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Lab and field V̇O2peak testing in highly trained cyclists

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ABSTRACT

The issues with traditional maximal oxygen uptake (V̇O$_{2max}$) testing include an inability to regulate intensity due to fixed resistance and a lack of conscious decision making during the test (Noakes, 2008). Depending on the test and conditions, some athletes do not reach V̇O$_{2max}$ despite reaching volitional exhaustion, and in this case, the result is recorded as the highest, or peak oxygen uptake attained in this test, known as V̇O$_{2peak}$. To investigate this, a study was conducted to determine if a field-based test would result in a higher V̇O$_{2peak}$ value than a lab-based test. Twelve highly trained cyclists performed a 20w/minute ramp test on a cycle ergometer and a 3.2km hill climb on their own racing bike wearing a portable gas analyser (MetaMax 3b, Cortex GmbH, Leipzig, Germany). A paired t-test revealed that the hill climb resulted in a higher but not statistically significant absolute V̇O$_{2peak}$: lab 5.49 ± 0.8 L·min^{-1} vs. field 5.59 ± 0.7 L·min^{-1}, p = .189 and relative V̇O$_{2peak}$: lab 71.9 ± 10.0 ml·kg^{-1}·min^{-1} vs. field 74.0 ± 9.9 ml·kg^{-1}·min^{-1}, p = .060. Additionally, field testing resulted in a significantly higher RER$_{max}$: lab 1.07 ± 0.0 vs. field 1.16 ± 0.1, p = .019, end lactate: lab 9.24 ± 1.6 mmol·L^{-1} vs. field 11.99 ± 2.3 mmol·L^{-1}, p = .039, and 5-minute-post lactate: lab 7.56 ± 1.4 mmol·L^{-1} vs. field 11.87 ± 2.0 mmol·L^{-1}, p < 0.001. There was no difference in HR$_{max}$ between tests: lab 187.9 ± 11.6 b·min^{-1} vs. field 187.6 ± 10.6 b·min^{-1}, p = .952. Slightly higher V̇O$_{2peak}$ values recorded during the field test may be explained by the closed-loop format allowing riders to pace their effort better, the cooling effect of the wind outdoors, freedom to ride out-the-saddle (leading to greater muscle recruitment), or perhaps the sub-optimal length of the lab test 20.4 ± 3.0 mins vs 8.4 ± 1.2 mins field test. Findings suggest the increased ecological validity of field testing led to higher (but not statistically significant) V̇O$_{2peak}$ values and can be considered a viable alternative to lab-based testing if a climb with suitable length and gradient is available.

1. Introduction

Maximal oxygen uptake (V̇O$_{2max)}$ is viewed as the gold standard measure for cardiorespiratory fitness (Williams *et al*., 2017), aerobic endurance (Bassett & Howley, 2000), and forms a key predictor of overall performance in endurance sports (McLaughlin *et al*., 2010).

Traditional V̇O$_{2max}$ testing consists of an incremental increase in exercise intensity (Poole *et al*., 2008) until the participant reaches volitional exhaustion. This increase may be in the form of a constant ramp or longer steps of 2-5 minutes, which allow participants to reach a steady state of O_2 consumption. Tests are usually designed to last around 8-12 minutes as longer tests were found to result in lower V̇O$_{2max}$ values in trained males (Yoon *et al*., 2007). This is likely due to premature local muscular fatigue before the maximum capacity of the cardiovascular system is reached (Buchfuhrer *et al*., 1983; Yoon *et al*., 2007).

Noakes (2008) describes further issues with the V̇O$_{2max}$ testing process that affect the ecological validity and outcome; as the athlete is not aware of the endpoint, there is an open-loop scenario which leads to an inability to regulate intensity.

The fixed and progressive method of increasing pedalling resistance is unlike anything experienced while cycling outdoors, limiting the role of decision-making and conscious pacing control during the test. All an athlete is able to decide is when to terminate the test: maximum volitional exhaustion.

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Recent studies have attempted to follow Noakes (2008) suggestions for a maximal test, which considers the role of the brain in exercise; for example, using rate of perceived exertion (RPE). RPE-clamped protocols that use a fixed length test of 10 minutes have been used. These are made up of 5x2-minute stages in which participants were instructed to target a specific incremental RPE value (11, 13, 15, 17, 20, Borg 6-20). This protocol was found to result in significantly higher $\dot{V}O_{2max}$ values than a traditional step test in untrained participants (RPE 40 ± 10 $ml \cdot kg^{-1} \cdot min^{-1}$ vs Ramp 37 ± 8 $ml \cdot kg^{-1} \cdot min^{-1}$) (Mauger & Sculthorpe, 2012). In contrast, the same protocol in trained cyclists did not result in a significant difference (Ramp 3.86 ± 0.73 $L \cdot min^{-1}$ vs 3.87 ± 0.72 $L \cdot min^{-1}$ in the RPE-clamped) (Straub *et al*., 2014). It is notable, however, that trained cyclists did significantly better on the test format they favoured. Participants were divided between those who preferred not having to consciously regulate the intensity and those who preferred control over their pacing.

While RPE-clamped protocols improve ecological validity, as they allow conscious intensity regulation, this is still limited as ergometer cycling is biomechanically and physiologically different to riding outdoors due to differences in inertial load and muscle activation patterns (Fregly, Zajac & Dairaghi, 2000; Bertucci, Grappe & Groslambert, 2007). Outdoor cycling can feature greater total muscle activation when riding out the saddle (Ryschon & Stray-Gundersen, 1991; Hansen & Waldeland, 2008), and a cooling effect from the wind (Brito *et al*., 2017). Additionally, a known endpoint of exercise allows conscious control of pacing, which Noakes (2008) suggests may lead to greater motivation and ability to push harder; e.g. when athletes are capable of a final sprint to the line after a hard race.

Meyer *et al*. (2003) conducted a study in trained runners comparing a treadmill-based ramp protocol with an identical protocol performed on a running track (paced by a light system). While this protocol increased ecological validity by taking runners off the treadmill, and perhaps increasing the role of conscious pacing by asking them to match their running speed to light cues, the participants were not self-paced to the same extent as those in Mauger and Sculthorpe (2012) and Straub *et al*. (2014) were. The results found no significant difference in $\dot{V}O_{2max}$ between tests (lab 4.65 ± 0.51 $L \cdot min^{-1}$, field 4.63 ± 0.55 $L \cdot min^{-1}$, $p = .71$). HR_{max} was reported as significantly higher in the field (lab 188 ± 6 $b \cdot min^{-1}$, field 189 ± 6 $b \cdot min^{-1}$, $p = .02$). Finally, test duration was significantly longer in the field (lab 691 ± 39 seconds, field 727 ± 42 seconds, $p < .001$). This 5% increase in test duration, and therefore performance, was put down to greater running economy on the track leading to lower $\dot{V}O_2$ throughout.

Ricci and Leger (1983) performed a study examining the difference in $\dot{V}O_{2max}$ between cyclists riding on an ergometer, on a velodrome and on a treadmill. This study has several limitations, such as the type of participants (7 male, 1 female), the age of the participants (13-40 years), as well as the equipment and method for calculating $\dot{V}O_{2max}$ used (backwards extrapolation), especially during the velodrome test. In comparison, Meyer *et al*. (2003) used a MetaMax portable, breath-by-breath gas analyser. Ricci and Leger (1983) found a significantly higher $\dot{V}O_{2max}$ during ergometer testing compared to both treadmill and velodrome tests (ergometer 62.4 ± 8.2 $ml \cdot kg^{-1} \cdot min^{-1}$, treadmill 54.7 ± 6.3 $ml \cdot kg^{-1} \cdot min^{-1}$, velodrome 53.0 ± 7.8 $ml \cdot kg^{-1} \cdot min^{-1}$). Ricci and Leger (1983) struggled to explain the ~15% higher $\dot{V}O_{2max}$ during the ergometer test, but suggested cadence, fibre recruitment or mechanical efficiency may play a role.

While Bassett and Howley (2000) define $\dot{V}O_{2max}$ as the maximum amount of O_2 that can be taken in and utilised by the body during severe exercise, it is difficult to ascertain whether the value achieved during a test truly represents an athlete's $\dot{V}O_{2max}$. Hill and Lupton (1923) noted that past a certain running pace O_2 consumption ceased to rise with the increased workload. This plateau, defined by BASES (1997) as an increase of < 150 $ml \cdot min^{-1}$ or 2 $ml \cdot kg^{-1} \cdot min^{-1}$ is often used to signify that an athlete has reached $\dot{V}O_{2max}$, although studies have found that this phenomenon can appear in 0-100% of tests (Midgley & Carroll, 2009) and at as low as 61% (Midgley *et al*., 2009) and 73% (Poole *et al*., 2008) of $\dot{V}O_{2max}$. Because of this, secondary criteria are used to help determine $\dot{V}O_{2max}$ attainment. BASES (1997) use 5-minute-post blood lactate (BLac) ≥ 8.0 $mmol \cdot L^{-1}$, heart rate (HR) ≥ 10 beats of age predicted max (220-age), respiratory exchange ratio (RER) ≥ 1.15, along with subjective fatigue and volitional exhaustion. Other studies may be less strict with lower values of RPE ≥ 17-19 or RER ≥ 1.05-1.1 permitted, which may be influenced by the mode of exercise.

Some criteria have been found to be achieved at a submaximal workloads, for example RER ≥ 1.1 can be satisfied 27% below $\dot{V}O_{2max}$ and ≥ 1.15 at 16% below $\dot{V}O_{2max}$. (Poole, Wilkerson & Jones, 2008). While other criteria may be too rigorous for participants to achieve, as Poole *et al*. (2008) found that heart rate ≥ 10 $b \cdot min^{-1}$ of age predicted max led to the rejection of 3/8 participants' tests and BLac ≥ 8.0 $mmol \cdot L$ rejected 6/8 participants tests. Due to these uncertainties in determining $\dot{V}O_{2max}$ attainment, we prefer the term $\dot{V}O_{2peak}$ and report the highest, repeated values participants reached over a 30 second period.

Due to the issues described with traditional laboratory-based testing, we sought to determine if a real-life cycling event with (approximately) the optimal length and intensity of a $\dot{V}O_{2peak}$ test would be comparable to that of a traditional lab-based test. The course was chosen specifically because it hosts an annual hill climb race (our route was extended slightly, from 2.5km to 3.23km, to result in a duration of 8-12 minutes) (Buchfuhrer *et al*., 1983; Yoon *et al*., 2007), and featured a gradient that got progressively steeper towards the summit, with the intention of forcing an increase in participants' power output similar to a lab test.

It was hypothesised that due to the greater conscious control of pacing, closed-loop format with a known endpoint, and greater muscle recruitment (Ryschon & Stray-Gundersen, 1991, Hansen & Waldeland, 2008), $\dot{V}O_{2peak}$ would be significantly higher in field-based testing than lab based testing; both measured with participants wearing a portable breath-by-breath gas analyser.

2. Methods

2.1. Study design

To test the hypothesis that field testing would lead to a higher $\dot{V}O_{2peak}$ compared to lab testing a randomised, counterbalance study was conducted. Differences in $\dot{V}O_{2peak}$, maximal heart rate (HR_{max}), maximal respiratory exchange ratio (RER_{max}) and peak

BLac concentrations were compared between the lab and field tests.

2.2. Participants

Highly trained, competitive cyclists, with over two years racing experience, from the north east of England were recruited to complete a lab and field test. The study was approved by the Teesside University ethics committee and all participants gave written informed consent prior to testing. 12 participants undertook the lab and field tests. Mean ± SD age 28.4 ± 12 years, height 182.8 ± 7 cm, (lab) mass 76.99 ± 10.9 kg.

2.3. Procedures

Participants were randomly allocated to complete either the lab or field test first. They were instructed to avoid strenuous exercise for 24 hours prior to testing and a minimum of 24 hours was left between tests, which were conducted at the same time of day to minimize diurnal variations in performance. All participants were familiar with the course of the field-based test (hill climb), while half had previously completed a lab-based $\dot{V}O_{2peak}$ test.

2.4. Procedures for lab test

Participants rested for at least 5 minutes before BLac (YSI 2300 Yellow Springs, OH), height (Seca stadiometer, Birmingham, UK) and body mass (Seca 869, Birmingham, UK) were measured before commencing the 20w/min ramp test on a cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands) set up to match their road bike position, using their own pedals and shoes, and wearing bib shorts and either a vest or no top. All testing was completed in a well-ventilated laboratory at a temperature of 20°C. The use of a fan was not permitted to minimise any cooling effect associated with riding outdoors, and as it has been shown that the use of a fan can increase maximal oxygen uptake (Brito *et al*., 2017). Participants were instructed to ride at their normal cadence throughout and the test was terminated when they could not maintain a cadence ≥70 $rev \cdot min^{-1}$. A warm-up was not conducted prior to the lab test as it started from 0 w resistance therefore it was not until 10 minutes into the test that the participants reached 200 w (around the warm-up intensity for the field test).

At the point of failure peak power, HR (Polar H7, Polar Electro Oy, Kempele, Finland) and BLac were recorded, and a further BLac sample after 5 minutes of active recovery (cycling at 100 w) was taken. Breath-by-breath data was analysed using Microsoft Excel (Excel 2016, Microsoft, Redmond, WA, USA) and MetaSoft Studio (Cortex GmbH, Leipzig, Germany) to determine both absolute and relative $\dot{V}O_{2peak}$ and RER.

2.5. Procedures for field test

Body mass and resting BLac (Lactate Pro, Arkray KDK, Japan) were measured prior to participants commencing a standardised 10-minute warm-up at 55-60% of their current, self-reported functional threshold power (FTP). This was conducted using a turbo trainer and participants own bike and power meter, displayed in table 1. Following the warm-up, power meters were calibrated according to the manufacturer's instructions and participants were fitted with the portable gas analyser. The Lactate Pro used for field testing was found to be an accurate measure of BLac (Bonaventura *et al*., 2015). Pyne *et al*. (2000) reported a near-perfect correlation (r = .99) between the Lactate Pro and YSI 2300 (lab test analyser).

Table 1: Power meters used by participants

Power Meter	Number	Measurement Location	Manufacturer claimed accuracy
4iii Precision 2nd gen	1	Left crank	1%
Favero BePro	2	Pedals	2%
Quarq DZero	2	Crank spider	1.5%
Quarq Riken	1	Crank spider	1.5%
Stages Ultegra 2nd gen	1	Left crank	2%
Powertap P1	1	Pedals	1.5%
Rotor INpower	1	Left side, axle based	1%
SRM Dura Ace 9000	1	Crank spider	1%
TeamZwatt Zimanox	1	Left crank	No reported data

*One participant did not have a power meter and bottom bracket compatibility did not allow them to borrow an available left crank-based unit (4iiii Precision).

