision) causes slower or less accurate anticipation in response to deceptive side-steps in rugby? In the current study, expert, intermediate and novice rugby players were required to anticipate the final running direction of players changing direction using a side-step, (i.e., deceptive movements to provide misleading kinematic information about their intentions) or using non-deceptive movements. It is unclear how movement reinvestment will affect anticipatory performance, due to the novelty of this line of inquiry. However, it is hypothesised that decision reinvestment will have a deleterious effect on anticipation of both deceptive and non-deceptive movements.

2. Methods

2.1. Participants

A novice group (N=10) was formed of participants with less than two years of rugby union playing experience, at no higher than a recreational level (age 22.4 ± 4.69 years). An intermediate group (N=10) was formed of participants with at least two years of club level experience (average 9.1 years), but no professional playing experience (age 22.8 ± 4.23 years). An expert group (N=10) was formed of professional players from the top two leagues in New Zealand, with an average of 16.6 years playing experience (age 23.7 ± 2.49 years). Ethical approval was obtained from a university panel and all participants provided informed consent prior to involvement.

2.2. Test trials

The experimental task represented a 'one-on-one' tackle situation in rugby (c.f. Jackson et al, 2006), with participants assuming the role of a defending player tasked to prevent the attacking player from progressing up-field. A major departure from other studies (i.e., Jackson et al, 2006) was that the tackle situations were filmed using a 360° camera, so they could be viewed in a virtual reality headset.

Two highly skilled rugby players - of the same ability as the expert participants - were used to create the tackle scenarios. Players were filmed using a 360° camera (Ricoh Theta V, Japan) on a tripod at a height of 1.5m. Players ran towards the camera, from a starting point at a distance of 16m (see Figure 1). At a distance of 2m from the camera, players changed direction using either a deceptive change of direction (Deceptive Trials) or a non-deceptive change of direction (Non-Deceptive Trials). In Deceptive Trials, players feinted towards one target before changing direction to run towards the other target. In Non-Deceptive trials, players changed direction towards one of two targets located at an angle of 45° (triangles below). Players were filmed multiple times running to both the left and the right.

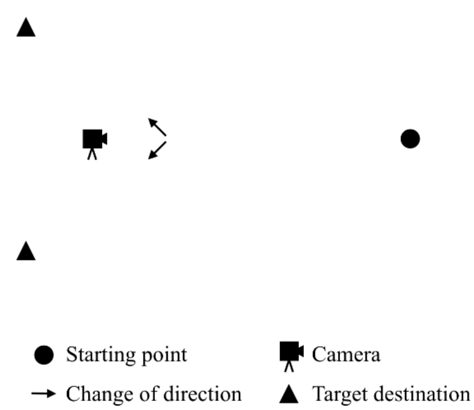

Figure 1: A visual representation of the filming set up used

Adobe Premiere Pro (Version 12.1, California) was used to edit each clip so that it occluded at one of three time points relative to the final foot contact prior to change of direction: t1 (-100ms), t2 (0ms) and t3 (+100ms). Figure 2 displays an example of the final frame before occlusion for each time point. All clips commenced with a 3-2-1 countdown and concluded with a black screen at occlusion for 2 seconds between trials.

To facilitate response timing, a tone was inserted in each clip 3s before final foot contact prior to change of direction; response times less than 3 seconds indicated that participants responded prior to change of direction. A final bank of trials (N=120) was created, including Deceptive Trials (N=60) and Non-Deceptive Trials (N=60). Twenty Deceptive and twenty Non-Deceptive trials were randomly occluded at each of the three time points.

A block of practice trials and four blocks of experimental trials were created. The practice block consisted of 10 randomly selected clips that included deceptive trials (N=5) and non-deceptive trials (N=5). Each block of experimental trials consisted of 20 clips (allocated in a random order using a random sequence generator) that included deceptive trials (N=10) and non-deceptive trials (N=10).

Figure 2: The final frames of a non-deceptive trial (top row) and a deceptive trial (bottom row) occluded at T1 (left), T2 (middle) and T3 (right).

2.3. Test procedure

Prior to starting, participants completed a health questionnaire to ensure they would not experience negative symptoms from the VR headset. Participants also provided information about their age and rugby union experience (level and number of years), and completed the MSRS (Masters, et al., 2005) and the DSRS (Kinrade, et al., 2010). The MSRS assesses propensity for conscious monitoring and control of movements via questions that are categorised under two separate sub-scales: movement self-consciousness (an individual's propensity to monitor public perceptions of their style of moving) and conscious motor processing (and individual's propensity to consciously engage in controlling their movements). Acceptable internal consistency has been reported for both movement self-consciousness ($\alpha = .79$) and conscious motor processing ($\alpha = .71$) (Masters et al, 2005). The DSRS assesses propensity for conscious monitoring and processing of decisions via questions that are also categorised under two separate subscales: decision reinvestment (an individual's propensity to consciously monitor the processes involved in making a decision), and decision rumination (an individual's propensity to focus on negative evaluation of previous poor decisions). Acceptable internal consistency has been reported for both decision reinvestment ($\alpha = .89$) and decision rumination ($\alpha = .91$) (Kinrade, Jackson, Ashford, & Bishop, 2010). For both the MSRS and the DSRS, scores on each sub-scale can be computed or a global propensity score can be examined.

In the test procedure, participants viewed each trial using a virtual reality (VR) headset (Gear VR, Samsung, South Korea). Viewing 360° footage through VR headsets allows observers to immerse themselves within the environment. Following technological advancements in recent years, VRVR has become increasing popular as a method to mirror real life scenarios more closely (e.g., Bideau, Kulpa, Vignais, Brault, Multon, & Craig, 2010; Stinson & Bowman, 2014).

Participants first completed a block of practice trials before completing the blocks of experimental trials (allocated in a random order using a random sequence generator). The practice trials familiarised participants with the apparatus and test procedure, with any questions answered prior to completion of the test trials. All blocks were completed in one session (approx. 20 min). In each trial, participants were asked to anticipate the final destination of the observed player as quickly and accurately as possible by providing a verbal response: "left" or "right". Participants were encouraged to stand in a position that they would typically adopt when defending and were allowed to accompany their verbal response with physical responses if they chose to. Other studies have chosen to adopt movement tracking to measure participants' responses (e.g. Brault, Bideau, Kulpa, & Craig, 2012). However, due to the exploratory nature of the current investigation the authors believed verbal responses would be sufficient in this case, with promising findings warranting more sophisticated methodologies in follow up studies.

Following each block of trials, the VR headset was removed and participants rested for approximately 2 min (based on personal preference) before proceeding to the next block of trials. At the end of the procedure, participants were debriefed about the purpose of the study. They were also asked to judge the realism of footage, ranging from 1 (completely unrealistic) to 10 (completely realistic) to ascertain the fidelity of the methodology for future studies.

2.4. Data analysis

Response Accuracy and Time were computed for deceptive and non-deceptive trials as a function of time of occlusion (i.e., -100ms, 0ms, +100ms). Response Time was calculated using Audacity software (Version 2.3, Pennsylvania, USA) to identify the time that elapsed between the tone (3s before final foot contact at change of direction) and initiation of the verbal response (left/right). Scores on the MSRS and DSRS (and each subscale) were recorded.

Statistical analyses were completed using SPSS (Version 24, IBM, UK). Two 3 (Skill level: Novice/Intermediate/Expert) x 2 (Stimuli Type: Deceptive Trials/Non-Deceptive Trials) x 3 (Occlusion Point: -100ms/0ms/+100ms) mixed design ANOVAs were computed to examine Response Accuracy and Response Time. Post hoc analyses in the form of Bonferroni corrected pairwise comparisons were completed where necessary.

To examine the role of reinvestment in anticipation performance, hierarchical regression analyses were conducted for Response Accuracy on deceptive trials and non-deceptive trials (occluded at -100ms) and for Response Time on deceptive and non-deceptive trials (occluded at -100ms). Only trials occluded at -100ms were included as they were the only trials in which stepping information was completely unavailable (pure anticipation). In the first step of each regression analysis, skill level was accounted for by coding Novices, Intermediates and Experts as 1, 2 and 3, respectively. In the second step, the predictor variables MSRS Global (all questions), MSRS Self-Consciousness, MSRS Conscious Motor Processing, DSRS Global (all questions), DSRS Decision Reinvestment and DSRS Decision Rumination, were entered. A significant R^2 change in the second model was considered an indication that reinvestment (one or multiple scores) had an effect on anticipation, regardless of skill level.

3. Results

3.1. Response Accuracy

The mean Response Accuracy scores for Deceptive and Non-Deceptive trials are shown in Figure 3. Main effects were evident for Stimulus Type ($F(1,27) = 29.158$, $p = 0.001$, $\eta_p^2 = 0.519$), Occlusion Point ($F(2,54) = 39.952$, $p = 0.001$, $\eta_p^2 = 0.597$) and Skill Level ($F(2,27) = 3.961$, $p = 0.031$, $\eta_p^2 = 0.227$). Bonferroni corrected pairwise comparisons showed that for Stimulus Type, Response Accuracy was significantly greater in non-deceptive compared to deceptive trials ($p = 0.001$). For Occlusion Point, Response Accuracy at +100ms and 0ms was significantly greater than at -100ms (p's < 0.05), but no significant difference was found between 0ms and +100ms ($p > 0.05$). For Skill Level, the only significant difference identified was that experts were significantly more accurate than novices ($p = 0.046$).

A significant interaction was evident between Stimulus Type and Occlusion Point ($F(2,54) = 14.693$, $p = 0.001$, $\eta_p^2 = 0.352$). Follow-up analysis, using one-way ANOVAs, showed that for Non-Deceptive trials there were no significant differences in Response Accuracy as a function of Occlusion ($F(2,87) = 2.229$, $p = 0.238$). For Deceptive trials, there were significant differences in Response Accuracy as a function of Occlusion ($F(2,87) = 22.632$, $p = 0.001$). Post hoc tests in the form of Bonferroni corrected pairwise comparisons, showed that Response Accuracy improved significantly between -100ms and 0ms, and -100ms and +100ms; (p's < 0.05). No further two-way or three-way interactions were evident (p's > 0.05).

3.2. Response Time differences

The mean Response Times for Deceptive and Non-Deceptive trials are shown in Figure 4. Main effects were evident for Stimulus Type ($F(1,27) = 12.762$, $p = 0.001$, $\eta_p^2 = 0.321$), Occlusion Point ($F(2,54) = 5.898$, $p = 0.005$, $\eta_p^2 = 0.179$) and Skill Level ($F(2,27) = 5.301$, $p = 0.011$, $\eta_p^2 = 0.282$). Bonferroni corrected pairwise comparisons showed that for Stimulus Type, Response Times were significantly quicker in deceptive, as opposed to non-deceptive, trials ($p < 0.05$). For Occlusion Point, Response Times were significantly slower in -100ms trials than 0ms trials ($p < 0.05$). The main effect for Skill Level found that experts were significantly slower than novices ($p < 0.05$). No significant two-way or three-way interactions were found (p's $>$ 0.05).

3.3. Reinvestment and Response Accuracy

In the first hierarchical regression analysis, Response Accuracy during Deceptive trials (occluded at -100ms) was used as the dependent measure, with skill level controlled for in Step 1. Skill level did not account significantly for Response Accuracy variance ($p > 0.05$). In Step 2, the various reinvestment scores were entered. MSRS (Conscious Motor Processing) significantly predicted 13% of Response Accuracy variance, with higher Conscious Motor Processing scores associated with decreased Response Accuracy ($\beta = -0.359$, $p = 0.047$). No other scores contributed significantly (p's > 0.05). The second hierarchical regression, investigating Response Accuracy during Non-Deceptive trials (occluded at -100ms), revealed no effect for any of the reinvestment scores entered (*p's* > 0.05).

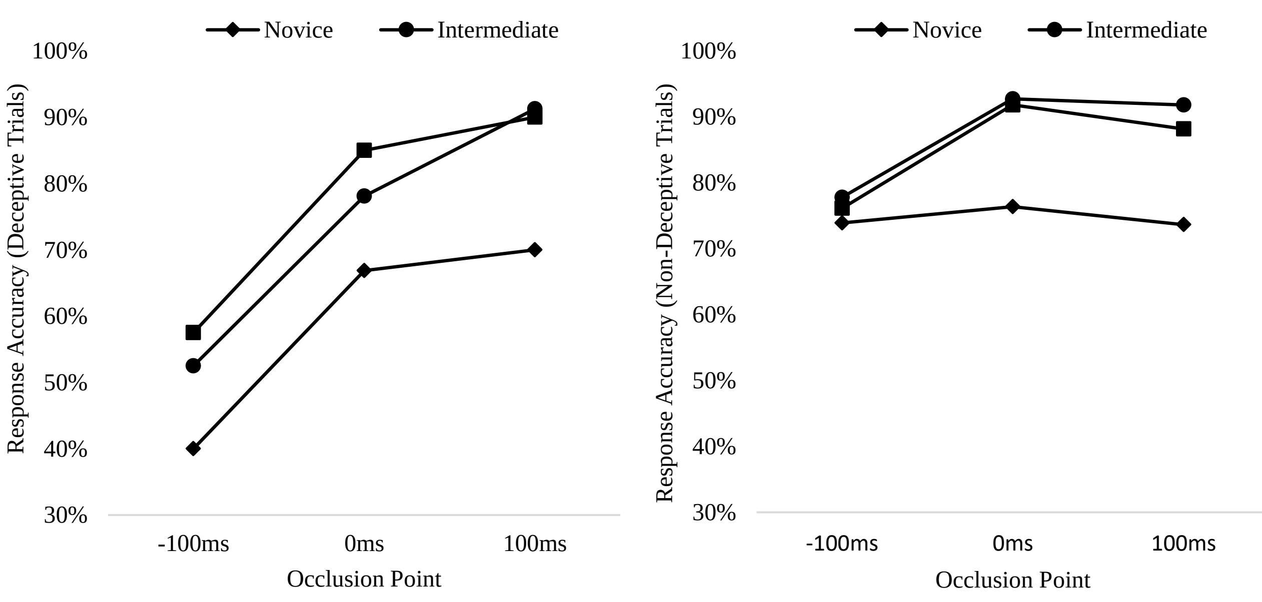

Figure 3: Mean Response Accuracy scores on Deceptive trials (left) and Non-Deceptive trials (right) at each occlusion point

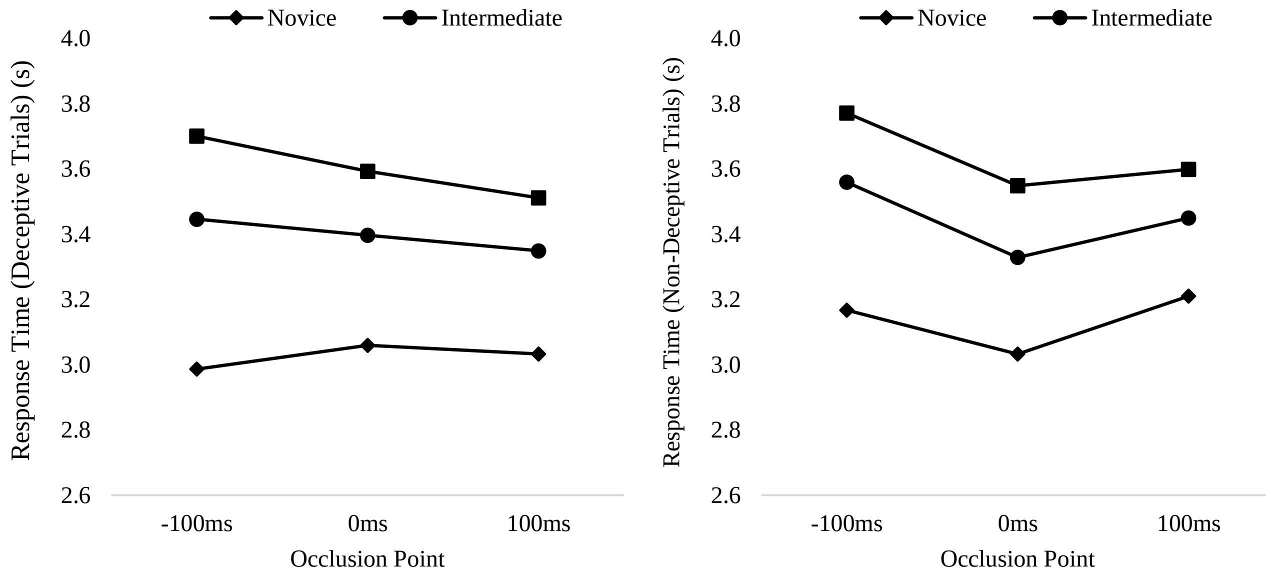

Figure 4: Mean response times on Deceptive trials (left) and Non-Deceptive trials (right) at each occlusion point

3.4. Reinvestment and Response Time

Hierarchical regression analyses were used to investigate the effect of reinvestment on Response Time during Deceptive and Non-Deceptive trials (both occluded at -100ms). No significant models were identified (*p*'s > 0.05).

4. Discussion

The current study was designed to improve understanding about anticipation of deceptive and non-deceptive movements, with particular emphasis on skill level differences and propensity for reinvestment. To investigate this, expert, intermediate and novice rugby players anticipated deceptive and non-deceptive changes of direction, viewed through a VR headset. We believe the study undertaken has improved the understanding of anticipation, especially in relation to skill level and reinvestment.

With regards to skill level differences, experts were significantly more accurate than novices during deceptive and non-deceptive trials, consistent with previous research (Cañal-Bruland & Schmidt, 2009; Abernethy, Jackson, & Wang, 2010; Cañal-Bruland, et al., 2010). Throughout the analysis, intermediates' Response Accuracy or Response Time were not significantly different to the other skill levels. The superiority of experts, compared to novices, could be due to greater experience of perceiving and performing such actions (Cañal-Bruland et al., 2010), which allows them to more effectively comprehend the underlying kinematics that indicate movement outcome, thus, reducing erroneous judgements. Runeson and Frykholm (1983) showed that even when a person attempts to move deceptively, kinematics that indicate movement outcome remain present.

Consistent with previous research, accuracy when anticipating both deceptive and non-deceptive changes of direction was highest when trials were occluded later. Consequently, experts were more accurate that novices at all occlusion points - even before reliable information was available (-100ms and 0ms). Previous studies have found that the expert advantage persists in picking up information from early kinematics (i.e., before reliable information is presented) that specifies the outcome of an action (Jackson et al., 2006; Aglioti et al., 2008; Abernethy, Zawi, & Jackson, 2008). Experts in the current study were also shown to take significantly longer to respond than novices in both deceptive and non-deceptive trials. This is consistent with Brault et al. (2012), who concluded that waiting longer allowed experts to pick up more information about final running direction. These findings suggest that through experience experts develop a speed-accuracy trade off that allows them to make an accurate judgement before the decision making threshold (the point when a decision must be made – Johnson, 2006).

In the present study, novice, intermediate and expert players were found to make significantly more erroneous judgements on deceptive compared to non-deceptive side-steps. This differs from Jackson et al's (2006) finding that less skilled participants were more susceptible to deceptive movements. However, experts' Response Accuracy in the current investigation was a mere 2.25% higher in non-deceptive than deceptive trials - compared to 7.5% and 11.75% for intermediates and novices, respectively. A further finding was that regardless of skill level participants took significantly longer to respond during non-deceptive trials. This may show a learning effect. In non-deceptive trials, participants may have waited to see if the player would change direction (as in deceptive trials) or continue in the primary direction (as in non-deceptive trials). The current study used single side-steps for deceptive trials (i.e., step to the left before changing direction to the right) as opposed to double side-steps (i.e., step to the left, step to the right then finally change direction to the left as per Mori & Shimada, 2013). Therefore, once participants saw the player change direction in deceptive trials they could be fairly sure that this was the final running direction.

The second line of inquiry in the current study asked whether higher reinvestment scores lead to slower and/or less accurate decisions during deceptive and non-deceptive side-steps. Contrary to our hypothesis, DSRS scores seemed to play no part in speed or accuracy of anticipation in either deceptive or non-deceptive trials. This differs from findings such as Jackson et al’s (2013), where DSRS scores were found to be a significant predictor of poorer passing under pressure in netball. However, the results observed may be due to the low complexity of the task (i.e., the viewed player could only run to the left or right). In Kinrade et al’s (2015) basketball study, performance decrements were associated with DSRS scores in the high complexity (4 choice) condition, but not the low complexity (2 choice) condition. This suggests that decision specific reinvestment may only have a deleterious effect on high-complexity decisions.

MSRS scores were shown to predict poorer accuracy during deceptive trials (occluded at -100ms) when skill level was controlled for. High reinvestors, who are more aware of the opponent’s movement patterns may focus too much on the superficial cues that are presented during the deceptive movement (e.g., the initial shift towards the unintended final direction; gaze direction etc) and fail to distinguish the underlying kinematics. It is also possible that the high reinvestors responses are more likely to suffer performance decrements because of the psychological refractory period (Schmidt & Wrisberg, 2008), during which the second stimulus (underlying kinematics of the actual running destination) cannot be processed until the deceptive kinematics have been fully processed (most likely in a conscious and more timely manner). This is a novel finding in the literature to date and warrants further consideration to understand the underlying mechanisms.

A limitation of the current study was that verbal responses rather than movement responses were used to measure response accuracy and time. Participants were encouraged to couple these responses with a physical response; however, a more sophisticated method, similar to Brault et al (2012), may be desirable. Brault et al (2012) attached external markers over body joints to compute the participant’s centre of mass, which were compared to the opponent’s movements at various time points (e.g., initiation of deceptive signals). This would allow researchers to assess the effect of reinvestment throughout the decision making process - not just the final decision, as in the current study. Future studies should also implement a range of side-step types (i.e., single and double). With regard to the fidelity of the stimuli, participants rated these as 7.83 out of 10, suggesting that the stimuli were realistic within the VR environment - providing a promising methodology for future studies in areas such as immersive learning or skill acquisition.