Participants were instructed to reach the summit of the 3.2 km, 173 m elevation gain, 5% average gradient route (Figure 3) as quickly as possible while recording HR (Polar H7, Polar Electro Oy, Kempele, Finland), power data and time on their personal cycle computer and wearing the portable gas analyser (Cortex MetaMax 3B, Cortex GmbH, Leipzig, Germany) to record expired gasses breath-by-breath. The system weighed 1.4 kg (Mcfarlane & Wong, 2011) and was worn in the same manner as during the lab test. Participants wore bib shorts and a cycling top, used the same shoes and pedals as during the lab test, but were also required to wear a helmet for the field test, which was not worn during lab testing. Environmental conditions stayed relatively stable over the testing period, with temperatures ranging from 15-23°C and with low wind speeds.

A support car followed each participant to monitor the ride and provide protection from upcoming traffic. Upon completion, BLac was sampled immediately afterward and 5 minutes post-test, following active recovery at a self-selected power. Participants power output, HR (Polar H7), speed and time data was downloaded from their cycle computer for analysis.

2.6. Statistical analyses

Field test cycling data were analysed using Training Peaks (Peaksware, Boulder, CO, USA) to determine average and HRmax and average power.

V̇O2peak was determined using Microsoft Excel (2016, Redmond, WA, USA) scatter graph function to determine the highest individual V̇O2 recorded over a 30 second period. This excluded any outlying breaths, and the highest value had to be agreed on by both authors, independent of each other. If there were any discrepancies a third person would be consulted, although this was not required.

SPSS for Windows (V25; IBM, Armonk, NY, USA) was used for a paired *t*-test to determine significant differences and confidence intervals for HRmax, RERmax, end BLac, 5-minutes-post BLac, absolute V̇O2peak, relative V̇O2peak and test duration between lab and field tests. The alpha level of significance was set at $p < 0.05$. 95% Confidence Intervals (C.I.) were calculated using a customised spreadsheet (Hopkins, 2006). Effect Size thresholds for Hedge's G are: 0.2=> small effect, 0.5=> medium effect, and 0.8=> large effect (Cohen, 2013).

3. Results

All twelve participants completed both the lab and field tests.

Field-based testing resulted in a higher value for all variables measured with the exception of HR_{max}, which was less than half a beat per minute higher in the lab, and body mass, which was half a kilo heavier in the lab. Of these results, statistically significant findings were reported for end BLac, 5-minute-post BLac and RER_{max} (Table 2). Despite a field test increase in absolute and relative $\dot{V}O_{2peak}$ of 100 $ml \cdot min^{-1}$ and 2.14 $ml \cdot kg^{-1} \cdot min^{-1}$ respectively, they did not reach statistical significance.

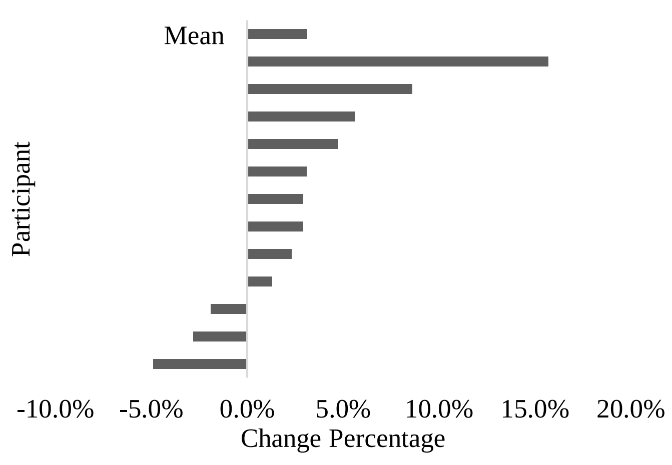

Figure 1: Individual changes in relative $\dot{V}O_{2peak}$ from the lab test to the field test

7/12 participants displayed a greater absolute $\dot{V}O_{2peak}$ in the field. Mean $\dot{V}O_{2peak}$ was 2.33% higher in the field than lab.

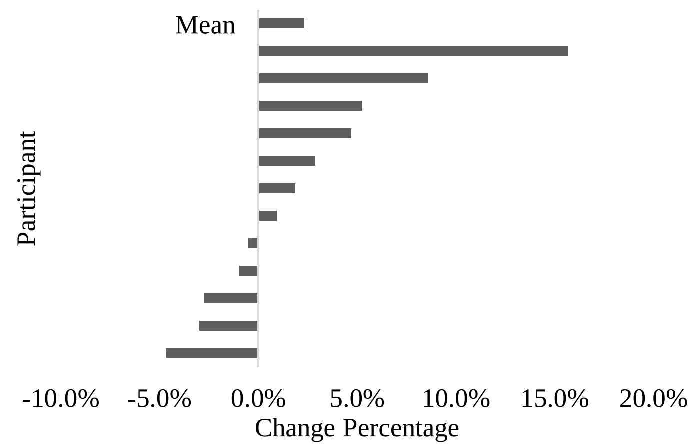

Figure 2: Individual changes in absolute $\dot{V}O_{2peak}$ from the lab test to the field test

Due to lower body mass recorded in the field 76.5 ± 11.7 kg compared to the lab 76.99 ± 10.9 kg, relative $\dot{V}O_{2peak}$ (figure 1) is higher for more participants than absolute $\dot{V}O_{2peak}$ (figure 2). Here 9/12 report a greater field $\dot{V}O_{2peak}$. Mean field $\dot{V}O_{2peak}$ was 3.13% higher than in the lab.

Figure 3 displays participants displayed a high peak power value at the start of the test as they accelerated up to speed. Peak power (1 second) was 774 ± 168 w. Power dropped over the next 500 m as they maintained speed on the flatter parts of the course, as gradient increased power output did too, with the exception of the penultimate 500 m where power output dropped, possibly due to fatigue and an unsustainable pacing strategy. As expected, power output increased over the last 230 m. Average power output sustained during the field test was 393 ± 50 w, which was 89.9% of lab test peak power (422 ± 60 w), defined as the power output achieved at the point of failure.

Figure 4 displays lab test power output, which was fixed at a linear increase of 20 w/minute. The highest peak power output was 503 w, the lowest 328 w and the mean was 422 ± 60 w.

Table 2: Participant results

n=12	Lab Test Mean ± SD	Lab Test 95% CI	Field Test Mean ± SD	Field Test 95% CI	Percentage Difference	Significance	Effect Size (Hedges' G)
Body Mass (kg)	76.99 ± 10.9	67.03 – 85.68	76.48 ± 11.7	65.69 – 85.69	-0.66	.135	0.04
HR_{max} (b·min^{-1})	187.91 ± 11.6	185 – 196.14	187.55 ± 10.6	186.14 – 195.89	-0.19	.952	0.03
End BLac (mmol·L^{-1})	9.24 ± 1.6	8.36 – 10.75	11.99 ± 2.3	11.3 – 13.29	29.76	.039*	1.43
5-Minute-Post BLac (mmol·L^{-1})	7.56 ± 1.4	6.47 – 8.72	11.87 ± 2.0	10.09 – 12.5	57.01	.000*	2.57
RER_{peak}	1.07 ± 0.0	1.04 – 1.09	1.16 ± 0.1	1.10 – 1.28	8.41	.019*	1.22
Absolute $\dot{V}O_{2peak}$ (L·min^{-1})	5.49 ± 0.8	4.87 – 6.04	5.59 ± 0.7	5.08 – 6.04	1.82	.189	0.13
Relative $\dot{V}O_{2peak}$ (ml·kg^{-1}·min^{-1})	71.90 ± 10.0	65.45 – 80.93	74.04 ± 9.9	66.95 – 82.97	2.98	.060	0.21
Test Duration (s)	1266.75 ± 178.8	1156.71 – 1422.43	506.17 ± 69.1	438.6 – 531.71	-60.03	.000*	5.44

* Denotes significant difference ($p < 0.05$)

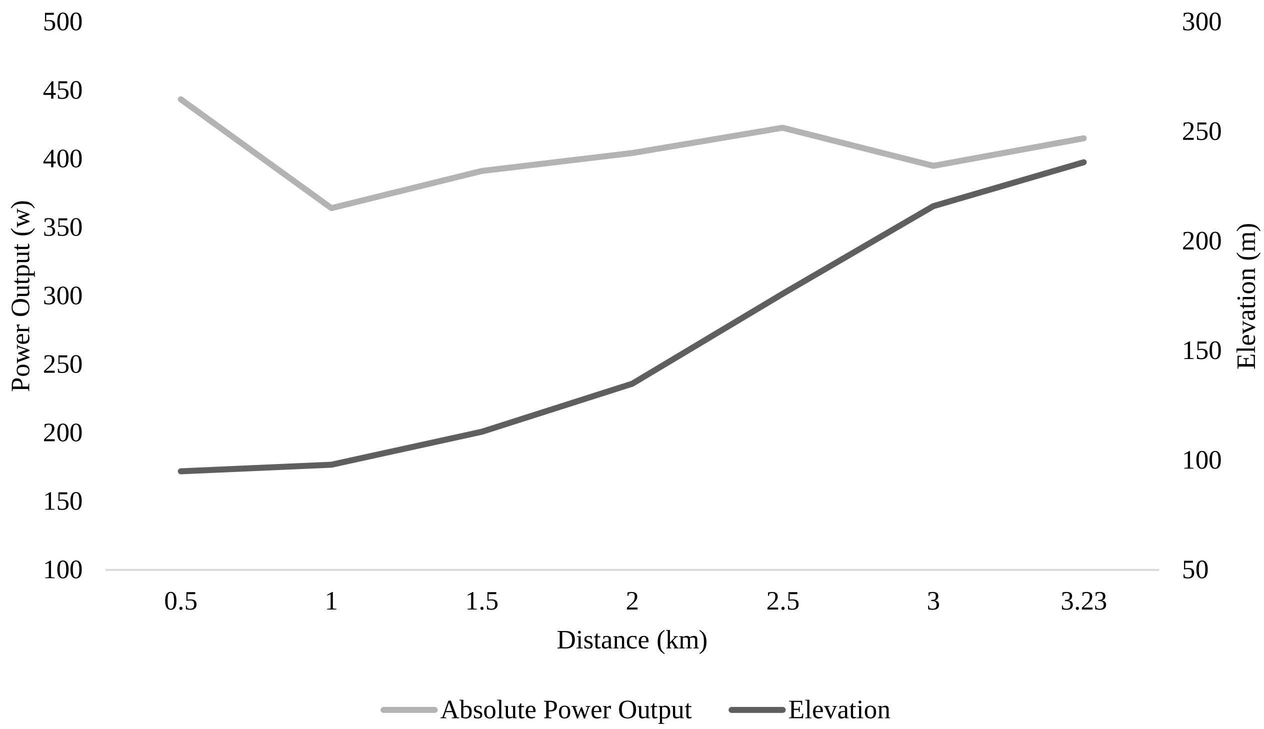

Figure 3: Mean power output in 500 m intervals during the field test

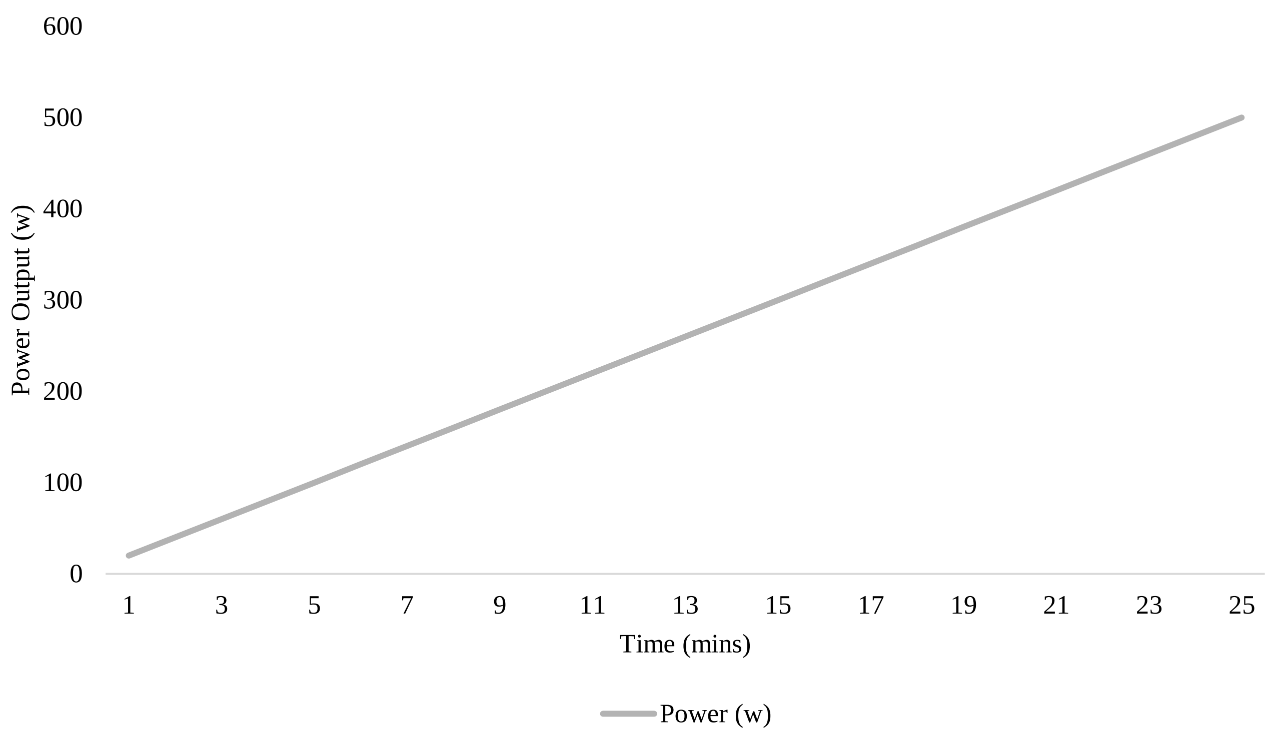

Figure 4: Lab test power output

4. Discussion

The aim of this study was to determine if there was a difference between $\dot{V}O_{2peak}$ measured through a conventional laboratory-based ramp test and a field test over a 3.2 km hill climb. It was hypothesised that the field test would lead to a greater $\dot{V}O_{2peak}$ as it accurately represents the real world, maximal effort cycling conditions the participants are used to. In addition, the field-based test has a set endpoint creating a closed-loop scenario which allows conscious control of pacing, thus increasing ecological validity; something lab-based tests lack (Noakes, 2008).

This study discovered that field-based testing resulted in a higher absolute and relative $\dot{V}O_{2peak}$ compared to the lab test, although this did not reach statistical significance, possibly due to the mixed responses to the field-based testing and the small sample size. This finding is similar to that of Straub *et al.* (2014) who did not find a difference in $\dot{V}O_{2max}$ between traditional $\dot{V}O_{2max}$ testing and a self-paced test in trained cyclists.