5. Conclusion

Side-steps are a common deceptive tactic used by attacking players to deceive a defender. Our results suggested that expert rugby players were significantly more accurate than novices when anticipating deceptive and non-deceptive changes of direction. Experts also took significantly longer to respond than novices. To date, the propensity for reinvestment has not been investigated with regards to anticipation of deceptive movements. MSRS (Conscious Motor Processing) scores were associated with poorer response accuracy during deceptive trials. A propensity to consciously process one’s movements may disrupt the processes individuals use to understand an opponent’s kinematics (by comparing them to their own movement technique). The current investigation uncovers some novel findings that future research should seek to clarify while examining the underlying mechanisms.

Conflict of Interest

The authors declare no conflict of interest.

References

Abernethy, B., Jackson, R. C., & Wang, C. (2010). The perception of deception: the role of kinematic and other information in detecting deceptive intent within movements. *Journal of Sport and Exercise Psychology, 32*, S56.

Abernethy, B., Zawi, K., & Jackson, R. C. (2008). Expertise and attunement to kinematic constraints. *Perception, 37*(6), 931-948.

Aglioti, S. M., Cesari, P., Romani, M., & Urgesi, C. (2008). Action anticipation and motor resonance in elite basketball players. *Nature Neuroscience*, *11*(9), 1109-1116.

Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: What governs choking under pressure? *Journal of Experimental Psychology: General, 130*(4), 701-725.

Bideau, B., Kulpa, R., Vignais, N., Brault, S., Multon, F., & Craig, C. (2010). Using virtual reality to analyze sports performance. *IEEE Computer Graphics and Applications, 30*(2), 14-21.

Brault, S., Bideau, B., Kulpa, R., & Craig, C. M. (2012). Detecting deception in movement: the case of the side-step in rugby. *PLoS One, 7*(6), e37494.

Cañal-Bruland, R., & Schmidt, M. (2009). Response bias in judging deceptive movements. *Acta Psychologica, 130*(3), 235-240.

Cañal-Bruland, R., van der Kamp, J., & van Kesteren, J. (2010). An examination of motor and perceptual contributions to the recognition of deception from others’ actions. *Human Movement Science, 29*(1), 94-102.

Chang, B. F., & Yang, C. C. (2011). A study of the accuracy of anticipated tennis serve placement and cognitive reaction time. In: Lim C. T., & Goh J. C. H. (Eds.) 6th World Congress of Biomechanics, Singapore, 31 (1), 274-277.

Dicks, M., Button, C., & Davids, K. (2010). Availability of advance visual information constrains association-football goalkeeping performance during penalty kicks. *Perception, 39*(8), 1111-1124.

Farrow, D., Abernethy, B., & Jackson, R. C. (2005). Probing expert anticipation with the temporal occlusion paradigm: Experimental investigations of some methodological issues. *Motor Control, 9*(3), 330-349.

Güldenpenning, I., Kunde, W., & Weigelt, M. (2017). How to trick your opponent: A review article on deceptive actions in interactive sports. *Frontiers in Psychology, 8*, 917.

Howarth, C., Walsh, W. D., Abernethy, B., & Snyder, C. W. (1984). A field examination of anticipation in squash: Some preliminary data. *Australian Journal of Science and Medicine in Sport*, *16*(3), 7-11.

Jackson, R. C., Kinrade, N. P., Hicks, T., & Wills, R. (2013). Individual propensity for reinvestment: Field-based evidence for the predictive validity of three scales. *International Journal of Sport Psychology*, *44*(4), 331-350.

Jackson, R. C., Warren, S., & Abernethy, B. (2006). Anticipation skill and susceptibility to deceptive movement. *Acta Psychologica*, *123*(3), 355-371.

Kinrade, N. P., Jackson, R. C., & Ashford, K. J. (2015). Reinvestment, task complexity and decision making under pressure in basketball. *Psychology of Sport and Exercise*, *20*, 11-19.

Kinrade, N. P., Jackson, R. C., Ashford, K. J., & Bishop, D. T. (2010). Development and validation of the decision-specific reinvestment scale. *Journal of Sports Sciences, 28*(10), 1127-1135.

Law, J., Masters, R., Bray, S. R., Eves, F., & Bardswell, I. (2003). Motor performance as a function of audience affability and metaknowledge. *Journal of Sport and Exercise Psychology*, *25*(4), 484-500.

Liao, C. M., & Masters, R. S. (2001). Analogy learning: A means to implicit motor learning. *Journal of Sports Sciences, 19*(5), 307-319.

Loffing, F., & Cañal-Bruland, R. (2017). Anticipation in sport. *Current Opinion in Psychology*, *16*, 6-11.

Masters, R. S. W. (1992). Knowledge, knerves and know-how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology, 83*(3), 343-358.

Masters, R. S. W., Eves, F. F., & Maxwell, J. P. (2005). Development of a movement specific reinvestment scale. In: Morris T., Terry P., Gordon S., Hanrahan S., Ievleva L., Kolt G., et al (Eds.) Proceedings of the International Society of Sport Psychology (ISSP) 11th World Congress of Psychology. Sydney, Australia.

Masters, R. S. W., & Maxwell, J. (2008). The theory of reinvestment. *International Review of Sport and Exercise Psychology, 1*(2), 160-183.

Mori, S., & Shimada, T. (2013). Expert anticipation from deceptive action. *Attention, Perception, & Psychophysics*, *75*(4), 751-770.

Rizzolatti, G., & Luppino, G. (2001). The cortical motor system. *Neuron, 31*(6), 889-901.

Runeson, S., & Frykholm, G. (1983). Kinematic specification of dynamics as an informational basis for person-and-action perception: expectation, gender recognition, and deceptive intention. *Journal of Experimental Psychology: General, 112*(4), 585-615.

Schücker, L., Ebbing, L., & Hagemann, N. (2010). Learning by analogies: Implications for performance and attentional processes under pressure. *Human Movement*, *11*(2), 191-199.

Schmidt, R. A., & Wrisberg, C. A. (2008). Motor learning and performance: A situation-based learning approach. Champaign: Human Kinetics.

Singer, R. N., Cauraugh, J. H., Chen, D., Steinberg, G. M., & Frehlich, S. G. (1996). Visual search, anticipation, and reactive comparisons between highly-skilled and beginning tennis players. *Journal of Applied Sport Psychology*, *8*(1), 9-26.

Smeeton, N. J., Williams, A. M., Hodges, N. J., & Ward, P. (2005). The relative effectiveness of explicit instruction, guided-discovery and discovery learning techniques in enhancing perceptual skill in sport. *Journal of Experimental Psychology: Applied, 11*(2), 98-110.

Stinson, C., & Bowman, D. A. (2014). Feasibility of training athletes for high-pressure situations using virtual reality. *IEEE Transactions on Visualization and Computer Graphics, 20*(4), 606-615.

Wheeler, K. W., Askew, C. D., & Sayers, M. G. (2010). Effective attacking strategies in rugby union. *European Journal of Sport Science, 10*(4), 237-242.

Wright, M. J., Bishop, D. T., Jackson, R. C., & Abernethy, B. (2011). Cortical fMRI activation to opponents' body kinematics in sport-related anticipation: expert-novice differences with normal and point-light video. *Neuroscience Letters, 500*(3), 216-221.

SESNZ
SPORT & EXERCISE SCIENCE
NEW ZEALAND

The Journal of Sport and Exercise Science, Vol. 4, Issue 1, 33-39 (2020)

www.sesnz.org.nz

JSES

ISSN: 2703-240X

Effect of a 6-week exercise intervention for improved neck muscle strength in amateur male rugby union players.

Michael J. Hamlin[1 *], Richard Deuchrass[2], Catherine E. Elliot[1], Tilak Raj[1], Donlaya Promkeaw[3], Sirisuda Phonthee[3]

[1]*Department of Tourism, Sport and Society, Lincoln University, New Zealand*
[2]*Recreation Centre, Lincoln University, New Zealand*
[3]*Improvement of Physical Performance and Quality of Life (IPQ) Research Group, Khon Kaen University, Thailand*

ARTICLE INFO

Received: 13.12.2019
Accepted: 31.03.2020
Online: 03.04.2020

Keywords:
Strength Training
MVC
Isotonic
Isometric
Head Injury

ABSTRACT

Neck strengthening for players in impact sports like rugby is receiving greater attention lately due to postulated associations with head and neck injury and concussion and while research is available on the effectiveness of neck strengthening interventions on professional rugby players, the same research has not been conducted on amateurs who make up the majority of rugby players. The aim of this study was to investigate the effectiveness of a 6-week neck strengthening intervention on a group of male amateur rugby union players (20.1 ± 2.0 yr, mean ± SD). In a randomized controlled trial, players worked with their trainer to practice neck-specific strengthening exercises 3 times per week for 6 weeks (strength group, n = 22) or performed no additional neck strengthening exercises (control group, n =17). Isometric maximal voluntary contraction (MVC) was measured pre and post the intervention in 4 different directions (flexion, extension, left and right lateral flexion). Compared to the control group the strength group improved neck strength in all directions except flexion (flexion 7.1 ± 13.0 kg, mean ± SD, 75/18/7%, chances of positive/trivial/negative increase in strength, p = 0.28; extension 13.5 ± 14.6 kg, 92/7/1%, p = 0.07; left lateral flexion 13.5 ± 11.3 kg, 97/3/0%, p = 0.02; right lateral flexion 13.8 ± 14.9 kg, 92/7/1%, p = 0.07. Our results indicate that a simple 6-week neck strengthening program improves isometric MVC strength in male amateur rugby players.

1. Introduction

Rugby union is a fast moving collision sport that involves relatively short periods of high-intensity sprinting, interspersed with long periods of lower-intensity exercise (walking/jogging) (Jones, West, Crewther, Cook, & Kilduff, 2015). Rugby union also involves a high number of collisions (King, Cummins, Hume, Clark, & Pearce, 2018) which can occur from tackling, scrummaging, rucking, mauling and colliding with the ground or other players. Due to the physical nature of the game, a rugby player's body must be able to sustain considerable stress which results in significant tissue damage (Lindsay et al., 2016) and may result in injury (Quarrie et al., 2001).

The explosive and dynamic characteristics of the game means a rugby player's body is occasionally placed in compromising positions, particularly during the initial physical contact of a tackle, and it's the tackle that is associated with the highest risk of injury (Fuller et al., 2010; McIntosh, McCrory, Finch, & Wolfe, 2010; Quarrie & Hopkins, 2008). Often the neck and shoulders are intricately involved in the tackle situation, and, some researchers have postulated an association between neck strength and reduced injury incidence (Frounfelter, 2008). Moreover, since cervical musculature is the tissue mainly responsible for neck and head stabilization (Panjabi et al., 1998), any fatigue or weakening of neck strength during a rugby game may compromise its supportive role and place the player at an increased risk of neck injury (Collins et al., 2014).