To our knowledge, this study was the first to use an actual competitive event of optimal duration to field-test cyclists $\dot{V}O_{2peak}$, free from any prescribed intensity regulation guidelines. A route with increasing gradient throughout was predicted to cause an increase in power output as the test progressed, although power data analysis revealed that all participants displayed steady pacing throughout. Despite the steady intensity, field testing still resulted in a higher (but not statistically significant) $\dot{V}O_{2peak}$.

The cooling effect of wind outdoors may have influenced performance. The ramp test was conducted in an air-conditioned laboratory without a fan for participants. Previous research showed that a 10km·h^{-1} airflow led to a lower $\dot{V}O_2$ at all stages of a maximal test, except for the last stage where maximal oxygen uptake was higher with a fan (Brito *et al*., 2017). This effect may be more significant outdoors, as during this test participants' average speed was 22.6 km·h^{-1}, resulting in increased airflow. Although it is important to point out that Brito *et al.* (2017) used a lower threshold to determine $\dot{V}O_{2max}$ attainment. Only one out of three criteria (O_2 plateau, RER ≥ 1.15 or HR ≥ 10 b·min^{-1} age predicted max) had to be satisfied, which has previously found to be met at an intensity as low as 61% $\dot{V}O_{2max}$ (Midgley *et al*., 2009), reducing the validity of their findings.

Despite this, previous research has found testing methods with higher ecological validity result in a lower $\dot{V}O_{2max}$. This was also the case with Ricci and Leger (1983), who found that a velodrome-based test resulted in a significantly lower $\dot{V}O_{2max}$ compared to cycling treadmill and ergometer tests. They did however not control for cadence, which resulted in significant differences between velodrome and ergometer (100 rev·min^{-1} vs 60 rev·min^{-1}). Moore *et al*. (2008) showed that O_2 consumption at 100 rev·min^{-1} was significantly higher than at 80 rev.min^{-1}. While the opposite effect was shown with Ricci and Leger (1983), it appears cadence causes variations in oxygen consumption. This study allowed participants to ride at a self-selected cadence for both lab and field tests which should have ensured cadence was matched during both tests, although it was not recorded during the lab test. Gearing did not limit participants cadence on this test (88.1 ± 10.5 rev·min^{-1}), although it may be an issue on longer and/or steeper climbs.

Biomechanical differences may explain changes in $\dot{V}O_{2peak}$ between lab and field tests. Cycle ergometers have a lower inertial load compared to road cycling (Fregley *et al*., 2000), which increases the torque production required at the top and bottom of the pedal stroke (Bertucci *et al*., 2007), resulting in a higher RPE and likely changes in muscle activation patterns. This is likened to riding in an extremely strong headwind in a very low gear (Fregley *et al*., 2000). In addition, the field test permitted out-the-saddle cycling, which has been found to result in a significantly higher O_2 consumption than seated pedaling. (Ryschon & Stray-Gunderson, 1991) Maximal oxygen uptake ($\dot{V}O_{2max)}$ is viewed as the gold standard measure for cardiorespiratory fitness (Williams *et al*., 2017), aerobic endurance (Bassett & Howley, 2000), and forms a key predictor of overall performance in endurance sports (McLaughlin *et al*., 2010).

Traditional $\dot{V}O_{2max}$ testing consists of an incremental increase in exercise intensity (Poole *et al*., 2008) until the participant reaches volitional exhaustion. This increase may be in the form of a constant ramp or longer steps of 2-5 minutes, which allow participants to reach a steady state of O_2 consumption. Tests are usually designed to last around 8-12 minutes as longer tests were found to result in lower $\dot{V}O_{2max}$ values in trained males (Yoon *et al*., 2007). This is likely due to premature local muscular fatigue before the maximum capacity of the cardiovascular system is reached (Buchfuhrer *et al*., 1983; Yoon *et al*., 2007).

Noakes (2008) describes further issues with the $\dot{V}O_{2max}$ testing process that affect the ecological validity and outcome; as the athlete is not aware of the endpoint, there is an open-loop scenario which leads to an inability to regulate intensity.

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Recent studies have attempted to follow Noakes (2008) suggestions for a maximal test, which considers the role of the brain in exercise; for example, using rate of perceived exertion (RPE). RPE-clamped protocols that use a fixed length test of 10 minutes have been used. These are made up of 5x2-minute stages in which participants were instructed to target a specific incremental RPE value (11, 13, 15, 17, 20, Borg 6-20). This protocol was found to result in significantly higher $\dot{V}O_{2max}$ values than a traditional step test in untrained participants (RPE 40 ± 10 ml·kg^{-1}·min^{-1} vs Ramp 37 ± 8 ml·kg^{-1}·min^{-1}) (Mauger & Sculthorpe, 2012). In contrast, the same protocol in trained cyclists did not result in a significant difference (Ramp 3.86 ± 0.73 L·min^{-1} vs 3.87 ± 0.72 L·min^{-1} in the RPE-clamped) (Straub *et al*., 2014). It is notable, however, that trained cyclists did significantly better on the test format they favored. Participants were divided between those who preferred not having to consciously regulate the intensity and those who preferred control over their pacing.

While RPE-clamped protocols improve ecological validity, as they allow conscious intensity regulation, this is still limited as ergometer cycling is biomechanically and physiologically different to riding outdoors due to differences in inertial load and muscle activation patterns (Fregly *et al*., 2000; Bertucci *et al*., 2007). Outdoor cycling can feature greater total muscle activation when riding out the saddle (Ryschon & Stray-Gundersen, 1991; Hansen & Waldeland, 2008), and a cooling effect from the wind (Brito *et al*., 2017). Additionally, a known endpoint of exercise allows conscious control of pacing, which Noakes (2008) suggests may lead to greater motivation and ability to push harder;

e.g. when athletes are capable of a final sprint to the line after a hard race.

Meyer *et al*. (2003) conducted a study in trained runners comparing a treadmill-based ramp protocol with an identical protocol performed on a running track (paced by a light system). While this protocol increased ecological validity by taking runners off the treadmill, and perhaps increasing the role of conscious pacing by asking them to match their running speed to light cues, the participants were not self-paced to the same extent as those in Mauger and Sculthorpe (2012) and Straub *et al*. (2014) were. The results found no significant difference in $\dot{V}O_{2max}$ between tests (lab 4.65 ± 0.51 $L·min^{-1}$, field 4.63 ± 0.55 $L·min^{-1}$, $p = .71$). HR_{max} was reported as significantly higher in the field (lab 188 ± 6 $b·min^{-1}$, field 189 ± 6 $b·min^{-1}$, $p = .02$). Finally, test duration was significantly longer in the field (lab 691 ± 39 seconds, field 727 ± 42 seconds, $p < .001$). This 5% increase in test duration, and therefore performance, was put down to greater running economy on the track leading to lower $\dot{V}O_2$ throughout.

Ricci and Leger (1983) performed a study examining the difference in $\dot{V}O_{2max}$ between cyclists riding on an ergometer, on a velodrome and on a treadmill. This study has several limitations, such as the type of participants (7 male, 1 female), the age of the participants (13-40 years), as well as the equipment and method for calculating $\dot{V}O_{2max}$ used (backwards extrapolation), especially during the velodrome test. In comparison, Meyer *et al*. (2003) used a MetaMax portable, breath-by-breath gas analyser. Ricci and Leger (1983) found a significantly higher $\dot{V}O_{2max}$ during ergometer testing compared to both treadmill and velodrome tests (ergometer 62.4 ± 8.2 $ml·kg^{-1}·min^{-1}$, treadmill 54.7 ± 6.3 $ml·kg^{-1}·min^{-1}$, velodrome 53.0 ± 7.8 $ml·kg^{-1}·min^{-1}$). Ricci and Leger (1983) struggled to explain the ~15% higher $\dot{V}O_{2max}$ during the ergometer test, but suggested cadence, fibre recruitment or mechanical efficiency may play a role.

While Bassett and Howley (2000) define $\dot{V}O_{2max}$ as the maximum amount of O_2 that can be taken in and utilised by the body during severe exercise, it is difficult to ascertain whether the value achieved during a test truly represents an athlete's $\dot{V}O_{2max}$. Hill and Lupton (1923) noted that past a certain running pace O_2 consumption ceased to rise with the increased workload. This plateau, defined by BASES (1997) as an increase of < 150 $ml·min^{-1}$ or 2 $ml·kg^{-1}·min^{-1}$ is often used to signify that an athlete has reached $\dot{V}O_{2max}$, although studies have found that this phenomenon can appear in 0-100% of tests (Midgley & Carroll, 2009) and at as low as 61% (Midgley *et al*., 2009) and 73% (Poole *et al*., 2008) of $\dot{V}O_{2max}$. Because of this, secondary criteria are used to help determine $\dot{V}O_{2max}$ attainment. BASES (1997) use 5-minute-post blood lactate (BLac) ≥ 8.0 $mmol·L^{-1}$, heart rate (HR) ≥ 10 beats of age predicted max (220-age), respiratory exchange ratio (RER) ≥ 1.15, along with subjective fatigue and volitional exhaustion. Other studies may be less strict with lower values of RPE ≥ 17-19 or RER ≥ 1.05-1.1 permitted, which may be influenced by the mode of exercise.

Some criteria have been found to be achieved at a submaximal workload, for example RER ≥ 1.1 can be satisfied 27% below $\dot{V}O_{2max}$ and ≥ 1.15 at 16% below $\dot{V}O_{2max}$. (Poole *et al*., 2008). While other criteria may be too rigorous for participants to achieve, as Poole *et al*. (2008) found that heart rate ≥ 10 $b·min^{-1}$ of age predicted max led to the rejection of 3/8 participants' tests and BLac ≥ 8.0 mmol·L rejected 6/8 participants tests. Due to these uncertainties in determining $\dot{V}O_{2max}$ attainment, we prefer the term $\dot{V}O_{2peak}$ and report the highest, repeated values participants reached over a 30 second period.

Due to the issues described with traditional laboratory-based testing, we sought to determine if a real-life cycling event with (approximately) the optimal length and intensity of a $\dot{V}O_{2peak}$ test would be comparable to that of a traditional lab-based test. The course was chosen specifically because it hosts an annual hill climb race (our route was extended slightly, from 2.5km to 3.23km, to result in a duration of 8-12 minutes) (Buchfuhrer *et al*., 1983; Yoon *et al*., 2007), and featured a gradient that got progressively steeper towards the summit, with the intention of forcing an increase in participants' power output similar to a lab test.

It was hypothesised that due to the greater conscious control of pacing, closed-loop format with a known endpoint, and greater muscle recruitment (Ryschon & Stray-Gundersen, 1991, Hansen & Waldeland, 2008), $\dot{V}O_{2peak}$ would be significantly higher in field-based testing than lab based testing; both measured with participants wearing a portable breath-by-breath gas analyser (Ryschon & Stray-Gundersen, 1991; Hansen & Waldeland, 2008).

This study showed some, but not all, secondary $\dot{V}O_{2max}$ determination criteria to be higher in the field; e.g. HR_{max} was only half a beat higher in the lab. End BLac, 5-minute-post BLac and RER_{max} were all significantly higher in the field. It is surprising that HR_{max} was not higher in the field given the hypothesis participants would increase their intensity in a final sprint to a known endpoint, especially since the higher end BLac suggests they finished the hill climb at a higher intensity, or spent a longer period above lactate threshold than during the lab test. This suggests if a higher HR was not responsible for the greater $\dot{V}O_{2peak}$ in the field, other physiological and biomechanical factors are responsible. Riding out the saddle leads to greater muscle activation (Ryschon & Stray-Gundersen, 1991; Hansen & Waldeland, 2008), causing a greater muscle pump action and venous return (Astorino *et al*., 2004), and thus a greater stroke volume and cardiac output (Faulkner *et al*., 2015). Other reasons may be a greater peripheral blood flow (Mauger *et al*., 2013) and/or oxygen extraction by the muscles (Faulkner *et al*., 2015).

A limitation of the study is the choice of lab test used. The 20w/minute ramp test was of a suboptimal length for $\dot{V}O_{2max}$ attainment in highly trained cyclists, as on average it took 20.4 minutes to complete compared to 8.4 minutes on the hill climb. It was found by Buchfuhrer *et al*., (1983) that tests lasting between 8-17 minutes led to a higher $\dot{V}O_{2max}$ than those of shorter or longer duration. Yoon *et al.* (2007) recommended tests of 8-10 minutes in length, as they found longer tests of 14-16 minutes resulted in a lower $\dot{V}O_{2max}$. Explanations include cardiac output reaching a peak during exercise of 5-9 minutes duration (Lepretre, Koralsztein & Billat, 2004), which is the same as the duration of the hill climb for most participants. Furthermore, the stronger a rider is, the shorter their time trial was likely to be (depending on mass), while their ramp test would last longer. The extended duration of the ramp test meant participants rode longer at high power outputs, possibly causing premature local muscular fatigue and failure to reach maximal workloads limiting lab test $\dot{V}O_{2peak}$ (Astorino *et al*., 2004).

We propose a modified version of this test be trialled in future research, based on the average duration of the field test (8.5 minutes), and literature identifying the 8-12-minute time-period as optimal for maximal testing (Buchfuhrer *et al*., 1983; Yoon *et* *al*., 2007). As well as the pre-existing 8-minute test used by cycling coaches (Carmichael & Rutberg, 2012), and training software, which consists of two 8-minute maximal efforts separated by 10 minutes of active recovery. The second 8-minute test would serve as a verification test for the first and allows training zones to be set based on the functional threshold power figure, calculated as 90% average power of the two 8-minute tests (Carmichael & Rutberg, 2012).

While this test is often carried out on a static turbo trainer, it would better be performed outdoors on a slight incline to provide resistance which leads to higher ecological validity due to the cooling effect of the wind (Brito *et al*., 2017), and also avoids the sub-optimal torque profile and muscle activation patterns of ergometer cycling (Fregley *et al*., 2000). Previous research conducted on the 8-minute field test (Klika *et al*., 2007; Sanders *et al*., 2017) has found that 8-minute power was strongly related to power at 4 $mmol \cdot L^{-1}$ BLac, commonly used as a physiological threshold. Sanders *et al.* (2017) warn of switching between lab and field testing as power measurement accuracy can vary, although the field test is likely more useful to an athlete as they are testing with the same equipment they train and compete with. This is supported by Klika *et al.* (2007) who report the 8-minute field test is a valid measure for changes in fitness and allows for the setting of training zones. However, changing environmental conditions may affect the accuracy of this. For example, hot conditions may result in lower than expected values if an athlete is not acclimatised to the heat.