Previous research on civilians (Nikander et al., 2006) and pilots (Äng, Monnier, & Harms-Ringdahl, 2009) has reported a significant reduction in neck pain after a structured exercise program targeting the cervical muscles. This correlation between neck strengthening exercises and reduced neck pain lead to the

*Corresponding Author: Michael J. Hamlin, Department of Tourism, Sport and Society, Lincoln University, New Zealand, mike.hamlin@lincoln.ac.nz

suggestion that specific neck strengthening may help to reduce neck injuries (Salmon et al., 2011), and possibly concussion (Collins et al., 2014). In a cross-sectional study of over 6000 high school students, Collins et al. (2014) reported that overall neck strength was a significant predictor of concussion. More recently, female soccer players with weaker neck strength sustained significantly greater head impacts while heading the soccer ball (Gutierrez, Conte, & Lightbourne, 2014). Similarly, Eckner et al. (2014) showed that athletes with greater neck strength reduced the magnitude of the kinematic response to impulsive loads (Eckner, Oh, Joshi, Richardson, & Ashton-Miller, 2014). However, other researchers using a head and neck model in lab experiments have reported that increased cervical muscle force does not influence short term head kinematics (Eckersley, Nightingale, Luck, & Bass, 2019).

Even though the hypothesized reduced concussive risk with increased neck strength requires more experimental evidence (Toninato et al., 2018), improved neck strength has been associated with reduced neck pain (Nikander, Mälkiä et al. 2006, Äng, Monnier et al. 2009) and injury (Naish, Burnett et al. 2013, Collins, Fletcher et al. 2014). Therefore, neck strength training, particularly in collision sports such as rugby union, may have a positive impact on injury incidence, but very little information exists on the potential to improve neck strength in rugby players. One previous article has indicated the effectiveness of neck strength training in professional rugby union players (Geary, Green, & Delahunt, 2014), however the vast majority of players are non-professional (amateur club rugby) athletes who are generally lighter, weaker (Smart, Hopkins et al. 2013), and have less opportunity to utilize professional strength and conditioning expertise during training compared to professional athletes.

In general, forwards are involved in more physical impacts during a game (Takamori, Hamlin et al. 2020), particularly in the ruck and maul but also during scrums where more stress is exerted on the neck and shoulders. Neck strength is therefore an important fitness component for forwards and most forwards are accustomed to training their neck muscles. Backs on the other hand, are involved in a fewer number of impacts (Takamori, Hamlin et al. 2020), and in our experience, devote less time to training areas such as the neck muscles. Therefore, part of this study was to split the rugby players into forwards and backs to investigate whether the strength training protocol was effective for relatively experienced (forwards) and inexperienced (backs) neck-training groups.

Therefore, this study aimed to investigate the effectiveness of a specific 6-week neck strengthening program on the neck strength of non-elite amateur senior premier level rugby players (both forwards and backs) that may then be utilized by club coaches and strength and conditioning personnel to assist with training and development of these non-elite athletes.

2. Methods

A randomized controlled trial was conducted where neck strength was tested twice (pre and post) to determine the effectiveness of a targeted 6-week neck strengthening program on amateur senior premier rugby players. Isometric neck strength was measured in a seated upright position in the flexion, extension, left lateral flexion and right lateral flexion positions.

2.1. Participants

Thirty-nine players from the Christchurch region in New Zealand participated in this study which was conducted over 6 weeks (Table 1). Players were uninjured young non-professional male rugby union players currently training in a provincial development academy or a university sports scholarship program. Subjects continued with their regular competition-season training during the 6 weeks of the study which included 3 gym sessions, 2 skill sessions, 2 conditioning sessions and 1 competition game per week. All protocols for this study were submitted to and approved by the local University Human Ethics Committee (reference 2019-22). All players were over the age of 18, and informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to voluntarily participate in the study.

Table 1: Physical characteristics of the rugby players in each training group.

	Control (n = 17)	Strength (n = 22)
Age (yr)	20.5 ± 2.0	19.9 ± 2.0
Height (cm)	181.0 ± 7.6	183.5 ± 5.3
Weight (kg)	91.0 ± 17.6	97.6 ± 12.4
Lean body mass (kg)	73.4 ± 9.2	75.3 ± 14.4
Body fat (%)	18.1 ± 8.6	19.3 ± 5.4
Neck girth (cm)	40.7 ± 3.2	42.4 ± 2.3
Neck length (cm)	7.8 ± 1.9	7.6 ± 1.2
Forwards/backs (n)	9/8	13/8
Playing history (yr)	12.8 ± 3.4	12.4 ± 3.9

Data are mean ± SD except for the number of forwards and backs in each group.

2.2. Strength Testing

Participants were given a familiarization session on testing equipment and protocols approximately 1 week prior to the baseline testing. Players were instructed not to change their diet throughout the study. Players were instructed to present themselves for testing in a rested and hydrated state, having avoided heavy exercise and the consumption of alcohol in the preceding 24 hours, and having avoided consuming a heavy meal and caffeinated beverages in the preceding 2 hours.

Testing for each subject was completed at approximately the same time of day (± 1 hour) at the research lab located close to where the athletes train. Prior to the baseline test, the player's height was measured to the nearest 0.1 cm with shoes and socks removed using a portable stadiometer (Seca 213, Hamburg, Germany). Bioelectrical impedance analysis (Accuniq, BC380, Korea) was performed to assess participants lean body mass, body fat percentages and total body mass. Participants were asked to void their bladders prior to measurement to minimize measurement error. Neck girth was taken superior to the thyroid cartilage with the head in the Frankfort plane. The measurement was taken while the participants were seated by having the Lufkin steel tape held perpendicular to the long axis of the neck and recording to the nearest 0.2 mm (Norton et al., 1996). Neck length was measured using a sliding steel bone caliper from the spinous process of the vertebral prominence (C7) to the occipital notch at the base of the skull, while the head was in the Frankfort plane (Olivier & Du Toit, 2008). The same examiner recorded the average of 2 girth and length measurements.

To ensure consistency, players were required to complete a standardized warm-up procedure which consisted of 3 sets of 10 reps of shoulder elevations and depressions, shoulder circumduction, shoulder protractions and retractions, and neck half circles in each direction. After the warm-up isometric neck strength was measured using a commercially available head harness (Neck Flex, USA) attached to a load cell (10Hz, Tesion/S-beam load cell, AST 500, PT Instruments, UK) fixed to an immovable squat rack set-up (Figure 1). During the test, participants sat on an incline bench press chair with their back upright and arms folded across their chest. Participants were held in place by 2 Velcro straps around the upper and lower torso to avoid movement of the torso and lower body, thereby isolating the neck muscles during testing. The head harness was fitted to each participant so that the lower border of the harness was aligned with the eyebrow line (Figure 1) and that the starting position was at a neutral position where the head was aligned with the torso and spine (Strimpakos, Sakellari, Gioftsos, & Oldham, 2004). For each test, participants were asked to perform an isometric maximal voluntary contraction (MVC) in flexion, extension, left lateral flexion and right lateral flexion positions. To avoid ballistic movements, participants were asked to first take the strain, and then over a 2-3 second period gradually increase the force to maximal exertion to be held for 3 seconds. Verbal encouragement was provided for each MVC (3 trials in each of the 4 head positions) and a 60-second rest period was given between each trial (Salmon, Handcock, Sullivan, Rehrer, & Niven, 2015). The peak force (kg) was recorded during the 3-second MVC.

Figure 1: Experimental set up for testing players isometric MVC in a) flexion, b) extension, and c) right lateral flexion.

2.3. Strength Training

The 22 players in the strength group undertook a 6-week neck strengthening program performed three times per week under the guidance and advice of a strength and conditioning coach. Players completed four exercises each day including; weighted head harness isotonic extension, weighted isometric flexion and weighted head harness isotonic lateral flexion left and right (Figure 2). In the weighted head harness exercises, the head harness was adjusted for the height of the player then players completed 3 sets of 10 reps (week 1-2), 8 reps (weeks 3-4) and 6 reps (weeks 5-6). For the isometric flexion exercises players completed 2 reps of 40s (week 1), 2 reps of 30s (week 2), 2 reps of 20s (week 3), 3 reps of 15s (week 4), 3 reps of 10s (week 5) and 4 reps of 5s (week 6). Due to the unique nature of this training we calculated training load via the resistance training specific rating of perceived exertion (Zourdos et al., 2016), where players adjusted the load lifted according to a 10-point Likert scale where 1-2 is little or no effort and 10 is maximal effort (Helms, Cronin, Storey, & Zourdos, 2016). The load was therefore adjusted to give a perceived rating of 8 in set 1, 9 in set 2 and 9-10 in the last set.

Figure 2: Exercises used in the neck strengthening intervention program. a, b) weighted head harness isotonic extension, c) weighted isometric flexion, d, e) weighted head harness isotonic lateral flexion (right and left).

2.4. Statistical Analysis

Changes in the peak measurement from the 3 trials (highest force generated from all 3 trials) and standard deviations representing the between-and within-subject variability were estimated using a mixed modelling procedure (Proc Mixed) in the Statistical Analysis System (Version 9.3, SAS Institute, Cary, North Carolina, USA). The differences in peak isometric MVC were compared between groups and Cohen's value of 0.2 of the between-subject standard deviation was used to assess the smallest worthwhile change (Cohen, 1988). Results are displayed as mean ± SD or raw change ± 95% confidence interval. All data were assessed using the clinical inference, which is more conservative regarding the risk of harm (Batterham & Hopkins, 2006). In this regard, an odds ratio of benefit:harm was only accepted if it was above 66%; if not, the effect was considered "unclear". The magnitude of the change was reported using the following scale <0.5% = most unlikely; 0.5–5% = very unlikely; 5–25% = Unlikely; 25–75% = possibly; 75–95% = likely, 95–99.5% = very likely, >99.5% = most likely (Hopkins, Marshall, Batterham, & Hanin, 2009). P-values are also given for the between-group comparisons for those who use traditional hypothesis testing. We used an alpha level of $p \leq 0.05$ for significance in this study and calculated the effect size statistics (ES) from the change in the mean between groups divided by the between subject SD. The best measure of reliability is the standard error of the estimate (also known as the typical error of the estimate) (Smith & Hopkins, 2012) which is reported along with the intraclass correlation coefficients (ICCs) for the MVC values from the 3 trails for each of the 4 directions. A Pearson correlation was also conducted to investigate the association between key dependent variables.

3. Results

There were no substantial differences between the control and strength groups at baseline for any of the measured characteristics (Table 1). Separating the players into broad playing categories, we found at baseline that forwards had a substantially higher total body mass, lean body mass, percent body fat and neck girth compared to backs (Table 2).

Table 2: Physical Characteristics of the forwards compared to the backs.

	Forwards (n = 23)	Backs (n = 16)	Between Group Difference (± 95% CL)	Between Group Effect Size
Age (yr)	20.4 ± 1.9	19.8 ± 2.0	-0.6 (1.3)	0.3
Height (cm)	183.6 ± 5.9	180.7 ± 7.0	-2.9 (4.1)	0.4
Weight (kg)	102.4 ± 13.0	83.8 ± 10.6	-18.5 (8.9)*^	1.2
Lean body mass (kg)	78.7 ± 6.3	68.4 ± 16.1	-10.3 (7.5)*^	0.8
Body fat (%)	22.2 ± 6.6	13.8 ± 3.6	-8.4 (4.1)*^	1.2
Neck girth (cm)	42.8 ± 2.4	40.1 ± 2.6	-2.7 (1.6)*^	1.0
Neck length (cm)	7.8 ± 1.8	7.5 ± 0.9	-0.3 (0.9)	0.2
Flex (kg)	59.7 ± 15.3	56.3 ± 11.9	-3.3 (9.5)	0.2
Ext (kg)	67.8 ± 15.4	62.9 ± 15.9	-4.9 (10.8)	0.3
LeftFlex (kg)	58.7 ± 12.4	55.8 ± 16.5	-2.9 (8.7)	0.2
RightFlex (kg)	58.7 ± 15.5	62.9 ± 19.3	4.2 (11.0)	0.2

Data are mean ± SD of each group with the difference between groups given as the mean ± 95% confidence interval and the effect size of this difference. Flex, flexion; Ext, extension; LeftFlex, left lateral flexion; RightFlex, right lateral flexion
*Statistical significance ($p < 0.05$); ^Clinically substantial change between groups.

Neck strength over the course of the 6-week period changed little in the control group, however neck strength in all directions except flexion showed clear increases in the strength training group after the 6-week training period (Table 3). Compared to the control group, neck strength was likely or very likely to be increased in the strength group post training except in flexion (flexion 7.1 ± 13.0, mean ± SD, 75/18/7%, chances of positive/trivial/negative increase in strength, $p = 0.28$; extension 13.5 ± 14.6, 92/7/1%, $p = 0.07$; left lateral flexion 13.5 ± 11.3, 97/3/0%, $p = 0.02$; right lateral flexion 13.8 ± 14.9, 92/7/1%, $p = 0.07$). Players undertaking neck strength training improved regardless of whether they were forwards or backs with no statistically significant or clinically relevant differences between groups (Table 4). The coefficient of variation indicating the reliability of the MVC measurements over the 3 trials at baseline was 8.4% (flexion), 11.1% (extension), 10.5% (left lateral flexion) and 10.4% (right lateral flexion). Similarly the ICC ranged from 0.92 (right lateral flexion) to 0.86 (flexion), suggesting reasonable reliability in the measurement.

4. Discussion

This randomized controlled experiment aimed to determine whether the implementation of a 6-week neck strengthening program was effective at improving the isometric strength of amateur rugby union players. The main finding was a clinically worthwhile increase in isometric strength in three of the four movement directions (extension, left and right lateral flexion). While other researchers have investigated the effectiveness of neck strengthening programs on elite rugby players (Geary et al., 2014; Naish, Burnett, Burrows, Andrews, & Appleby, 2013), helicopter pilots (Äng et al., 2009; Salmon et al., 2013), and office workers (Nikander et al., 2006), as far as we know, this is the first to report the effects of such training on non-elite amateur senior premier level rugby players. This is an important finding as the vast majority of rugby players are amateurs and therefore these athletes should expect to gain similar results if they follow the training program outlined in this study.

Overall, compared to the control group the players that completed the 6-week neck strengthening program in this study improved their isometric neck strength by approximately 12-24% which equates to a moderate to large effect size (Table 3). Such strength changes are similar to increases reported by Geary et al. (2013) on professional rugby union players after 5-weeks of isometric training (17-21%), but are in contrast to the findings of Naish et al. (2013) who found small (1-4%) and not statistically significant changes in neck strength on similar players after 13 weeks of isometric neck strength training. It may be argued that professional rugby players are well-conditioned athletes and that a ceiling effect may be responsible for the differences in results (Naish et al., 2013). However, this seems unlikely since the average isometric MVC from all 4 neck directions was lower in Naish et al. (2013) (~ 346N), compared to Geary et al. (2013) (~ 517N) participants. While both the Naish et al. and Geary et al. studies employed isometric training, the way in which the isometric load was established was slightly different; the Geary study had participants exert force to resist a manual resistance supplied by the strength and conditioning coach (e.g. the coaches hand was placed on the head and the participant was required to "prevent" the coach from moving the head), while the Naish et al. study had participants exert force by pulling on an immoveable object. Therefore, in the Naish et al. study participants would have been exerting purely isometric force, whereas depending on the amount of movement in the manual resistance, the participants in the Geary et al. study may be exerting eccentric, concentric or isometric force. Slight differences in the way the force was generated in the muscle, along with differences in total load (Geary et al. 3 sets x 10 s holds twice per week and Naish et al. 2-3 sets x 4-12 reps 2-3 sessions per week) may account for differences in neck strength adaptation in these studies.

It is interesting to note that the only non-significant improvement in neck strength in this study (flexion) was also the only exercise that used isometric training, whereas the exercises for the other 3 directions (extension, left and right lateral flexion) used isotonic exercises. The addition of the isometric training in the program in this study was to increase the time under tension of the players and thereby increase hypertrophy and strength adaptation. In hindsight, we speculate that the time under tension in the isometric exercise was probably too long at the start of training (2 sets of 40 s and 30 s in weeks 1 and 2 respectively), which was combined with a relatively light resistance (7.1 ± 2.5% and 10.8 ± 4.0%, mean ± SD of baseline MVC in week 1 and 2 respectively). Such prolonged and relatively light resistance training would allow the muscle to follow the hierarchical order of fibre activation with Type I (slow twitch) muscle fibres being predominantly activated at this intensity (Beltman et al., 2004), which may explain the lack of strength improvement in the flexion direction.

Table 3: Maximal isometric strength change in the rugby players before (pre) and after (post) 6 weeks of neck strength training.

	Control Group			Strength Group				
	Pre (n = 17)	Post (n =17)	Control Group Pre-Post Change (± 95% CL)	Pre (n = 22)	Post (n = 22)	Strength Group Pre-Post Change (± 95% CL)	Between Group Pre-Post Change (± 95% CL) and Clinical Inference	Between Group Effect Size
Flex (kg)	54.9 ± 7.7	54.3 ± 10.9	-0.6 (9.9)	60.8 ± 16.8	67.2 ± 15.7	6.4 (8.4)	7.1 (13.0) unclear	0.57
Ext (kg)	65.9 ± 8.8	63.1 ± 10.8	-2.9 (8.1)	65.9 ± 19.1	76.5 ± 18.1	10.6 (8.9)*	13.5 (14.6)^ likely increased	0.81
LeftFlex (kg)	62.8 ± 10.6	59.2 ± 11.1	-3.6 (8.9)	54.3 ± 14.9	64.2 ± 10.9	9.9 (7.4)*	13.5 (11.3)*^ very likely increased	1.21
RightFlex (kg)	64.4 ± 12.1	60.5 ± 11.8	-3.9 (11.4)	57.6 ± 19.1	67.5 ± 17.1	9.8 (9.4)*	13.8 (14.9)^ Likely increased	0.90

Data are mean ± SD of each group with the difference between groups given as the mean ± 95% confidence interval along with the effect size of between group difference. Flex, flexion; Ext, extension; LeftFlex, left lateral flexion; RightFlex, right lateral flexion
*Statistical significance ($p < 0.05$); ^Clinically substantial change between groups.

Table 4: Maximal isometric strength change in the Forward and Back positions before (pre) and after (post) 6 weeks of neck strength training

	Pre			Post			
	Forward (n = 14)	Back (n = 8)	Between Group Difference (± 95% CL) and Clinical Inference	Forward (n = 14)	Back (n = 8)	Between Group Difference (± 95% CL) and Clinical Inference	Pre-Post Between Group Difference (± 95% CL) and Clinical Inference
Flex (kg)	61.8 ± 18.9	58.9 ± 13.3	-2.9 (12.2) unclear	69.9 ± 17.4	62.8 ± 12.2	-7.2 (12.4) unclear	-4.4 (17.5) unclear
Ext (kg)	67.6 ± 18.7	62.9 ± 20.7	-4.6 (13.8) unclear	80.9 ± 18.2	69.2 ± 16.5	-11.7 (14.0) likely decreased	-7.1 (19.8) unclear
LeftFlex (kg)	56.4 ± 12.5	50.7 ± 18.7	-5.7 (10.9) unclear	64.7 ± 11.4	63.5 ± 10.9	-1.2 (10.5) unclear	-4.4 (15.4) unclear
RightFlex (kg)	55.7 ± 17.4	60.9 ± 22.5	-5.2 (14.1) unclear	70.0 ± 16.6	63.4 ± 18.1	-6.6 (14.3) unclear	-11.9 (20.2) unclear

Data are mean ± SD of each group with the difference between groups given as the mean ± 95% confidence interval. Flex, flexion; Ext, extension; LeftFlex, left lateral flexion; RightFlex, right lateral flexion
*Statistical significance ($p < 0.05$); ^Clinically substantial change between groups.

While the effect of neck strengthening exercises on concussion in sportspeople is controversial (Collins et al., 2014; Eckersley et al., 2019), the effect of such training on reduction in neck pain and injury is more consistent. Training the cervical muscles and deep neck flexors has a beneficial effect on the incidence of neck pain (Äng et al., 2009) and injury (Salmon et al., 2011). Moreover, in a retrospective analysis of professional rugby union players, Naish et al. (2013) reported a significant decrease in the number of match-related cervical spine injuries after a 26-week neck strengthening program. Furthermore, a neck strengthening program, similar to that described in this study, has been found to be effective at reducing neck injuries in rugby players (Hrysomallis, 2016). It is well known that tackling in rugby union is responsible for the most injuries sustained by players (Williams, Trewartha, Kemp, & Stokes, 2013), and that head placement is an important factor in these injuries (Tucker et al., 2017). If improved neck strength helps to reduce the load during impacts (Eckner et al., 2014), or helps to stabilize other muscles (O'Leary, Falla, Hodges, Jull, & Vicenzino, 2007) we speculate that less injury may occur in the head and neck area. However, this theory would need to be corroborated with longitudinal injury statistics before recommendations on the effect of neck strength training on injury could be made.

The substantially higher neck girths in forwards compared to backs (Table 2) is likely to be due to the higher body mass since body mass was moderately correlated to neck girth ($r = 0.69$). Apart from body mass (and the accompanying body fat and lean body mass) forwards were similar to backs in terms of strength (Table 2) and their adaptation to the neck strength training program. The similarity in response between players indicates that such a program should benefit all players (forwards and backs) equally.

A limitation of the study was low subject numbers which minimized the ability to identify the effect of neck strength training on the various rugby player positions. We were able to look at the overall differences between backs and forwards, barring a larger and more varied sample, we cannot be certain of the effects on specific playing positions (e.g. fullback versus a prop). It is also important to note that the training completed in this study only looked at neck muscles contributing to force production in two planes of movement (frontal and sagittal) and that training muscles which contribute to all neck movement may produce different results.

5. Conclusion

If increasing the neck strength in rugby players is a training goal we would recommend a training program similar to that described in this study. However, we would caution against the use of isometric training for neck strength improvement unless training loads can be adequately measured and adjusted.