5. Conclusion

Field-based testing likely resulted in a higher $\dot{V}O_{2peak}$ due to: greater familiarity with the course, known end-point allowing pacing (Noakes, 2008) and possibly higher motivation, optimal test duration (Buchfuhrer *et al*., 1983; Yoon *et al*., 2007) out-the-saddle riding allowing greater muscle recruitment (Ryschon & Stray-Gundersen, 1991; Hansen & Waldeland, 2008), and a cooling effect from the wind (Brito *et al*., 2017). Field-based testing can be considered a valid and likely more convenient alternative to laboratory testing for well-trained cyclists, assuming environmental conditions do not vary significantly between tests. Further testing with a larger sample size may result in a significantly higher $\dot{V}O_{2peak}$ in the field although it is difficult to predict as individual responses were mixed.

6. Practical Applications

Using a portable gas analyser to measure $\dot{V}O_{2max}/_{peak}$ is a valid alternative to lab-based testing as this study and previous studies (Mauger & Sculthorpe, 2012; Mauger *et al*., 2013; Straub *et al*., 2014; Hogg, Hopker & Mauger, 2015) have found it to result in similar if not higher $\dot{V}O_{2max}/_{peak}$ values. Field testing may be preferred by athletes due to their greater familiarity with the testing process and use of their own equipment. Care should be taken when comparing the results between lab tests, and future field tests with temperature, barometric pressure, humidity and wind potentially affecting results.

There is potential to combine this test with the 2x8 minute test (Klika *et al*., 2007; Carmichael & Rutberg, 2012; Sanders *et al*., 2017) to determine functional threshold power (FTP) in addition to $\dot{V}O_{2max}/_{peak}$ if a hill climb of 8-12 minutes length (Buchfuhrer *et al*., 1983; Yoon *et al*., 2007) and gradient is selected.

Conflict of Interest

The authors declare no conflict of interests.

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References

Astorino, T. A., Rietschel, J. C., Tam, P. A., Taylor, K., Johnson, S. M., Freedman, T. P., & Sakarya, C. E. (2004). Reinvestigation of optimal duration of Vo2max testing. *Journal of Exercise Physiology Online*, *7*(6).

Bassett, D. R., & Howley, E. T. (2000). Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Medicine and Science in Sports and Exercise*, *32*(1), 70-84.

Bertucci, W., Grappe, F., & Groslambert, A. (2007). Laboratory versus outdoor cycling conditions: differences in pedaling biomechanics. *Journal of Applied Biomechanics*, *23*(2), 87-92.

Bonaventura, J. M., Sharpe, K., Knight, E., Fuller, K. L., Tanner, R. K., & Gore, C. J. (2015). Reliability and accuracy of six hand-held blood lactate analysers. *Journal of Sports Science & Medicine*, *14*(1), 203-214.

Brito, J. P., Costa, A. M., Bento, P., Garrido, N., Reis, V. M., Conceição, A., & Louro, H. (2017). Air ventilation effects during the stationary roller bicycle test. *Journal of Physical Education and Sport*, *17*(1), 361-366.

Buchfuhrer, M. J., Hansen, J. E., Robinson, T. E., Sue, D. Y., Wasserman, K. A., & Whipp, B. J. (1983). Optimizing the exercise protocol for cardiopulmonary assessment. *Journal of Applied Physiology*, *55*(5), 1558-1564.

Cohen, J., 2013. *Statistical power analysis for the behavioural sciences*. Routledge.

Faulkner, J., Mauger, A. R., Woolley, B., & Lambrick, D. (2015). The efficacy of a self-paced VO2max test during motorized treadmill exercise. *International Journal of Sports Physiology and Performance*, *10*(1), 99-105.

Fregly, B. J., Zajac, F. E., & Dairaghi, C. A. (2000). Bicycle drive system dynamics: theory and experimental validation. *Journal of Biomechanical Engineering*, *122*(4), 446-452.

Hansen, E. A., & Waldeland, H. (2008). Seated versus standing position for maximization of performance during intense uphill cycling. *Journal of Sports Sciences*, *26*(9), 977-984.

Hill, A.V. and Lupton, H., 1923. Muscular exercise, lactic acid, and the supply and utilization of oxygen. *QJM: An International Journal of Medicine*, (62), 135-171.

Hogg, J. S., Hopker, J. G., & Mauger, A. R. (2015). The self-paced VO2max test to assess maximal oxygen uptake in highly trained runners. *International Journal of Sports Physiology and Performance*, *10*(2), 172-177.

Hopkins, W. G. (2006). Spreadsheets for analysis of controlled trials, with adjustment for a subject characteristic. *Sportscience*, *10*(1), 46-50.

Klika, R. J., Alderdice, M. S., Kvale, J. J., & Kearney, J. T. (2007). Efficacy of cycling training based on a power field test. *The Journal of Strength & Conditioning Research*, *21*(1), 265-269.

Lepretre, P. M., Koralsztein, J. P., & Billat, V. L. (2004). Effect of Exercise Intensity on Relationship between VO2max and Cardiac Output. *Medicine and Science in Sports and Exercise*, *36*, 1357-1363.

Macfarlane, D. J., & Wong, P. (2012). Validity, reliability and stability of the portable Cortex Metamax 3B gas analysis system. *European Journal of Applied Physiology*, *112*(7), 2539-2547.

Mauger, A. R., & Sculthorpe, N. (2012). A new VO2max protocol allowing self-pacing in maximal incremental exercise. *British Journal of Sports Medicine*, *46*(1), 59-63.

Mauger, A. R., Metcalfe, A. J., Taylor, L., & Castle, P. C. (2013). The efficacy of the self-paced VO2max test to measure maximal oxygen uptake in treadmill running. *Applied Physiology, Nutrition, and Metabolism*, *38*(12), 1211-1216.

Mclaughlin, J., Howley, E., Bassett, D., Thompson, D. And Fitzhugh, E. (2010). Test of the classic model for predicting endurance running performance. *Medicine & Science in Sports & Exercise*, *42*(5), 991-997.

Meyer, T., Welter, J. P., Scharhag, J., & Kindermann, W. (2003). Maximal oxygen uptake during field running does not exceed that measured during treadmill exercise. *European Journal of Applied Physiology*, *88*(4-5), 387-389.

Midgley, A. W., & Carroll, S. (2009). Emergence of the verification phase procedure for confirming ‘true’ VO2max. *Scandinavian Journal of Medicine & Science in Sports*, *19*(3), 313-322.

Midgley, A. W., Carroll, S., Marchant, D., McNaughton, L. R., & Siegler, J. (2009). Evaluation of true maximal oxygen uptake based on a novel set of standardized criteria. *Applied Physiology, Nutrition, and Metabolism*, *34*(2), 115-123.

Moore, J. L., Shaffrath, J. D., Casazza, G. A., & Stebbins, C. L. (2008). Cardiovascular effects of cadence and workload. *International Journal of Sports Medicine*, *29*(2), 116-119.

Noakes, T. D. (2008). Testing for maximum oxygen consumption has produced a brainless model of human exercise performance. *British Journal of Sports Medicine*, *42*(7), 551-555.

Poole, D. C., Wilkerson, D. P., & Jones, A. M. (2008). Validity of criteria for establishing maximal O2 uptake during ramp exercise tests. *European Journal of Applied Physiology*, *102*(4), 403-410.

Pyne, D.B., Boston, T., Martin, D.T., & Logan, A. (2000). Evaluation of the Lactate Pro blood lactate analyser. *European Journal of Applied Physiology*, *82*(1-2), 112-116.

Ricci, J., & Leger, L. A. (1983). Vo2 max of cyclists from treadmill, bicycle ergometer and velodrome tests. *European Journal of Applied Physiology and Occupational Physiology*, *50*(2), 283-289.

Ryschon, T.W., & Stray-Gundersen, J. (1991). The effect of body position on the energy cost of cycling. *Medicine and Science in Sports and Exercise*, *23*(8), 949-953.

Sanders, D., Taylor, R. J., Myers, T., & Akubat, I. (2017). A field-based cycling test to assess predictors of endurance performance and establishing training zones. *Journal of Strength and Conditioning Research*.

Straub, A. M., Midgley, A. W., Zavorsky, G. S., & Hillman, A. R. (2014). Ramp-incremented and RPE-clamped test protocols elicit similar VO 2max values in trained cyclists. *European Journal of Applied Physiology*, *114*(8), 1581-1590.

Williams, C. J., Williams, M. G., Eynon, N., Ashton, K. J., Little, J. P., Wisloff, U., & Coombes, J. S. (2017). Genes to predict VO 2max trainability: a systematic review. *BMC Genomics*, *18*(8), 831.

Yoon, B. K., Kravitz, L., & Robergs, R. (2007). VO2max, protocol duration, and the V O2 plateau. *Medicine & Science in Sports & Exercise*, *39*(7), 1186-1192.

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Fielding specific walk/run patterns in English professional Cricket

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ABSTRACT

In cricket research, players are typically categorized by role. However, players of a certain role, for instance fast bowlers may not consistently field in the same position which leads to inaccurate representations of the physical demands of fielding. To identify fielding specific movement demands across three cricket formats (4 multi-day, 6 one day, 4 T20), 14 professional male cricketers had positional movements determined with 10 Hz Optimeye S5 (Catapult, Melbourne, Australia) global positioning system (GPS) units. Players observed fielding in 35 common cricket locations were described as either being in a stationary catching, 30m ring or boundary position. Data were totalled in movement velocities bands: Walking (<7 km/h), Jogging (7 - 15 km/h), Striding (15 - 20 km/h), High speed running (20 - 25 km/h), Sprinting (> 25 km/h), and further classified into low intensity running (walking and jogging) or high intensity running (HIR). The HIR running was significantly different for each fielding position within each game format. Boundary fielders covered the most HIR distance per hour (930 ± 1085 m/h) in One day compared to multi-day (889 ± 435 m/h) and Twenty20 (T20) (628 ± 438 m/h) formats. Similarly, 30m ring fielders also covered relatively greater distance in the One day format (594 ± 286 m/h) compared to multi-day and T20 formats (227 ± 345, 170 ± 165 m/h) respectively. The catching positions had similar hourly demands between Multi-day (370 ± 291 m/h) and One day (385 ± 342 m/h) formats. This study identifies that the boundary positions have the greatest HIR demands across all three cricket formats. When setting a field, captains should be mindful not only of position-specific skill requirements, but also of movement speed, fitness characteristics and within-session recovery needs of players. This information is able to better inform cricket's physical preparation coaches and tacticians.

1. Introduction

With the proliferation of microtechnology for sportspeople, cricket conditioning coaches are seeking detailed information on positional movement demands. Given that fielding is an essential component to winning matches, the lack of research in this area is disconcerting (MacDonald et al., 2013). To date, what little information there is has been largely reported by player role as opposed to fielding position. Yet, players in the same playing role could field in very different types of position and subsequently have very different movement demands. Additionally, game to game the same player may field in different types of fielding positions. In order to physically prepare their players, conditioning coaches need to know the normative data for the likely demands encountered by their players who are known to specialise in certain positions. Cricket has numerous possible fielding positions which creates logistical issues as to how these should be classified and reported in motion analysis studies.

In the last decade, several motion analysis studies have been conducted in cricket and its three main match formats. In real-time, Rudkin and O'Donoghue (2008) coded the movement of the cover-point fielder during the first 10 overs of play in each session of three multi-day cricket games. The extrapolated data revealed this fielding position required players to cover ~15500 m in a day, with high intensity activity representing 1.6% of match time. High intensity bursts were found to last ~1.3 seconds. Given, the considerable logistics of live-coding a single position and the time intensive extrapolation techniques required this data collection

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method was quickly superseded by GPS technology. Improved miniaturisation, fast downloading and over time the reduced cost of GPS devices has resulted in most professional clubs investing in this technology.

Several studies have investigated the physical demands of cricket and the playing roles within the game using GPS. Petersen et al., (2009) found that in T20 fast bowlers covered a distance of 8489 ± 1493m (mean ± SD) during the fielding innings with 723 ± 186m consisting of "sprinting" (5+ $m.s^{-1}$ or 18 $km.h^{-1}$), whereas spin bowlers covered 8141 ± 1308m with 154 ± 144m of "sprinting". This study highlights the variation in "sprinting" demands between playing roles in T20 cricket, with fast bowlers completing significantly more meters "sprinting". When investigating fielding Petersen et al., (2009) found that fielders during Twenty20 Games covered a total distance of 8141 ± 1308m, including 154 ± 144m of "sprinting" (5+ $m.s^{-1}$). More recently, Sholto-Douglas et al., (2020) has reported fielders cover a total distance of 5900 ± 900m during Twenty20 innings ranging in length from 40 – 97 min. Petersen et al., (2010) also compared distance covered in metres/hour over the three formats of cricket for fielders, finding that Twenty20 was the most intense, followed by One-Day and then Multi-Day.

The major limitation with current research utilising GPS to identify cricket demands is that all studies are identifying workloads performed by a player's role within the game (bowler, fielder and wicketkeeper). In a cricket match, during the fielding innings, a player's role will not be the single factor when dictating the work performed. A high variation comes within the fielding activity itself, regardless of a players role. Geographically where players are positioned on the field, will have a strong influence on the work performed during that fielding innings. If the demands of various fielding positions were to be better understood then a much clearer representation of work performed can be identified for each individual. Obviously, actual specific role demands of bowling (fast versus spin bowlers) will also need to be accounted for when predicting future upcoming workload requirements.

This paper proposes a new methodological approach to classify fielding positions. Specifically, the main aim of this study was to identify the demands of fielding by analysing three general positions within the game (catcher, ring fielder and boundary fielder) as well as the specialist wicketkeeping position, across three formats played (T20, One Day and Multi Day) by professional English county cricketers. Identifying the physical demands of fielding positions will help better inform the strength and conditioning coach in planning the athletes physical preparation not only by playing role, but by additionally taking into consideration the athletes typical fielding position.

2. Methods

2.1. Participants

Fourteen members of a professional team that played in the England and Wales Cricket Board (ECB) domestic competitions during the 2017 season volunteered to participate in the study. Participants (mean ± SD: age = 26 ± 6 years, height = 182.7 ± 6.6 cm, and body mass = 85.0 ± 6.0 kg) played in the following domestic competitions: The County Championship (Multi day), The Royal London One Day Cup (One day) and The NatWest T20 Blast (T20). Participants provided written informed consent before participation along with the ECB providing ethical approval for use of the data. The study also received local institutional research ethics approval.