Conflict of Interest

The authors declare no conflict of interests.

Acknowledgment

The authors thank the rugby players and their coaches for their assistance.

References

Äng, B. O., Monnier, A., & Harms-Ringdahl, K. (2009). Neck/shoulder exercise for neck pain in air force helicopter pilots: a randomized controlled trial. *Spine*, *34*(16), E544-E551.

Batterham, A. M., & Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. *International Journal of Sports Physiology and Performance*, *1*(1), 50-57.

Beltman, J., De Haan, A., Haan, H., Gerrits, H., Van Mechelen, W., & Sargeant, A. (2004). Metabolically assessed muscle fibre recruitment in brief isometric contractions at different intensities. *European Journal of Applied Physiology*, *92*(4-5), 485-492.

Cohen, J. (1988). Statistical power for the behavioural sciences. Hilsdale. In: NJ: Lawrence Erlbaum.

Collins, C. L., Fletcher, E. N., Fields, S. K., Kluchurosky, L., Rohrkemper, M. K., Comstock, R. D., & Cantu, R. C. (2014). Neck strength: a protective factor reducing risk for concussion in high school sports. *The Journal of Primary Prevention*, *35*(5), 309-319.

Eckersley, C. P., Nightingale, R. W., Luck, J. F., & Bass, C. R. (2019). The role of cervical muscles in mitigating concussion. *Journal of Science and Medicine in Sport*, *22*(6), 667-671.

Eckner, J. T., Oh, Y. K., Joshi, M. S., Richardson, J. K., & Ashton-Miller, J. A. (2014). Effect of neck muscle strength and anticipatory cervical muscle activation on the kinematic response of the head to impulsive loads. *American Journal of Sports Medicine*, *42*(3), 566-576.

Frounfelter, G. (2008). Selected exercises for strengthening the cervical spine in adolescent rugby participants. *Strength and Conditioning Journal*, *30*(3), 23-28.

Fuller, C. W., Ashton, T., Brooks, J. H., Cancea, R. J., Hall, J., & Kemp, S. P. (2010). Injury risks associated with tackling in rugby union. *British Journal of Sports Medicine*, *44*, 159-167.

Geary, K., Green, B. S., & Delahunt, E. (2014). Effects of neck strength training on isometric neck strength in rugby union players. *Clinical Journal of Sports Medicine*, *24*(6), 502-508.

Gutierrez, G. M., Conte, C., & Lightbourne, K. (2014). The relationship between impact force, neck strength, and neurocognitive performance in soccer heading in adolescent females. *Pediatric Exercise Science*, *26*(1), 33-40.

Helms, E. R., Cronin, J., Storey, A., & Zourdos, M. C. (2016). Application of the repetitions in reserve-based rating of perceived exertion scale for resistance training. *Strength and Conditioning Journal*, *38*(4), 42-49.

Hopkins, W., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3-12.

Hrysomallis, C. (2016). Neck muscular strength, training, performance and sport injury risk: a review. *Sports Medicine*, *46*(8), 1111-1124.

Jones, M. R., West, D. J., Crewther, B. T., Cook, C. J., & Kilduff, L. P. (2015). Quantifying positional and temporal movement patterns in professional rugby union using global positioning system. *European Journal of Sport Science*, *15*(6), 488-496.

King, D., Cummins, C., Hume, P. A., Clark, T. N., & Pearce, A. J. (2018). Physical demands of amateur senior domestic rugby union players over one round of competition matches in New Zealand assessed using heart rate and movement analysis. *International Journal of Sports Science and Medicine*, *2*(3), 066-071.

Lindsay, A., Healy, J., Mills, W., Lewis, J., Gill, N., Draper, N., & Gieseg, S. (2016). Impact‐induced muscle damage and urinary pterins in professional rugby: 7, 8‐dihydroneopterin oxidation by myoglobin. *Scandinavian Journal of Medicine and Science in Sports*, *26*(3), 329-337.

McIntosh, A. S., McCrory, P., Finch, C. F., & Wolfe, R. (2010). Head, face and neck injury in youth rugby: incidence and risk factors. *British Journal of Sports Medicine*, *44*(3), 188-193.

Naish, R., Burnett, A., Burrows, S., Andrews, W., & Appleby, B. (2013). Can a specific neck strengthening program decrease cervical spine injuries in a men's professional rugby union team? A retrospective analysis. *Journal of Sports Science and Medicine*, *12*(3), 542.

Nikander, R., Mälkiä, E., Parkkari, J., Heinonen, A., Starck, H., & Ylinen, J. (2006). Dose-response relationship of specific training to reduce chronic neck pain and disability. *Medicine and Science in Sports and Exercise*, *38*(12), 2068-2074.

Norton, K., Whittingham, N., Carter, L., Kerr, D., Gore, C., & Marfell-Jones, M. (1996). Measurement techniques in anthropometry. *Anthropometrica*, *1*, 25-75.

O'Leary, S., Falla, D., Hodges, P. W., Jull, G., & Vicenzino, B. (2007). Specific therapeutic exercise of the neck induces immediate local hypoalgesia. *The Journal of Pain*, *8*(11), 832-839.

Olivier, P. E., & Du Toit, D. E. (2008). Isokinetic neck strength profile of senior elite rugby union players. *Journal of Science and Medicine in Sport*, *11*(2), 96-105.

Panjabi, M. M., Cholewicki, J., Nibu, K., Grauer, J., Babat, L. B., & Dvorak, J. (1998). Critical load of the human cervical spine: an in vitro experimental study. *Clinical Biomechanics*, *13*(1), 11-17.

Quarrie, K. L., Alsop, J. C., Waller, A. E., Bird, Y. N., Marshall, S. W., & Chalmers, D. J. (2001). The New Zealand rugby injury and performance project. VI. A prospective cohort study of risk factors for injury in rugby union football. *British Journal of Sports Medicine*, *35*(3), 157-166.

Quarrie, K. L., & Hopkins, W. G. (2008). Tackle injuries in professional rugby union. *American Journal of Sports Medicine*, *36*(9), 1705-1716.

Rigg, P., & Reilly, T. (1987). A fitness profile and anthropometric analysis of first and second class rugby union players. In T. Reilly, A. Lees, K. Davids, & W. J. Murphy (Eds.), Science and football: proceedings of the first world congress of science and football (pp. 194-200). New York: E and F N Spoon.

Salmon, D., Harrison, M., Sharpe, D., Candow, D., Albert, W., & Neary, J. (2011). The effect of neck muscle exercise training on self-reported pain in CH-146 Griffon helicopter aircrew. In A. B. Aiken, SA. (Ed.), Shaping the future: military and veteran health research (pp. 79-105): Kingston, ON: Canadian Defence Academy Press.

Salmon, D. M., Handcock, P. J., Sullivan, S. J., Rehrer, N. J., & Niven, B. E. (2015). Reliability of repeated isometric neck strength and endurance testing in a simulated contact posture. *Journal of Strength and Conditioning Research*, *29*(3), 637-646.

Salmon, D. M., Harrison, M. F., Sharpe, D., Candow, D., Albert, W. J., & Neary, J. P. (2013). Exercise therapy for improved neck muscle function in helicopter aircrew. *Aviation Space and Environmental Medicine*, *84*(10), 1046-1054.

Smart, D. J., W. G. Hopkins and N. D. Gill (2013). "Differences and changes in the physical characteristics of professional and amateur rugby union players." *Journal of Strength and Conditioning Research*, *27*(11), 3033-3044.

Smith, T. B., & Hopkins, W. G. (2012). Measures of rowing performance. *Sports Medicine*, *42*(4), 343-358.

Strimpakos, N., Sakellari, V., Gioftsos, G., & Oldham, J. (2004). Intratester and intertester reliability of neck isometric dynamometry. *Archives of Physical Medicine and Rehabilitation*, *85*(8), 1309-1316.

Takamori, S., M. Hamlin, D. Kieser, D. King, P. Hume, T. Yamazaki, M. Hachiya and P. Olsen (2020). Senior club-level rugby union player's positional movement performance using individualized velocity thresholds and accelerometer-derived impacts in matches. *Journal of Strength and Conditioning Research*. DOI:10.1519/JSC.0000000000003523.

Toninato, J., Casey, H., Uppal, M., Abdallah, T., Bergman, T., Eckner, J., & Samadani, U. (2018). Traumatic brain injury reduction in athletes by neck strengthening (TRAIN). *Contemporary Clinical Trials Communications*, *11*, 102-106.

Tucker, R., Raftery, M., Kemp, S., Brown, J., Fuller, G., Hester, B., Quarrie, K. (2017). Risk factors for head injury events in professional rugby union: a video analysis of 464 head injury events to inform proposed injury prevention strategies. *British Journal of Sports Medicine*, *51*(15), 1152-1157.

Williams, S., Trewartha, G., Kemp, S., & Stokes, K. (2013). A meta-analysis of injuries in senior men's professional Rugby Union. *Sports Medicine*, *43*(10), 1043-1055.

Zourdos, M. C., Klemp, A., Dolan, C., Quiles, J. M., Schau, K. A., Jo, E., Merino, S. G. (2016). Novel resistance training–specific rating of perceived exertion scale measuring repetitions in reserve. *Journal of Strength and Conditioning Research*, *30*(1), 267-275.

SESNZ
SPORT & EXERCISE SCIENCE
NEW ZEALAND

The Journal of Sport and Exercise Science, Vol. 3, Issue 2, 30-35 (2019)

www.sesnz.org.nz

JSES

ISSN: 2703-240X

Performance characteristics of a winning polo team

Russell Best[1, 2 *], Regan Standing[1]

[1]*Centre for Sports Science & Human Performance, Waikato Institute of Technology, New Zealand*
[2]*School of Health and Life Sciences, Teesside University, Middlesbrough, United Kingdom*

ARTICLE INFO

Received: 15.08.2018
Accepted: 24.09.2018
Online: 04.12.2019

Keywords:
Polo
Quantitative analysis
Team sport
Equestrian
Correlation

ABSTRACT

Polo is played globally, and is contested by two teams of four players on horseback. Despite popularity, there is little academic literature assessing Polo players, and what constitutes successful Polo performance. One reason for this may be Polo's unique player rating system, the handicap, which quantifies individuals and teams' level of play. We sought to characterise the play of a tournament winning high-goal polo team (KPF) using percent and raw differences between teams using a customised matrix, which was designed with input from international polo players. Secondly, we assessed the association between player handicap and success rates of key performance metrics. KPF won five of seven games played, with forehand middle (FHM) being the least variable shot (-4 to 5% success rate), whereas long backhand shots were the most variable (-50 to 45% success rate). Fewer turnovers were conceded than the opposition in all games won, and in four out of the five winning games, more penalties were awarded to KPF than their opponents. At an individual level, FHM was significantly correlated to player handicap ($r = 0.562$, Large: $p < 0.05$). Player handicap was also moderately correlated with backhand middle ($r = 0.330$), backhand long ($r = 0.361$), and ride off ($r = 0.362$) success rates. Turnovers and penalties awarded confer clear attacking and goal-scoring opportunities. FHM, backhand shots and ability to contest for the ball (ride off) are key performance metrics, positively associated with player handicap, and higher handicap players demonstrate greater success rates and or less variability than those with lower handicaps. However, variability within players of the same handicap is evident, suggesting subjectivity of the handicapping system.

1. Introduction

Polo is an equestrian based sport played by two teams of four players, on a pitch measuring 270m by 150m. Each player is mounted on horseback and must play right-handed to encourage safety during open play, and when contesting for the right to play a shot, termed 'riding off'. Games are divided into seven-minute periods of play called chukkas; the number of chukkas played depends on the level of play. These naturally occurring breaks between chukkas, or breaks within match play, are often used by riders to change horses. The Hurlingham Polo Association (HPA) regulations state that a horse is not allowed to play in excess of two non-consecutive full chukkas per game or 15 minutes in total, per day (HPA, 2017). Players are assigned handicaps (-2 to +10 Goals), the cumulative total of which depicts the level of play for a tournament (HPA, 2017). Handicap is based on the number of goals the player is worth to the team, with aspects such as horsemanship, playing skills (individual and team), technique, and the quality of horses being considered (*Polo Handicap: The system explanation*, 2017; HPA, 2017). The area specific Polo association to which the player is registered assigns Player handicap (*Polo Handicap: The system explanation*, 2017).

Britain is largely credited for codifying and expanding the game (*History of Polo*, 2018) through the Hurlingham Club and HPA. However, Argentina is now considered the global hub of Polo, producing the largest number of 10-goal players and hosting three annual high goal tournaments.

Academic literature on Polo players is limited to four papers discussing injury prevalence of play (Clark *et al.*, 2002; Costa-Paz *et al.*, 1999; Innes & Morgan, 2015; Milne, 2011), one editorial (Butwin, 1981), two interviews (Sharma, 2015; Vali, 2009), and one psychological case study of a High Goal player (Chroni, 2011). To contextualise this paucity of literature, there are numerous articles published on conditions pertaining to, and

*Corresponding Author: Russell Best, Centre for Sports Science & Human Performance, Waikato Institute of Technology, New Zealand, Russell.Best@wintec.ac.nz

performance of Polo horses (Chanda *et al.*, 2017; da Silva *et al.*, 2017; Martin & Allen, 1999; Pfau *et al.*, 2016), which indicates their relative importance within the sport. Whilst these equine outputs are valuable, given the longevity, history and international presence of the game further research into Polo play and Polo players is warranted. This paper aims to quantify the performance of the winning team of a United Kingdom High Goal tournament (KPF), played under HPA rules. A secondary aim of this paper is to identify key performance metrics and correlate these with players' handicaps.

2. Methods

A quantitative analysis of actions performed during play (Table 1) was conducted across a U.K. High Goal (22-Goal) Polo tournament, tracking the performance characteristics of the tournament winning team (KPF), handicapped at 22 goals. This matrix was designed with input from international polo players. Footage was obtained from an online streaming website (Pololine, 2017). Players' actions were tallied and classified as either successful or unsuccessful: success was defined as maintenance of possession (by the rider or a member of the rider's team), or an action that led to a goal being scored. An unsuccessful action was recorded if possession was lost, a penalty conceded or the ball went out of play. The successful completion of an action by a player may also tally an unsuccessful completion from another player. Cumulative data for each game was tallied. Success rates for each action were calculated by dividing the number of successful attempts by the total number of attempts performed (successful + unsuccessful). Differences in success rates between teams were calculated as either percent or raw differences.

Success rates were then correlated against player handicap using the non-parametric Spearman's rank order correlation coefficient within SPSS software (Version 22, IBM, Armonk, NY); accompanying descriptors are included to report the magnitude of correlations (Hopkins *et al.*, 2009). In the instance that variables return a 0:0 input (successful:unsuccessful), these data points are removed to allow correlations to be calculated. This is less biased than providing a value of either 0 or 1, as technically no data point exists for that action, for that player.

Intra and inter-rater reliability were calculated for this analysis using intraclass correlation coefficient (ICC). Inter-rater reliability was obtained via a two-way mixed ICC, where all games were analysed twice by both researchers. Intra-rater reliability was assessed; games were randomly assigned via random number generator and reliability was calculated by one-way random ICC. Calculations were performed using SPSS software (Version 22, IBM, Armonk, NY) with accompanying qualitative descriptors (Hopkins *et al.*, 2009).

3. Results

KPF won five of the seven games played, with both losses occurring in the group stages (Games 2 and 4; Table 2). Table 2 depicts KPF's percentage and raw differences when compared to the opposition. Small percentage differences were observed between teams for FHM (-4% to 5%); whereas all other shots displayed greater variability, with BHL being most variable (-50% to 45%). Raw differences show fewer turnovers were conceded than the opposition in all games won. Further, in four out of the five games that were won more penalties were awarded to KPF, than their opposition. Further interpretation of the findings can be found within the discussion.

Spearman's rank order correlations between player handicap and success rate ranged from *Trivial* to *Large,* with only one variable (FHM) returning a significant finding ($r = 0.562$, *Large*: $p < 0.05$). Specifically, moderate correlations were returned for BHM ($r = 0.330$), BHL ($r = 0.361$), and RO ($r = 0.362$). Small correlations were observed for Dribble ($r = 0.136$), PEN ($r = 0.165$), and FHL ($r = 0.243$), with TUO only trivially correlated to player handicap ($r = -0.022$).

Table 1: Actions performed by High Goal Polo players

Action	Definition
Dribble	Possession maintained ≤2 horse lengths and two or more consecutive contacts with the ball
Forehand Middle (FHM)	>2 & ≤10 horse lengths – player elbow flexing
Forehand Long (FHL)	>10 horse lengths – player elbow flexing
Backhand Middle (BHM)	>2 ≤10 horse lengths – player elbow extending
Backhand Long (BHL)	>10 horse lengths – player elbow extending
Penalty Long (PL)	An attacking penalty taken 60 yards from the goal
Penalty Short (PS)	An attacking penalty taken 40 or 30 yards from the goal
Penalty Conceded (PC)	As action
Turnover (TUO)	Possession change following a shot or Ride Off
Ride off (RO)	Fair contest for the ball between two players, in line with the last shot hit
Melee	Coming together of two or more horses from each team

Note: The successful completion of an action by a player may also tally an unsuccessful completion from another player.

Table 2: Comparison of actions performed by KPF and opposing teams.

Action	Game 1	Game 2	Game 3	Game 4	Game 5	Game 6	Game 7
Dribble	-6	-22	1	21	1	-2	20
FHM	0	-3	-2	-4	-3	5	5
FHL	-7	17	-12	-8	16	4	9
BHM	16	-13	-17	1	-14	18	-3
BHL	34	-25	-50	-10	45	-4	12
PL*	0	-1	2	0	1	1	3
PS*	0	0	3	0	0	1	0
PC*	1	-2	7	0	0	2	2
TUO*	-4	4	5	0	-1	-6	-9
RO	9	-14	-27	16	26	8	-11
Melee*	0	3	1	5	-8	-1	-4

Note: Values are expressed as percentages unless asterisked (*), in which case they are expressed as raw differences

Individual player success rates with respect to handicap are reported for variables which produced large (FHM) and moderate (BHM, BHL, RO) correlations, which are reported in Figure 1, panels A,B,C and D, respectively. Across the tournament players with higher handicaps tend to produce greater success rates and/or display less variability (SD) than lower handicapped players.

Inter-rater reliability across all variables ranged from *Small* (0.23) to *Nearly Perfect* (0.94), with a mean reliability of 0.71 (±0.08; *Very Large*) between researchers. Intra-rater reliability demonstrates similar levels of reliability, ranging from *Small* (0.29) to *Nearly Perfect* (0.94). Investigator one had a mean ICC of 0.69 (±0.16; *Large*), with investigator two displaying similar vales of 0.72 (±0.16; *Very Large*). Both inter and intra-rater reliability coefficients are reported in Table 3.

Table 3: Inter and Intra-rater reliability of performance metrics across 7 game High Goal Polo tournament

Action	Outcome	Inter-rater ICC	Intra-rater ICC	
			Researcher 1	Researcher 2
Dribble	Successful	0.87	0.89	0.79
	Unsuccessful	0.63	0.68	0.53
FHM	Successful	0.94	0.80	0.91
	Unsuccessful	0.60	0.54	0.62
FHL	Successful	0.83	0.65	0.93
	Unsuccessful	0.70	0.81	0.94
BHM	Successful	0.81	0.71	0.74
	Unsuccessful	0.51	0.59	0.52
BHL	Successful	0.36	0.31	0.82
	Unsuccessful	0.44	0.55	0.77
PL*	Successful	0.23	0.74	0.91
	Unsuccessful	0.80	0.73	0.57
PS*	Successful	0.85	0.87	0.90
	Unsuccessful	1	NM	0.78
PC*	Awarded	0.75	0.86	0.55
	Conceded	0.87	0.78	0.79
TUO*	Received	0.85	0.74	0.70
	Conceded	0.84	0.82	0.70
RO	Successful	0.51	0.55	0.54
	Unsuccessful	0.47	0.29	0.34
Melee*	Successful	0.87	0.80	0.80
	Unsuccessful	0.87	0.80	0.80

Note: ICC values are interpreted to the following magnitudes: *Trivial* <0.1 *Small* 0.1-0.29 *Moderate* 0.30 to 0.49 *Large* 0.50 to 0.69 *Very Large* 0.70 to 0.89 *Extremely Large* ≥0.90. An asterisk (*) indicates that these actions are assessed as raw values not percentage outcomes. NM: No measure.

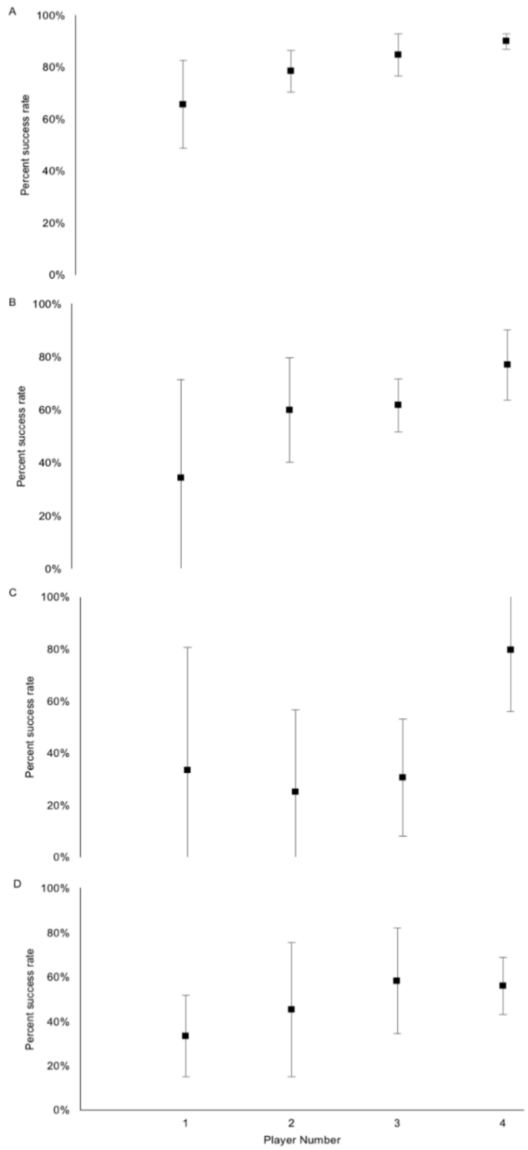

Figure 1: Percent success rates per player, for Forehand Middle (A), Backhand Middle (B), Backhand Long (C) and Ride offs (D). Values are expressed as mean percent success rate ± standard deviations.