2.2. Apparatus

Player movements were collected using Catapult optimeye S5 GPS (10 Hz) units. These units were randomly assigned to six players before the start of each days play. The GPS units were turned on 15 minutes before players took to the field to establish a GPS satellite lock in accordance with the manufacture's recommendations and prior studies (Petersen et al, 2009; Petersen et al, 2010; Reardon, Tobin, & Delahunt, 2015). Data was only collected during the fielding innings of each match. The GPS unit was placed in a protective sleeve integrated into a purpose-built vest; the position of the sleeve was between the shoulder blades overlying the player's upper thoracic spine. During multi day games (6 hours of play per day), units were charged during breaks between sessions. Throughout each match players wearing the GPS units were coded and had their positions recorded for every bowl delivered using SportsCode (Studiocode version 10, Sportstec, Australia). The assigned fielding roles were changed between balls and overs if a specific fielder changed their fielding position into a different category. Match footage was also recorded using a GoPro Hero Session (GoPro Inc. California, USA).

2.3. Task

Peak velocity assessment: Six days prior to the time motion analysis of the first competitive match the participants completed an assessment of maximum running velocity to establish the sprinting performance capability of players outside of a match environment. Each participant completed 3 x 40 m sprint efforts, with a 120s recovery between efforts, while wearing a Catapult optimeye S5 GPS (10 Hz) unit to calculate peak running velocity ($m.s^{-1}$).

Match analysis: Thirty-five specific fielding positions within the game of cricket were re-classified into three more generalised positions; catching, 30m inner ring and boundary (see Table 1). In addition, data was also collected on the specialised wicketkeeper position.

Specifically, at the start of the innings, fielders were placed into one of the three generalised categories above, dependent on their starting position on the field of play. This was documented before the first ball of the innings was bowled. Players were continuously monitored throughout the innings and their role was immediately altered if they changed their physical fielding position from one category to another between any ball. If there was no change between each ball, players would remain within their category until they crossed the threshold of another category and took their place within their next fielding position. For example, a 'Deep Mid-Wicket' (boundary) fielder might move into an 'Extra Cover' (inner-ring) position, or a 'Backward Point' (inner-ring) fielder might move into a 'Second-Slip' (stationary catching) position.

Table 1: Fielding positions classified into 3 generic positions

Catching	Inner Ring	Boundary
1st Slip	Mid on	Long on
2nd Slip	Mid wicket	Cow corner
3rd Slip	Square leg	Deep mid wicket
4th Slip	Backward square leg	Deep square leg
Gulley	Short fine leg	Deep backward square leg
Silly point	Fly slip	Deep fine leg
Silly mid off	Short third man	Third man
Silly mid on	Backward point	Deep backward point
Short Leg	Point	Deep point
Leg gully	Cover	Deep cover
Leg slip	Extra cover	Deep extra cover
	Mid off	Long off

2.4. Procedure

Participants were randomly assigned to wear GPS units during 14 of the competitive matches played across the three domestic competitions (4 x multi day, 6 x one day, and 4 x T20). Post-match, data stored on the OptimEye S5 GPS units were downloaded to OpenField 1.14.0 (Catapult Sports, Melbourne, Australia). Data were reviewed in both OpenField and Microsoft Excel (Microsoft Corporation, USA) and data were organised using Microsoft Excel. To increase the internal validity of the studies GPS data, video footage and SportCode data were aligned to identify the specific work done in each position. Given, the aim of the study was to investigate movement demands of general fielding positions, any bowling data recorded and any data collected while a player was off the field during play was not included.

2.5. Statistical Approach

The following movement speed bands on the openfield software were categorised as follows:

- Walking 0 - 7 km.h^{-1} (0 - 1.94 m.s^{-1})
- Jogging 7.01 - 15 km.h^{-1} (1.95 – 4.16 m.s^{-1})
- Striding 15.01 - 20 km.h^{-1} (4.17 – 5.55 m.s^{-1})
- High speed running 20.01 - 25 km.h^{-1} (5.56 – 6.94 m.s^{-1})
- Sprinting > 25 km.h^{-1} (> 6.94 m.s^{-1})

The data were downloaded to OpenField 1.14.0 software (Catapult Sports, Melbourne, Australia) and exported to Microsoft Excel where it was organized within the above movement speed bands for each data set. The positional analysis performed on SportsCode was then aligned with the data to identify the duration spent in each categorised fielding position and the work that was performed in that position was calculated. To identify the high intensity running demands of fielding positions, walking and jogging were considered as "low intensity running"; while striding, high speed running and sprinting were considered "high intensity running". Distances are all reported in meters (m). Peak velocity (m.s.^{1}) was also recorded.

To facilitate a direct comparison of fielding positions, and additionally between the three match formats, positional movement data collected on each player was collated for each match and scaled to per hour of play. If a player had spent less than 20 minutes (represents ~25% of the fielding duration of the shortest game format) of the match in a fielding position the data was excluded as a data set for the analysis. Magnitude based inferences were also used to analyse the within position distance data between game formats (Batterham & Hopkins, 2006). The effect size statistic was generated to characterise the magnitude of difference between positions across the three formats of the game. The criteria for interpreting effect sizes were: <0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2 – 2.0 large, and >2.0 very large (Hopkins, 2004).

3. Results

A player wearing a GPS unit needed to spend at least an accumulated 20 minutes in the same fielding position for the data to be included in the study as a single data set. From the 4 x T20 matches 9.0 hours of data were collected in the boundary position (n = 13), 7.6 hours on the ring fielder position (n = 11) and 3.2 hours on the wicketkeeper (n = 3) with no data collected on the position of catcher. From the 6 x One-day matches 29.4 hours of data were collected in the boundary position (n = 24), 57.8 hours on the ring fielder position (n = 31), 5.6 hours on the position of catcher (n = 9) and 8.4 hours on the wicketkeeper (n = 3). From the 4 x multi day matches 35.3 hours of data were collected in the boundary position (n = 14), 70.1 hours on the ring fielder position (n = 18), 38.8 hours on the position of catcher (n = 10) and 16.5 hours on the wicketkeeper (n = 2).

3.1. Fielding positional movement patterns

The relative distances covered by each fielding position for each game format is provided in Table 2. Extrapolating the data of a T20 innings (75 minutes) players fielding in the boundary position covered 4436 ± 769 m, the ring fielder position 3770 ± 804 m and the wicketkeeper 3325 ± 263 m. As noted above, no data was collected for the position of stationary catchers in T20 matches.

Extrapolating a One-day innings (3.5 h) players fielding in the boundary position covered 9221 ± 2593 m, the ring fielder position 8696 ± 1464 m, stationary catching positions 5754 ± 820 m and the wicketkeeper 7911 ± 500 m.

Meanwhile, extrapolating a full day of play of multi day cricket (3 x 2 h sessions) players fielding in the boundary position covered 12171 ± 1688 m, the ring fielder position 12659 ± 3533 m, catching positions 8185 ± 590 m and the wicketkeeper 10839 ± 1106 m.

3.2. High intensity running demands

The mean high intensity running distance covered per hour by players in each fielding position is illustrated in Figure 1. Extrapolated data for high intensity running during a T20 innings (75 minutes) revealed players fielding in the boundary position covered 628 ± 438 m, ring fielder position 170 ± 165 m and the wicketkeeper 97 ± 50 m.

During a One-day innings (3.5 h) players fielding on the boundary covered 930 ± 1085 m of high intensity running, while the ring fielder position 385 ± 342 m, catching position 227 ± 345

Table 2: Movement category distances by fielding position and game format

Format and position	Distance covered (meters / hour)					Total distance ($m.h^{-1}$)
	Walking (0 - 7 kph^{-1})	Jogging (7.1 - 15 kph^{-1})	Striding (15.1 - 20 kph^{-1})	High Speed Running (20.1 - 25 kph^{-1})	Sprinting (>25 kph^{-1})	
Twenty20 (n = 4)						
Wicket keeper (n = 3)	1777 ± 46	805 ± 161	78 ± 40	-	-	2660 ± 210
Catcher (n = 0)						
Ring (n = 11)	2015 ± 413	866 ± 435	114 ± 114	17 ± 29	4 ± 8	3016 ± 643
Boundary (n = 13)	1788 ± 379	1259 ± 305	354 ± 263	95 ± 73	53 ± 62	3549 ± 615
One Day (n = 6)						
Wicket keeper (n = 3)	1507 ± 129[4]	729 ± 14[2]	24 ± 5[3]	-	-	2260 ± 143[4]
Catcher (n = 9)	1042 ± 236	537 ± 188	65 ± 99	-	-	1644 ± 234
Ring (n = 31)	1808 ± 332[1]	567 ± 234[2]	66 ± 39[1]	29 ± 65	15 ± 21[2]	2485 ± 418[2]
Boundary (n = 24)	1604 ± 333[1]	765 ± 396[3]	173 ± 231[2]	72 ± 67[1]	20 ± 30[2]	2635 ± 741[3]
Multi day (n = 4)						
Wicket keeper (n = 2)	1216 ± 130[d]†	586 ± 53[c]†	5 ± 1[d]†	-	-	1807 ± 184[d]†
Catcher (n = 13)	966 ± 114[*]	336 ± 125‡	40 ± 37[*]	13 ± 21	10 ± 8	1361 ± 93‡
Ring (n = 19)	1605 ± 429[b*]	406 ± 207[c#]	60 ± 36[b]	20 ± 15	19 ± 15[c]	1988 ± 608[c#]
Boundary (n = 17)	1322 ± 252[c#]	558 ± 205[d#]	112 ± 76[c*]	26 ± 17[c#]	10 ± 10[c*]	2018 ± 290[d#]

[1]Small, [2]moderate, [3]large and [4]very large magnitudes of difference within position between Twenty20 and One Day cricket. [a]Small, [b]moderate, [c]large and [d]very large magnitudes of difference within position between Twenty20 and Multi day cricket. [*]Small, [#]moderate, ‡large and †very large magnitudes of difference within position between One Day cricket and Multi day cricket.

m and the wicketkeeper 83 ± 16 m performed a lot less high intensity running.

During a full day of play of multi day cricket (3 x 2 h sessions) players fielding in the boundary position covered 889 ± 435 m of high intensity running, in comparison the ring fielder position which covered 594 ± 286 m, and the positions of catcher 370 ± 291 m and the wicketkeeper 31 ± 8 m also performed considerably less.

3.3. Peak velocity

The mean peak velocity of participants prior to the season was 8.5 ± 0.5 $m.s^{-1}$ (30.5 ± 1.8 $km.h^{-1}$). When this is compared to the fielding positional values displayed in Figure 2 it is evident that players do not reach their full sprint speed potential during matches. Specifically, during a T20 innings mean peak velocity recorded for the boundary position was 90% (7.64 ± 1.15 $m.s^{-1}$) of their previously recorded peak velocity. In comparison, the ring fielding position only attained a classified high speed running intensity which equated to 73% of the pre-season recorded peak velocity (6.24 ± 1.13 $m.s^{-1}$). While the wicketkeeper only managed to achieve the classified striding intensity which equated to 62% (5.29 ± 0.42 $m.s^{-1}$) of the pre-season recorded peak velocity.

Again, comparing to the pre-season peak velocity (8.5 ± 0.5 $m.s^{-1}$) during One-day innings the mean peak velocity recorded for the boundary position was 89% (7.55 ± 0.64 $m.s^{-1}$), the ring fielding position reached 87% (7.36 ± 1.05 $m.s^{-1}$) and the catching position peaked at a striding classified intensity of 55% (4.66 ± 0.57 $m.s^{-1}$). Similarly, the wicketkeeper only reaches a striding classified intensity of 58% (4.97 ± 0.25 $m.s^{-1}$) of the previously recorded peak velocity.

In the final comparisons with the pre-season sprinting values, during multi day innings mean peak velocity recorded in the boundary position was 89% (7.53 ± 0.71 $m.s^{-1}$) of the previously recorded peak velocity. While, the ring fielding position at 94% (8.02 ± 0.87 $m.s^{-1}$) reached a higher peak sprinting speed. The catching position at 89%, (7.56 ± 1.50 $m.s^{-1}$) was similar to the boundary position, whereas the wicketkeeper again could only manage to attain a striding classified intensity at 63% (5.37 ± 0.45 $m.s^{-1}$) of the pre-season recorded peak velocity.

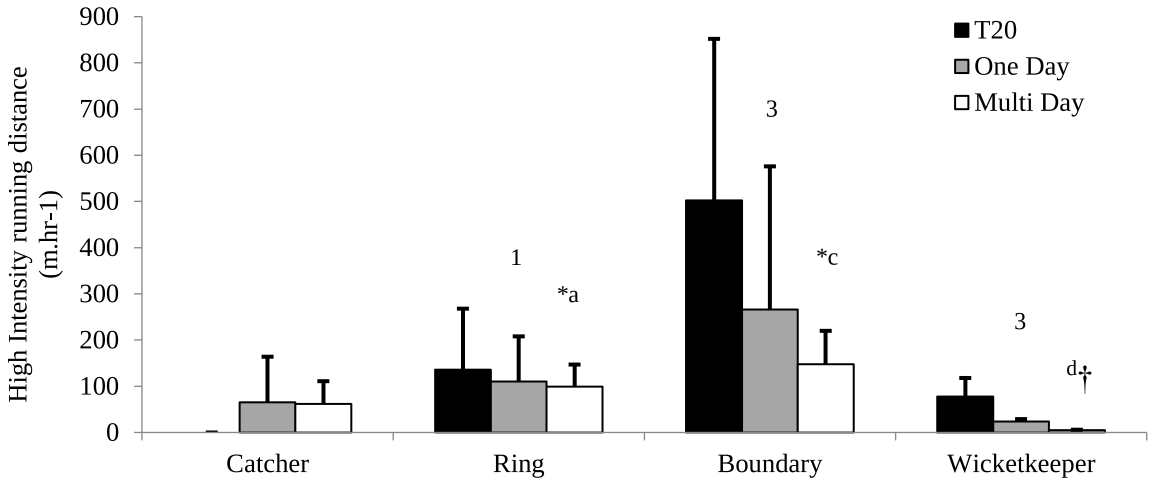

Figure 1: Mean (±sd) high intensity running distance covered per hour by fielding position
[1]Small, [2]moderate, [3]large and [4]very large magnitudes of difference within position between Twenty20 and One Day cricket. [a]Small, [b]moderate, [c]large and [d]very large magnitudes of difference within position between Twenty20 and Multi day cricket. [*]Small, [#]moderate, ‡large and †very large magnitudes of difference within position between One Day cricket and Multi day cricket.

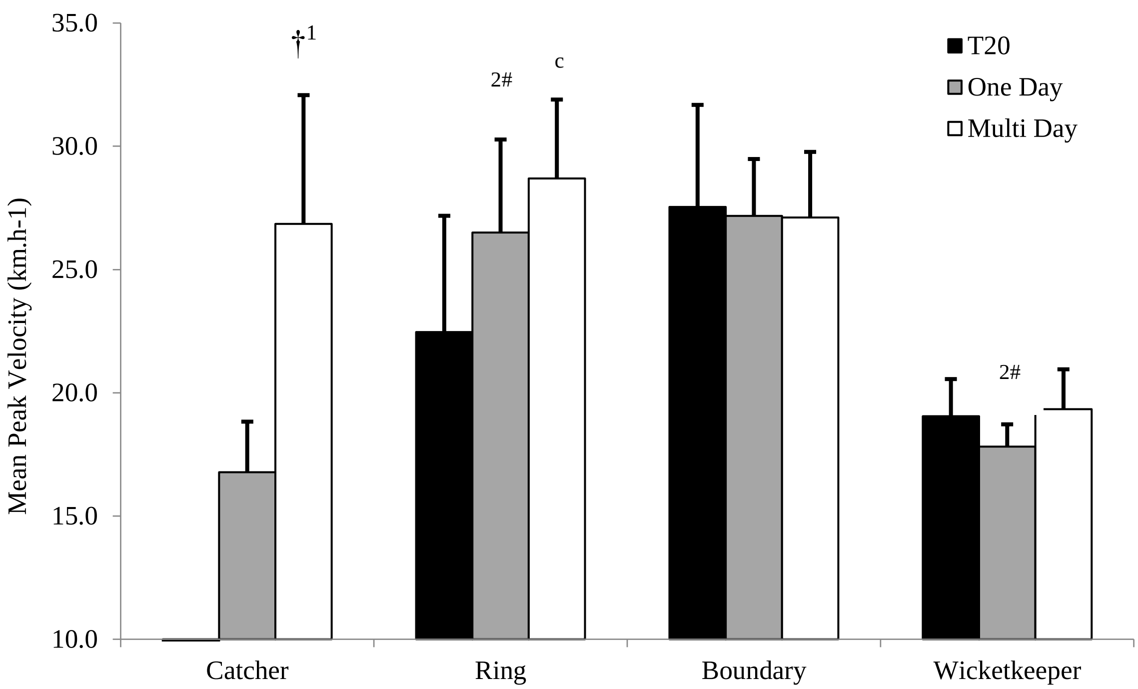

Figure 2: Mean (±sd) peak velocity by fielding position
[2]moderate magnitude of difference within position between Twenty20 and One Day cricket.
[c]large magnitude of difference within position between Twenty20 and Multi day cricket.
[#]moderate and †very large magnitudes of difference within position between One Day cricket and Multi day cricket.

4. Discussion

To our knowledge this is the first paper to address the limitation of role based reporting of Cricket GPS data. While there are a multitude of different cricket fielding positions from a logistical perspective with the given quantity of data these should be grouped together based on their similar skill demands. We therefore identified three main types of fielding position, but do recognise that with time and more sophisticated analyses using greater datasets it will be possible to define the actual specific demands of each individual position.

Roberts, Callaghan, and Jeffriess, (2014) found cricketers display similar sprint kinematics between two fielding generic positions (in-fielders versus out-fielders) and they hypothesised that this was due to players needing to field in either the infield or outfield depending on match situation. However, anecdotally, Strength and Conditioning coaches in the modern game have reported that most players specialise in fielding positions in the various game formats. While Strength and Conditioning Coaches could target developing all areas of general strength, speed and fitness in the off-season, knowing what each player will likely be exposed to or have to cope with will help identify 'worst case' scenarios, especially in regard to high speed and maximal sprinting distances. For these coaches who are responsible for the physical preparation and returning players back to play after injury, knowing the likely demands on their players based on their fielding position is very useful.

As we have previously outlined strength and conditioning coaches need to know the likely demands of fielding in different positions and these generic demands are summarised below.

4.1. Fielding on the boundary

There was a significant (~30%) increase in total distance per hour from multi day to one day (2028 to 2634 $m.hr^{-1}$) and ~35% increase in total distance (2634 to 3549 $m.hr^{-1}$) from one day to T20. High intensity running was significantly higher in One day when compared to Multi day, but there was no significant difference between One day and T20 demands. The mean peak velocity achieved during a match was not different between the formats.

4.2. Fielding in the ring

For fielders in the ring positions, despite small magnitudes of difference, there were no statistically significant differences in the amount of high intensity running per hour between the three match formats. When you consider that a day of multi day cricket lasts for 6 hours, players accumulate four times as much volume of high intensity running in multi day and twice as much volume in One day cricket compared to the shortest T20 match format.

Interestingly, the mean peak velocity for ring fielders was significantly higher in multi day compared to T20. Firstly, given the higher demands of getting boundaries in the shorter game formats there might be fewer opportunities to chase the ball. Additionally, it could be presumed that with more boundary fielders given the more defensive field placements of the T20 format this would offer less chances for ring fielders to chase a ball towards the boundary and hence offer less opportunities to reach their true peak velocity.

4.3. Fielding at a catching position

Total distance covered per hour was significantly higher in One day compared to the Multi day format, however there was no difference in high intensity running per hour between the formats. Mean peak velocity was significantly higher in the Multi day vs One day format. Again the difference in fielding strategies, i.e. using more attacking field placements in multi day compared to the One Day cricket format may help explain this difference with catchers having more chances to chase a ball in multi day cricket with the lack of a boundary fielder sweeping behind them. In the more explosive shorter game formats, players could be accumulating their total distance with more frequent but shorter distance running opportunities.

4.4. Wicketkeeper

There were significant increases in total distance per hour from Multi day to One day and from One day to the T20 formats. Likewise there was the same trend of significant increases in high intensity running per hour from Multi day to One day and from One day to T20 formats. The Wicketkeeper position is very specialised and while these running demands do not seem overly taxing, small fast reactions and quick change of direction movements including jumping and diving are likely to increase the overall loading of this position.

For One day and multi day matches, it is interesting to note the greater hourly total distances covered by generic fielders in the Australian game as reported by Petersen et al., (2011). The current positionally differentiated English fielding data has total hourly distances of ~1.6 – 2.6 $km{\cdot}h^{-1}$, whereas the Australian data reported ranges 3.0 – 3.6 $km{\cdot}h^{-1}$ (Petersen et al., 2011), speculatively this may be due to the differences in the respective ground sizes between the two countries. Alternatively, ground conditions, such as grass moisture and length could influence the number of opportunities to accumulate greater distances chasing balls in the outfield.

4.5. Conclusion

As demonstrated there are differences across specialist fielding positions therefore, there is a need to distinguish fielding demands from player roles to account for types of players that field in positions that break the stereotypical view of where certain players field. To emphasise this point some fast bowlers with good catching skills may be asked to field in close catching positions as opposed to the stereotypical boundary fielding role. Players also change between various types of fielding position within an innings so again we argue that it is more appropriate to present data for fielding position as opposed to player role.

Conflict of Interest

The authors declare no conflict of interests.

Acknowledgment

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References

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

Hopkins, W.G. (2004). How to interpret changes in an athletic performance test. *Sportscience*, *8*, 1-7.

MacDonald, D.C., Cronin, J., Mills, J., McGuigan, M., & Stretch, R. (2013). A review of cricket fielding requirements. *South African Journal of Sports Medicine*, *25*(3), 87- 92.

Petersen, C.J., Pyne, D., Dawson, B., Portus, M., & Kellet, A. (2010). Movement patterns in cricket vary by both position and game format. *Journal of Sport Sciences*, *28*(1), 45-52.

Petersen, C., Pyne, D.B., Portus, M.R., & Dawson, B. (2009). Quantifying positional movement patterns in Twenty20 cricket. *International Journal of Performance Analysis of Sport*, *9*, 165-170.

Petersen, C.J., Pyne, D.B., Portus, M.R., & Dawson, B.T. (2011). Comparison of player movement patterns between 1-day and Test Cricket. *Journal of Strength and Conditioning Research*, *25*(5), 1368-1373.

Reardon, C., Tobin, D.P., & Delahunt, E. (2015). Application of Individualized Speed Thresholds to Interpret Position Specific Running Demands in Elite Professional Rugby Union: A GPS Study. *PLoS One*, *10*(7):e0133410.

Robert, G.L., Callaghan, S.J., & Jeffriess, M.D. (2014). Acceleration kinematics in cricketers: implications for performance in the field. *Journal of Sorts Science and Medicine*, *13*(1), 128-136.

Rudkin, S.T., & O'Donoghue, P.G. (2008). Time-motion analysis of first-class cricket fielding. *Journal Science and Medicine in Sport*, *11*(6), 604-607.

Sholto-Douglas, R., Cook, R., Wilkie, M., & Christie, C. (2020). Movement Demands of an elite Cricket Team During the Big Bash League in Australia. *Journal of Sports Science and Medicine*, *19*, 59-64.

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Defining tactical competency during turnovers in Netball: Using the Delphi method to capture expert coach knowledge

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ABSTRACT

Traditional methods for understanding change of possession (turnovers) in team-based invasion sports have not accounted for how the dynamic, interactive actions of multiple players contribute to turnovers. One approach is to access the expertise of highly skilled coaches to determine the important tactical behaviours that create turnovers. In this study, we synthesised expert opinion from 12 experienced netball coaches with a consensus-based method (the Delphi method). The expert group undertook one-on-one interviews which were coded using thematic analysis to identify and code any tactical constructs. From this analysis, a preliminary list of tactical behaviour definitions were created and used for the subsequent rounds of data collection and analysis. Two rounds of questionnaire followed the initial interviews to validate the list of tactical behaviour definitions. As a result, the tactical principles guideline (TPG) was developed which included (nine attacking tactical behaviours and nine defensive tactical behaviours). The tactical behaviours can be grouped thematically into four overarching tactical principles, including; space and movement, timing, support and reading play. Each of the four tactical principles is derived from interactions between multiple players highlighting that, in high level netball, turnovers typically result from the team dynamics rather than from individual player behaviours (i.e., a poorly executed pass). Therefore, when using game statistics to assess performance it is important to acknowledge that errors and successes are the result of the interactions of multiple players on court, and not solely a reflection of individual players' tactical ability. The TPG has been incorporated into a Netball NZ player profiling tool as it is seen to be the first step in enhancing the effectiveness of coach and player communication, tactical behaviour assessment, as well as informing selection processes.

1. Introduction

The evaluation of tactical behaviour in team sports is a growing research area (Gonzalez-Villora, Serra-Olivares, Pastor-Vicedo, & da Costa, 2015). Given the inherently agonistic relationship that exists between opposition teams, the tactical behaviours which emerge can provide coaches, players and performance analysts with meaningful information about the tactical demands of the sport (Silva, Garganta, Araújo, Davids, & Aguiar, 2013). Notational analysis methods are often used in team sports to identify the performance indicators that describe successful or unsuccessful performance (Correia, Araujo, Vilar, & Davids, 2013). For example, statistics such as turnovers won or lost, passing frequencies, and penalties given, are collected and then used to discriminate between winning and losing teams, in order to describe the quality of a performance (Garcia, Ibanez, De Santos, Leite, & Sampaio, 2013; Hughes & Bartlett, 2002). In recent literature, a variety of performance variables have been shown to be related to match outcome. For example, In rugby 7's successful teams have been shown to win more lineouts from an opposition's throw (Higham, Hopkins, Pyne, & Anson, 2014); in basketball, winning teams gain more defensive rebounds (Garcia et al., 2013); and in handball, winning teams have a lower number of red card offenses (Saavedra, Porgeirsson, Chang, Kristjánsdóttir, & García-Hermoso, 2018). However, within the performance analysis literature it is acknowledged that recording these descriptive measures in isolation does little to provide an

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appropriate level of explanation for the complex inter and intra team dynamics that occur on the sports field (Mclean et al., 2019).

In order to extend our knowledge of tactical behaviour from simple description to an informative explanation, it is important to first define what a tactical behaviour is. In general terms, a 'tactic' is a means to achieve a specific objective, like to gain advantage over an opposition (Garganta, 2009). In team sports, successful tactical behaviour is typically associated with successful skill execution, as any decision only becomes valid once it is translated into action (Grehaigne, Godbout, & Bouthier, 2001). While many team sports are suitable to explore tactical behaviours, this study will focus on Netball. Netball is a 7 v 7 court-based invasion sport, played mostly by women in commonwealth countries (Croft, Willcox, & Lamb, 2018).

In netball, like other invasion sports, the overall objective is to outscore an opposition team, however, netball has many unique rules that dictate how the game can be played (Croft et al., 2018). For example, the player in possession of the ball cannot take more than one step and must pass the ball within three seconds of receiving it (Pulling, Eldridge, & Lomax, 2016). These rules mean that the player in possession of the ball (the 'passer') is heavily reliant on their teammates to create passing options for them to avoid losing possession of the ball. In addition, as netball is defined as a 'non-contact' sport, there are rules that restrict how defenders can regain possession (INF, 2016). The 'obstruction' rule states that a defender cannot defend within 0.9m of a player in possession of the ball, therefore, in order to legally gain possession, defensive players must force errors (e.g. force the attacking team to throw the ball out of court, hold the ball too long or take an extra step), or they can attempt to gain possession when the ball is in flight; by intercepting the ball (INF, 2016).

Various performance indicators in netball, such as successful and unsuccessful passes, goal scoring variables, turnovers, offensive and defensive rebounds, and penalties received have previously been reported (Croft et al., 2018; Mclean et al., 2019; O'Donoghue, Mayes, Edwards, & Garland, 2008; Pulling et al., 2016). For example, a sample of 59 British National Super League netball games from 2005-2008 were analysed to identify the key performance indicators that differentiate between top of the table and bottom of the table teams (O'Donoghue et al., 2008). The results indicate that across the 2005-2008 seasons, top of the table teams score from 53.4% of their centre passes, and bottom of the table teams score from 38.9% of their centre passes (referred to as the 'centre pass to score' or CP to score statistic) (O'Donoghue et al., 2008). In addition, top of the table teams gain more intercepts, defensive rebounds, and turnovers and score from more of those turnovers (referred to as the 'turnover to score' or T/O to score statistic) (O'Donoghue et al., 2008). This suggests that when a team is able to effectively score from their own centre pass, and score from the 'bonus' turnovers they create, they will be more successful (Pulling et al., 2016). However, from these statistics we are unable to determine the specific behaviours that are used to create these successful patterns of play, or help us understand *why* turnovers occur in netball.

As with research in other invasion sports, these performance indicators are often measured without context and without considering the team interdependencies that produce successful or unsuccessful behaviour (Mclean et al., 2019). A study conducted by Bruce, Farrow, Raynor, and May (2009), attempted to identify the contextual factors influencing pass decision making in netball, using concepts such as decisional complexity; measured through the number of passing options available for a passer. Decisional complexity was shown to be related to an increase in passing errors compared to when only one passing option was available, irrespective of the players skill level (Bruce et al., 2009). While these findings are noteworthy, the authors did not specify what constitutes an 'available option', (i.e. is 'availability' defined as a player who is completely unmarked?). This is important because, in netball, different styles of defence dictate the proximity of the defender to the attacker, and although a player may appear marked or unmarked, they can still be perceived as a good option depending on their movement and positioning. If there is any ambiguity or indecisiveness in a players movements, this will create more decisional complexity for the passer. Therefore, rather than stating that the quantity of options results in errors as shown in Bruce et al. (2009), it may also be important to note the wider contextual variables that indicate the quality of those options.