4. Discussion

This is the first paper to quantify Polo performance. Our primary aim was to quantify the performance of the winning team of U.K. Polo tournament; we have done so by calculating percentage and raw differences between the tournament winning team (KPF) and their opposition across the tournament duration for key performance metrics (Table 2), using footage obtained from an online platform (Pololine, 2017). We have shown this method of quantification to be largely reliable within and between researchers. A secondary aim of the paper was to correlate key performance metrics against player handicap, in effect scrutinising the success rates and variability of individual players for those actions most associated to handicap (Figure 1).

The assignment of the Polo handicap is not an exact science, as it is made up of numerous qualitative factors and is awarded by differing regional bodies (Anonymous, 2017). Based upon the apparently subjective nature of the handicap, players assigned the same handicap (goals) may display differences within key performance characteristics when assessed quantitatively. This is evident within our data (Figure 1), with Players 1 and 2, and 3 and 4 possessing the same equal handicaps of 1 and 10 goals respectively. Players 3 and 4 typically display higher success rates and less variability across key performance metrics, in comparison to players 1 and 2. Despite their parity in both being '10-goalers', differences still arise between these players with Player 3 being either more variable (Figure 1 panels A and D) or less successful (Figure 1 panels B and C) than Player 4. Player 4 is currently considered to be one of the best players in the world (Anonymous, 2017); this is supported by our data due to the high success rates and relatively low variability across the seven game tournament. More specifically in one of the most frequently utilised shots (FHM), Player 4 demonstrates a 90% success rate, with only 3% variability (Figure 1 Panel A). This trend is consistent in Players 1 and 2 who also share the same handicap (1 goal): Player 2 has either a higher success rate (Figure 1 panels A, B and D) and or lower variability (Figure 1 panels A, B and C) than Player 1. These differences are more marked than those between Players 3 and 4, suggesting that Player 2 may be under-handicapped, according to our analysis. We acknowledge that the players in the present analysis are from polar ends of the handicap spectrum, in order to draw definitive conclusions with respect to the relationship between success rate and accompanying variability to player handicap, players with handicaps ranging from 2-9 goals need to be included in future analyses.

In reference to the primary aim of the study, despite only respectively *Trivial* and *Small* correlations to individual handicap, turnovers and penalties awarded are apparent key performance metrics. In all five of the games won the winning team conceded fewer turnovers than their opponents, suggesting a superior ability to obtain and maintain possession. Similarly, in four out of five games won more penalties were awarded. In tandem conceding fewer turnovers and obtaining more penalties affords clear attacking and goal-scoring opportunities over the opposition.

Conversely, ride offs appear to show little agreement with match outcome at a team level (Table 2), despite ride off success rate being moderately correlated with individual handicap. An improvement in ride off success rates at the team level would directly influence the number of turnovers obtained by the team, hereby presenting further attacking and goal-scoring opportunities, as suggested above. Ride offs also take place off the ball, however were not quantified in this analysis due to inconsistencies in film and the attacking focus of the footage obtained. Recording of footage that was capable of tracking all players' actions would allow quantification of such potentially important actions. Melees are similarly inconsistent with regards to aligning with match outcome, this could be attributed to the inherent decrease in likelihood of retaining possession when multiple players from both teams contest for the ball. The large playing area and limited player numbers further complicate this; committing players to a melee may in fact expose a team to a counter-attack or increase the likelihood of conceding a penalty.

Backhand shots, irrespective of length, are more variable than all other shots measured, which may be due to the circumstances under which backhands are performed. Researchers observed that this shot tended to be played defensively, often resulting in the ball being cleared and relieving pressure from the opposition; such shots would often result in a turnover despite temporarily alleviating potential goal-scoring opportunities. Adjustment of the matrix to quantify these actions seems intuitive, but is hindered by the fact that researchers could not assess players' intent when playing a shot, regardless of outcome; a matter further complicated by the suggestion that until recently backhand shots were used to facilitate attacking play (B. Kay, personal communications).

As mentioned, forehand shots of 2-10 horse lengths (FHM) are surprisingly consistent between teams, and are significantly correlated with individual player handicap (0.562; *Large*). This suggests a shared importance at the team and individual level for this shot, with the ball hit either to another player or into space at a length where possession can be maintained. As the forehand increases in length (from FHM to FHL), percent success rate becomes more variable (-12% to 17%). There is no apparent trend with match outcome observed for FHL, but the increased variability of this shot in comparison to FHM may point to its serving of differing roles, as proposed for backhand shots.

Dribble success rates presented inconsistent findings when aligned to match outcome. The purpose of a dribble (maintenance of possession within 2 horse lengths) is multi-faceted and may extend to offensive or defensive action, maintaining possession or running down the clock. Our matrix could not account for this variation of intent therefore a more extensive breakdown of the dribble may be required in future studies.

Percentages are commonly employed to identify successful outcomes and performance differences in sports (Atkinson & Nevill, 2001; Hopkins *et al.*, 2009). Whilst convenient and easy to calculate they are descriptive in nature, which may not account for underlying complexities that contribute to their calculation, such as number of shots played or actions performed. This issue could be addressed by adopting a Bayesian statistical approach, which is increasingly recommended within the sport and exercise sciences (Bernards *et al.*, 2017; Mengerson *et al.*, 2016), however, such an in-depth statistical technique was considered beyond the exploratory nature of this work.

As previously mentioned, there is a strong body of research assessing the characteristics of Polo playing horses. We have shown that the match play characteristics of Polo players are variable, which requires support from players' horses to meet the demands of the game (Innes & Morgan, 2015), as behaviours of both player and horse manifest to produce Polo performance (Innes & Morgan, 2015). The individual characteristics of a horse will directly influence a player's ability to achieve the performance metrics outlined in this study, as the horse is the 'vehicle' by which these outcomes are achieved. Horses can be perceived to be a confounding variable, with players required to use multiple horses throughout a game (HPA, 2017). Identification of horses would allow for statistical adjustment within analysis, providing a clearer picture of their contribution to Polo performance.

5. Conclusion

To conclude, turnovers and penalties awarded were shown to be key performance metrics within a tournament winning Polo team, given the attacking and goal-scoring opportunities they confer. It is noted that defensive strategies and play off the ball may also influence team metrics, but these actions were not able to be quantified. Variability within players of the same handicap is apparent, this may be due to the subjectivity of the handicapping system and the dynamic nature of Polo play. Players of a higher handicap demonstrate greater success rates and or less variability than those with lower handicaps. The role of the horse within Polo performance is currently unsubstantiated and warrants investigation.

6. Applications in Sport

We recommend Polo players and teams aim to develop their backhand success rate, whilst conceding fewer penalties than the opposition. This both limits the opposition's time on the ball and increases a team's chances of scoring. The role of melees and ride-offs in the present analysis was unclear as they didn't seem to align with match outcomes. Those players wishing to improve their handicap should start by decreasing the variability and increasing the consistency of their shot play.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgement

We wish to thank Hazel Jackson-Gaona, of El Overo Polo, and Michael Kay of Kihikihi Polo Club for their enthusiasm and support of this research. We would also like to thank Steve Wills for his statistical guidance. No funding was received in the preparation of this manuscript.

References

Atkinson, G., & Nevill, A.M. (2001). Selected issues in the design and analysis of sport performance research. *Journal of Sports Sciences*, *19*, 811-827.

Bernards, J., Sato, K., Haff, G., & Bazyler, C. (2017). Current Research and Statistical Practices in Sport Science and a Need for Change. *Sports*, *5*(4), 87–10.

Butwin, D. (1981). Palm Beach Polo: A socially sporting affair. *The Physician and Sportsmedicine*, *9*(10), 121-123.

Chanda, M., Srikuea, R., Cherdchutam, W., Chairoungdua, A., & Piyachaturawat, P. (2016). Modulating effects of exercise training regimen on skeletal muscle properties in female polo ponies. *BMC Veterinary Research*, *12*(1), 245.

Chroni, S. (2011). A long-term consulting tale in professional polo. *Journal of Excellence*, *3*(15), 60-75.

Clark, R. J., Sizer, P. S., & Slauterbeck, J. (2002). Stress fracture of the ulna in a male competitive Polo player. *The American Journal of Sports Medicine*, *30*(1), 130-132.

da Silva, K. M., Otaka, J. N. P., Gonçalves, C. A. P., Silva, E. G. A., de Alencar, N. X., & Lessa, D. A. B. (2017). Association between exercise-induced pulmonary hemorrhage and inflammatory airway disease in polo ponies. *Journal of Equine Science*, *28*(2), 55-59.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Medicine & Science in Sports & Exercise*, *41*(1), 3-13.

Hurlingham Polo Association. (2017). *Rules and Regulations*. Available at: http://www.hpa-polo.co.uk/rules-regulations/rules-and-regulations/

Innes, C. M., & Morgan, K. L. (2015). Polo pony injuries: player-owner reported risk, perception, mitigation and risk factors. *Equine Veterinary Journal*, *47*(4), 422-427.

Inness, C. M., & Morgan, K. L. (2015). Falls and injuries to polo players: Risk perception, mitigation and risk factors. *Sports Medicine – Open, 1*(1), 1-6.

Marlin, D. J., & Allen, J. C. (1999). Cardiovascular demands of competition on low-goal (non-elite) polo ponies. *Equine Veterinary Journal*, *31*(5), 378-382.

Mengersen, K. L., Drovandi, C. C., Robert, C. P., Pyne, D. B., & Gore, C. J. (2016). Bayesian estimation of small effects in exercise and sports science. *PLoS ONE*, *11*(4): e0147311-23.

Milne, L. W. (2011). Thoracic trauma in polo: two cases and a review of the literature. *The Journal of Emergency Medicine*, *40*(4): 410-414.

Pfau, T., Parkes, R. S., Burden, E. R., Bell, N., Fairhurst, H., & Witte, T. H. (2016). Movement asymmetry in working polo horses. *Equine Veterinary Journal*, *48*(4), 517-522.

Polo Handicap: The system explanation. (2017). Available at: https://argentinapoloday.com.ar/blog/polo-handicap-2/

Pololine. (2017). Available at: https://www.pololine.tv.

Sharma, P. (2015) Pankaj Sharma: Addicted to playing polo. *British Medical Journal*, *351*, h3960.

Vail, J. D. (2009). Polo for all ages: exercise should be functional...and fun! *Journal of Psychosocial Nursing and Mental Health Services*, *47*(5), 24-27.