In recent research, Mclean et al. (2019), identified the need for a more holistic, systematic approach for understanding team behaviour in netball that moves beyond the reductionist notational methods currently being adopted. Using 'subject matter experts', Mclean et al. (2019) conducted a workshop to develop a model of netball to highlight the multiple interacting factors that influence match performance. Turnovers were identified as an important measure, however, rather than simply measuring the frequency of turnovers, the model includes 'purpose related functions' to guide a higher level of analysis to explain *how* teams maintain or gain possession of the ball (prevent or gain turnovers). For example, *maintaining unit structures*, *creating unpredictability for your opponents* and *controlling momentum* were identified as key aspects of match performance in netball (Mclean et al., 2019). These 'purpose related functions' form a foundation for understanding turnovers in netball, however, further clarification of the mechanisms or specific behaviours the contribute to turnovers are needed, i.e. *how* do players control momentum, what does it look like when players control momentum?

The use of 'subjects matter experts' in the above research emphasises the need to incorporate the unique knowledge of experts into applied sports science research (McLean, Salmon, Gorman, Read, & Solomon, 2017). The Delphi method, is another method used to solicit knowledge from experts, and to collate and synthesise their opinions in order to create group consensus across multiple rounds of questionnaires (Hsu & Sandford, 2007; Mullen, 2003). While the Delphi method has been used extensively in health and social science research there are fewer sports science studies that have used this method to capture expert knowledge (Morley, Morgan, McKenna, & Nicholls, 2014). One exception was completed by Cupples and O'Connor (2011), who sought to identify the performance indicators of junior rugby league players to create a practical guide for identifying, selecting, and retaining athletic potential. Unlike many studies that have a heavy focus on the physical attributes of performance, Cupples and O'Connor (2011) described many cognitive, psychological and game skill factors as key indicators of importance for higher performing athletes. Similarly, using the Delphi method, Morley et al. (2014) looked at the developmental features that encompass elite junior academy footballers. In both the aforementioned studies, it was recognised that using expert coach knowledge to develop guidelines or frameworks for player development pathways can maximise the engagement and respect for the tool.

The aim of the current study was to identify and clearly define the tactical behaviours that contribute to turnovers in netball. Through gathering expert opinion with a consensus-based method (the Delphi method), a practical framework for defining tactical behaviour will be created with multiple applications for coach and player development. The expected outcome of this research will be a list of tactical behaviour definitions, called the tactical behaviours guideline (TPG). This data is intended to be used to identify, assess and develop tactical competency in players; by drawing attention to the specific tactical behaviours that can create and prevent turnovers in netball.

2. Methods

2.1. Participants

A sample of netball experts were invited to participate in this research. Criteria for participation included having over 10 years of coaching experience. A total of 12 experts agreed to be involved in this study. Nine of the experts were head or assistant coaches in elite competitions (domestic and international), two experts were former Silver Ferns coaches, and one expert had coached at representative age group level, and had over 50 Silver Ferns test caps as a player. Although this expert had no experience coaching at the elite level, she has been involved at the elite level as a player for many years and thus had valuable knowledge to add. This group of experts are highly regarded in New Zealand Netball, with over 550 Silver Ferns test caps between them as either coaches or players, as well as extensive experience coaching and playing at the elite domestic level both in NZ and overseas. The attrition rate was low overall, with only two experts withdrawing after round one, and one expert withdrawing after round two. No explanations were offered for these withdrawals. The data gathered from these participants was still used regardless of their withdrawal.

Ethical approval was attained through AUTEC (16/436) on the 14 of September 2017.

3. Procedure

The Delphi method was selected to collect and distil the opinions and knowledge of the expert participants to create a list of tactical behaviour definitions. The Delphi method consisted of three rounds of data collection interspersed with analysis and feedback (the specific steps are outlined in Figure 1).

Traditionally, the Delphi method consists of multiple rounds of questionnaire that produce quantitative data, and a common modification is the use of one-on-one, semi-structured interviews in the first round of data collection (Keeny, Hasson, & McKenna, 2011). This modification has been used in previous research (Cupples & O'Connor, 2011; Paul & Donna, 2017) to allow for more open-ended, explorative questions to be used to produce multifaceted answers to the research question. Subsequent Delphi rounds then consist of online questionnaires. The details of each rounds of interview and questionnaire are explained below.

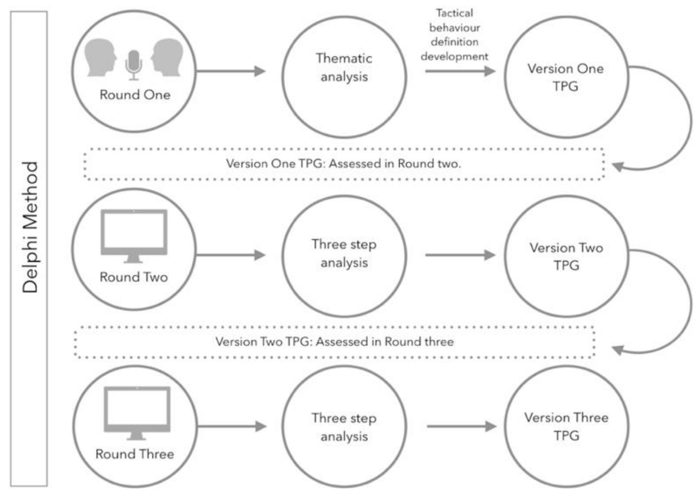

Figure 1: Outline of the Delphi research procedure.

Round 1: Each expert was interviewed in person by the first author with one interview conducted via Skype. The experts were guided by the broad question; "how do turnovers come about?" and were prompted to discuss and describe the key tactical behaviours used to create or prevent turnovers. Specifically, two questions; "what is done well on defence to create turnover opportunities" and "what is done well one attack to prevent turnovers, i.e. transfer the ball through the court" were written on a large sheet of paper, which the coaches had the opportunity to write down key areas to discuss. Probing questions were used to guide the conversation, such as; "can you explain what it looks like", "can you provide an example" were used until the expert could not provide any new information. Following the interviews, the research team analysed the expert responses to create a list of tactical behaviour definitions. These definitions were categorised into defensive and attacking behaviours and were used to create version one of the TPG (details in the data analysis section below).

Round 2: Using the tactical behaviour definitions developed in round one, an online questionnaire was created to enable the experts to rate their agreement to each of the definitions using a 4-point Likert scale; 4: strongly agree, no changes needed, 3: agree, minor changes needed, 2: disagree, major changes needed, 1: strongly disagree, should be excluded. If the definition was rated a three, two, or a one; the experts were given the opportunity to write amendments to the definition. If the tactical behaviour was rated as a one, the expert did not agree with the definition *and* believed the tactical behaviour should be excluded from the TPG, i.e. the tactical behaviour was not relevant.

While the primary intention was to create a list of definitions that expert coaches agreed upon, we also wanted to ensure that all the tactical behaviours in the TPG were considered important. In order to establish which behaviours were important the experts were asked to rank each of the tactical behaviours for their level of importance for creating turnovers on defence, and preventing turnovers on attack. The experts classified each tactical behaviour into one of four categories including; 4: very important, 3: important, 2: somewhat important, 1: not important (delete).

Based on the level of agreement and rank score for each definition, the research team analysed the results and where necessary, re-wrote the definitions to align with the experts suggested amendments to create version two of the TPG (details are provided in data analysis section below).

Round 3: The procedure for round two was repeated and the results were analysed to inform the development of the final version of the TPG (version three).

4. Data analysis

The overall aim of the analysis was to produce a list of tactical behaviour definitions which were agreed upon by the experts. Following round one, the interview data was analysed using a thematic analysis. Thematic analysis was used as the qualitative method for round one. Thematic analysis includes six steps, i) familiarization ii) generating initial codes iii) searching for themes, iv) reviewing themes, v) defining and naming themes and vi) producing the report (Braun & Clarke, 2006). Following this six step process, the interviews were transcribed verbatim and prepared for qualitative analysis. The primary researcher became familiar with the data through listening to the audio and reading the transcripts multiple times. The coding tool, Nvivo was used to aid in the organisation of codes. Each transcript was systematically read through to identify any interesting extracts within the text. Initial codes were inclusive of any areas of interest that related to the research question; 'how do turnovers come about'. Each relevant section of text was tagged, and sorted into the appropriate code within Nvivo. This process was repeated twice through the data set to ensure that all the relevant text was categorised into the appropriate codes. Codes were then sorted into potential themes by reading the extracts and combining similar codes. The second author independently cross-coded a section of the transcripts to ensure consistency in the coding process and discussions were had until agreement was reached. Each major theme that was identified was developed into a short definition with a title to describe the tactical behaviour. A small pilot study was conducted to ensure the tactical behaviour definitions were comprehensible before presenting them back to the original experts. This required two authors (AC & SM), as well as a netball participant (a local umpire), to read though the definitions and provide feedback. Following this pilot study, some very minor changes (one or two words) were made to four of the definitions. For rounds two and three, quantitative and qualitative data were used to inform the revision of the tactical behaviour definitions that were developed in round one.

The aim of the analysis for round two and three was to strengthen the validity of the definitions between each iteration, until the required level of consensus was reached (explained in the content validity section below). A secondary aim was to decrease the larger list of tactical behaviours into a smaller, more refined list, with only the most important tactical behaviours included. The process for editing the definitions and refining the list of behaviours is explained below.

4.1. Content validity: I-CVI and S-CVI

The 'item content validity index' (I-CVI) was used for each tactical behaviour definition to determine the strength of the agreement amongst the experts. Using the expert ratings of agreement, the I-CVI score was calculated by the proportion of experts who rated the definition a three or a four (agree or strongly agree to the definition) on the four point scale (Lynn, 1985; Polit & Beck, 2006). A conservative I-CVI score of 0.80 (80% of the participants) was considered content valid for this study, as only a small number of experts were involved (Lynn, 1985). The S-CVI (scale content validity) score is the content validity of the whole scale (TPG) and was also calculated by using the average I-CVI scores for all 18 tactical behaviour definitions within the TPG.

4.2. Rank order

Means and standard deviations were calculated to determine the average rank each of the tactical behaviours were given (from very important to not important, delete).

4.3. Qualitative review

A qualitative review of a definition was conducted when the content validity (I-CVI) was below 80% or the tactical behaviour was ranked as 'somewhat important' or 'not important, delete'. The suggested amendments provided by the experts were then analysed to determine whether any changes should be made to each definition, or if it should be deleted. This process was completed on a case-by-case basis using the following steps;1) all suggested amendments were summarised and were presented to the first two authors of this paper, 2) the suggested amendments were read through to look for common themes, 3) the first two authors re-wrote the definitions using the most common suggestions.

5. Results

5.1. Results: Round One

Six overarching themes were identified in the analysis including; (i) Space and movement, (ii) Timing, (iii) Deception, (iv) Support, (v) Reading play and (vi) Team cohesion. These six themes were defined as the tactical principles of netball. Sitting within these tactical principles, 26 tactical behaviours were identified and defined, which are organised into attacking, and defensive tactical behaviours. The attacking tactical behaviours include behaviours that the attacking team use to *prevent* turnovers from occurring, and the defensive tactical behaviours include behaviours that the defensive team use to *create* turnovers. The full list of tactical behaviours is shown in Table 1 below.

Table 1: Version one of the tactical principle guideline (TPG)

Tactical principles	Defensive tactical behaviours	Attacking tactical behaviours
Space and Movement	Court coverage Continuous movement Attack the line of the ball Deny catch space Dictate movement	Continuous movement Holding Penetration Balance Decisive movement
Timing	Delay and disrupt ball off-load	Reset Ball speed Getting free
Support	Defensive unity Full team defence	Options to the ball
Reading play	Reading patters Space awareness	Option selection Space awareness
Deception	Isolate	Decoy movements/fakes
Team cohesion	Role clarity within unit Communication Adapting to player tendencies	Role clarity within unit Communication Adapting to player tendencies

5.2. Results: Round two and three

5.2.1. Content validity

In version one, consensus was reached (I-CVI $\geq$ 0.80) for 23 of the 26 tactical behaviour definitions, with an S-CVI/Ave score of 0.90 (90% agreement for the definitions). In version two, consensus was reached for all 18 tactical behaviour definitions with an S-CVI/Ave score of 0.98 (98% agreement for the definitions). See Table 2 above for the I-CVI scores for the individual tactical behaviours.

5.2.2. Rank order

In version one of the TPG, 12 out of 26 tactical behaviours were ranked in the 'somewhat important' (2) or the 'not important, delete' (1) categories, including seven attacking tactical behaviours; *penetration, ball speed, continuous movement, decoy movements/fake, awareness of player tendencies, reset, and holding,* and five defensive tactical behaviours; *deny catch space, delay and disrupt ball off-load, court coverage, awareness of player tendencies, isolate*. These tactical behaviours risked being deleted from the TPG. The remaining attacking and defensive tactical behaviours were all rated in the 'important' category, with *options to the ball, getting free and decisive movement* ranked as the top attacking tactical behaviours, and *dictate movement* as the top defensive tactical behaviour. In version two of the TPG all 18 tactical behaviours we ranked in the average category. See Table 2 below to see the rank given to each tactical behaviour for rounds two and three.

Table 2: I-CVI scores and rank order for the attacking and defensive tactical behaviours.

ATTACK ING TACTICAL BEHAVIOURS							
Round Two: Version One				**Round Three: Version Two**			
Tactical behaviours	I-CVI	Rank	Qualitative review	Tactical behaviours	I-CVI	Rank	Qualitative review
Continuous movement	80%	11	Deleted				
Holding	100%	15	Definition change	*Protect space*	100%	8	No change
Penetration	90%	9=	Deleted				
Balance	90%	8	No change		100%	5	*Court balance*
Decisive movement	100%	2=	Definition change.		100%	1=	No change
Reset	100%	14	Deleted				
Ball speed	90%	9=	Definition change	*Pace of the ball*	89%	6=	No change
Getting free	90%	2=	Definition change		100%	1=	No change
Decoy movements/fakes	80%	12	Definition change	*Draw or fake*	89%	9	No change
Options to the ball	100%	4	No change		100%	1=	No change
Option selection	90%	1	Definition change		89%	4	No change
Space awareness	90%	7	Definition change		89%	6=	No change
Role clarity	100%	6	Deleted				
Communication	100%	5	Deleted				
Player tendencies	90%	13	Deleted				
DEFENSIVE TACTICAL BEHAVIOURS							
Round Two: Version One				**Round Three: Version Two**			
Tactical behaviours	I-CVI	Rank	Qualitative review		I-CVI	Rank	Qualitative review
Court coverage	80%	12	Deleted				
Continuous movement	80%	8=	Definition change	*Confuse space*	100%	4=	No change
Attack the line of the ball	50%	7	Definition change		100%	2=	No change
Deny catch space	70%	10=	Definition change	*Contest catch space*	100%	4=	Definition change
Dictate movement	100%	3=	Definition change		100%	1	No change
Delay and disrupt ball off-load	90%	10=	No change		100%	7=	No change
Isolate	70%	14	Deleted				
Defensive unity	90%	1	Definition change		100%	7=	No change
Full team defence	100%	3=	Definition change		100%	2=	Definition change
Reading patterns	100%	8=	Definition change		100%	6	No change
Space awareness	100%	2	No change		100%	9	No change
Role clarity	100%	3=	Deleted				
Communication	100%	3=	Deleted				
Player tendencies	90%	13	Deleted				

5.2.3. Qualitative review

Despite the high level of consensus achieved for the 26 tactical behaviour definitions, the suggested amendments made by the experts highlighted that further refinements were needed. The research team reviewed the definitions on a case-by-case basis to look for common themes in the suggested amendments. In some cases, the experts suggested changes for the tactical behaviour title, shown in *italics* in Table 2 above. For example, 'ball speed' was changed to 'pace of the ball'. Two in-depth examples of the qualitative review process are provided in Table 3 and Table 4 below, showing both a change of definition, and a change in title.

In round two, *continuous movement* was ranked eighth equal out of 14 tactical behaviours, and while the I-CVI score was sufficient (80% agreement), the suggested amendments made by the experts highlighted some minor changes that could be made. As shown in Table 3 below, experts four, six and eight, suggested a change in the title, and therefore *confuse space* was used. Expert three also suggested that there needed to be reference to the opposition player therefore, we added "movement around an attacking player". Following these changes, in round three, the new tactical behaviour *confuse space* achieved an improved I-CVI score of 1.0 (100% agreement) and was now ranked as the fourth equal (out of nine) for the most important tactical behaviours creating turnovers on defence.

Table 3: Example of suggested amendments for the continuous movement tactical behaviour

Version one definition: Continuous movement: The actions of players to create the illusion that spaces on court are covered.
Suggested amendments:

Expert 2: "Perhaps try "creating the illusion that spaces on court are available""

Expert 3: "The actions of players to create the illusion that spaces and or opposition players on court are covered"

Expert 4: "Continuous movement sounds frenetic, sometimes in defence I would want the illusion that there is space to pass the ball for the purpose of intercepting"

Expert 6: "Preference here would be "con to create" with definition being smart movement of players to create gains"

Expert 8: "Change continuous movement to confuse space or contest ball"

Version two definition: Confuse space: Varied movement around an attacking player to open or close the space they have available to receive a pass

In another example, the attacking tactical behaviour *holding* achieved an I-CVI score of 100% agreement in round two, however, it was ranked as the least important tactical behaviour. The expert amendments were used to re-write the definition and title. As shown in Table 4 below, many of the experts suggested adding "to receive a pass", therefore, we added "to show a clear space to receive a pass for yourself or another player". Expert six also raised concern about the title *holding* as this could be considered an illegal action in netball. A more passive title of *protect space* was put forward, which was included in the initial definition. In round two, the definition maintained an I-CVI score of 1.0 (100% agreement), and while it remained as a low ranked behaviour (8th out of nine), the authors agreed that it would remain in the TPG.

Table 4: Example of suggested amendments for the 'holding' tactical behaviour

Version one definition: Holding: The ability of the attacking player to use their body to protect space.
Suggested amendments:

Expert 3: "To receive a pass"

Expert 4: "Protect space in which to receive a pass or protect for a team mate to receive a pass i.e. screen"

Expert 6: "The ability of an attacking player to use their body to show a clear space for passer. I am slightly concerned at this one as internationally we have been getting a lot of umpiring calls against us due to our technique of "holding"".

Expert 8: "The ability of any player to use their body to protect or create space for self or others"

Version two definition: Protect Space: Using the body to create and show a clear space to receive a pass for yourself or another player

In summary, the expert responses from the questionnaire in Delphi round two, informed many changes to version one of the TPG including; fourteen re-written tactical behaviour definitions, five title changes, and eight deleted tactical behaviours. Five of the deleted definitions included the attacking tactical behaviours, *continuous movement*, *penetration and reset*, and the defensive tactical behaviours were *court coverage* and *isolate*. These five tactical behaviours were ranked low (9th= place or lower) in round one, and while they could have been re-written, a decision was made to exclude them, as many of definitions remaining in the TPG already captured the concepts the behaviours were attempting to define. In addition, *role clarity*, *communication* and *player tendencies* were removed from the list of definitions. While these three behaviours were considered important, upon reflection the researchers viewed them more as foundational concepts more underpinning all tactical behaviour and were therefore removed.

In round three, three minor changes to the definitions were made, however it was agreed upon by the research team that these changes did not alter the meaning of the definition in any significant way, and it was unanimously agreed that a fourth Delphi round was not needed to confirm definition agreement.

5.2.4. Version three: The final version of the TPG

The final version of the tactical principles guideline in Figure 2 below includes 18 tactical behaviour definitions (nine attacking behaviours and nine defensive behaviours), and four overarching tactical principles including; i) Space and movement, ii) Timing, iii) Support and iv) Reading play. The reduction of six tactical principles to four was informed by the changes made to the tactical behaviour definitions. The *team cohesion* tactical principle was removed following the removal of all of the tactical behaviours it categorised including; *role clarity, communication and player tendencies*. In addition, the *deception* tactical principle was removed following the removal of the defensive tactical behaviour *isolate*. The attacking tactical principle *draw and fake* was originally categorised in the *deception* principle, but was re-organised into the *space and movement* principle. The full list of definitions is not included in this paper but will be made available upon request.

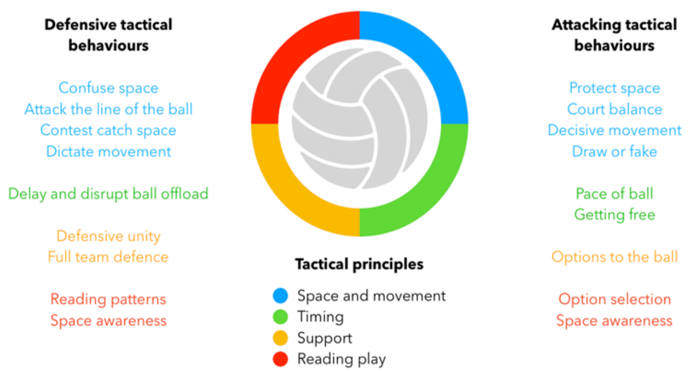

Figure 2: Final version of the tactical principles guideline (TPG).

6. Discussion

The primary aim of this study was to use expert knowledge to develop a clear understanding of the tactical behaviours that contribute to turnovers in netball. Furthermore, the study aimed to expand upon the context deficient notational measures currently being used in elite level netball (Mclean et al., 2019). Following three rounds of consultation with netball experts, four tactical principles were identified, and consensus was reached for 18 tactical behaviours which formed the tactical principles guideline (TPG). In line with current research trends in performance analysis, the tactical behaviours in the TPG adopt a holistic approach to describe *why* or *how* turnovers occur in netball, revealing a complex system of behaviour capturing a broader scope of tactical intentionality (Mclean et al., 2019).

The four tactical principles included in the TPG and the associated tactical behaviours are discussed below. This discussion will begin with *reading play* as logical start point as this principle reflects the perceptual-cognitive behaviours need to attend to environmental information. The *space and movement* and *timing* principles will be discussed next to describe how players use environment information to act (manipulating space and time), and then finally the *support* tactical principle will be explained to provide an overview for how tactical behaviours are used by teams to operate as a unit.

6.1. Reading play

The tactical principle *reading play* is closely linked to decision making as the ability to perform the right action at the right moment, requires players to 'read the game' and react with an appropriate response (Elferink-Gemser et al., 2010). The concept of *reading play* has been heavily researched in the team sport literature, where references to the perceptual-cognitive aspects of attention, pattern recall, and anticipation have been shown to be determining factors in sporting expertise (Farrow, 2010). The identification of the *reading play* principle by the experts in this current study is corroborated by the identification of a similar concept of 'spatial awareness' in the work conducted by Mclean et al. (2019). Spatial awareness was not specifically defined in the Mclean et al. (2019) research, however, in this current study the tactical behaviour *space awareness* was defined for both attack and defence. For attacking players, *space awareness*, relates to one's ability to read spaces to move into or pass to, and on defence, *space awareness* is concerned with the ability to read the spaces attacking players want to use, to stop them.

6.2. Space and movement and timing

The *space and movement* and *timing* tactical principles represent a variety of actions that players enact to solve tactical problems on court. Space and time represent two key constrains in team sports, as players must navigate different spatiotemporal barriers to maintain possession and score on attack, and prevent scoring and regain possession on defence (Grehaigne, Bouthier, & David, 1997). The tactical behaviours identified in the *space and movement* and *timing* principles define how players can create affordances for their teammates or create unpredictability for their opponents. The importance of these behaviours is reflected in the results of this current study as the experts identified the attacking tactical behaviours; *decisive movement, getting free* and *protect space* as the most important behaviours for *preventing* turnovers and *decisive movement* as the most important defensive tactical behaviour for *creating* turnovers.

The *timing* tactical principle is analogous to the concept of 'controlling momentum' identified in the study conducted by Mclean et al. (2019). In their study, *controlling momentum* was defined as "the ability to slow down or speed up play as the match situation demands" (Mclean et al., 2019, p. 9). The expert coaches in this present study, were able to expand on this concept and explain the potential mechanisms that players use to control momentum in netball. For example, the attacking tactical behaviour *pace of the ball*, explains how the varied use of timing (release of the pass on the 1st, 2nd or 3rd second) or the type of pass (a fast-flat pass compared to a slow lob pass), can create unpredictability and thus disrupt the defensive teams attempts to gain a turnover. In addition, the defensive tactical behaviour *delay and disrupt ball offload*, defines how defensive players can control momentum through disrupting the attacking players vision and slowing down the release of a pass.

6.3. Support

The final tactical principle is *support* which describes how players support each another to reach performance goals, i.e. gaining turnovers and maintaining possession. The *support* principle is prevalent in all 'passing-catching' dyads in netball, as the player in possession of the ball is constrained by the rules of the game (not being able to move and having to pass the ball within three seconds). Therefore, the passer becomes reliant on their teammates to create passing affordances for them (*options to the ball)*. For the defensive team, the *support* principle identifies how players work as a cohesive unit to create turnovers. The scenario in Figure 3 below, provides an example of the support principle, and specifically the tactical behaviour; defensive unity. In image A, Figure 3 below, the scenario shows the goal keep (GK) moving away from her opposition partner, leaving the goal shoot (GS) unmarked (as shown in arrow one). As a reaction, the GD moves into the goal circle (as shown by arrow two), to defend the GS. This movement is an example of defensive unity, and explains how defensive teams maintain a unit structure, or re-stabilise balance to provide support or cover for their teammates.

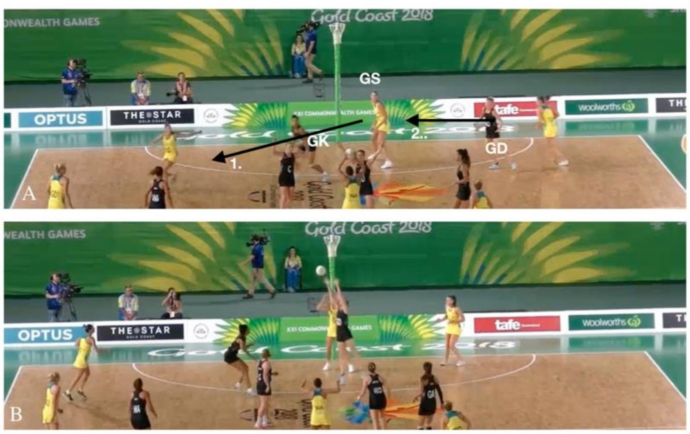

Figure 3: Example of the support tactical behaviour; defensive unity.

As shown in image B, Figure 3, the pass is released to the GS, and is subsequently intercepted by the GD. While this turnover was gained by the GD, the intercept affordance was created from the actions of the other defensive players. In addition to the movements of the GK, the ball carrier is also being guarded by two defensive players; wing defence (WD) and centre (C) who are *delaying and disrupting ball offload,* (as shown in image A, Figure 3). This tactical behaviour disrupts the passers vision and slows down the release of the pass, allowing the GD more time to read play. This example highlights that turnovers are the result of multiple interacting players, using a variety of tactical behaviours. While the GD in Figure 3 still had to use individual tactical behaviours such as *attack the line of the ball* and *contest catch space,* the opportunity to gain a turnover would not have been there, if not for the actions of the other defensive players.

7. Conclusion

The Delphi method used in this study has prioritised the expert voice, allowing for the development of clear and concise definitions for tactical competency in netball. A priority for future research is to understand the complex interactions that occur between these tactical behaviours to better understand how to create winning performances in netball (Araujo, Davids, & Hristovski, 2006). If future research is able to identify the factors that differentiate successful and unsuccessful teams, specific training for particular tactical behaviours can be prioritised and incorporated into training (Farrow, 2010).

7.1. Practical Applications

While it is important to assess individual behaviour in team sport, we recommend that tactical behaviour must be understood in the context of the team. Therefore, when using game statistics to assess performance i.e. individual statistics which show the number of passing errors or intercepts a player has, it is important to acknowledge that those errors or successes, are the result of the interactions of multiple players on court, and not solely a reflection of that players tactical ability. The tactical behaviour definitions developed from this study have been incorporated into Netball New Zealand's player profiling tool, using the four tactical principles, *space and movement, timing, support and reading play* to assess player competency. The definitions in the TPG, allow for the exchange of ideas through a shared vocabulary and therefore, can be used to increase the quality communication between coaches and players. The continued development of the TPG will create a strong foundation which to enhance tactical development and game analysis in netball. As a first step, further research is needed to determine if netball experts (coaches) are able to identify the tactical behaviours in the TPG in real game contexts, and specifically identify the complex relationships these tactical behaviours have to turnovers in netball.

Conflict of Interest

The authors declare no conflict of interests.

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References

Araujo, D., Davids, K., & Hristovski, R. (2006). Dynamics of decision making in sport. *Psychology of Sport and Exercise, 7*(6), 653-676.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77-101. https://doi.org/10.1191/1478088706qp063oa

Bruce, L., Farrow, D., Raynor, A., & May, E. (2009). Notational analysis of skills expertise differences in netball. *International Journal of Performance Analysis of Sport, 9*(2), 245-254.

Correia, V., Araujo, D., Vilar, L., & Davids, K. (2013). From recording discrete actions to studying continuous goal-directed behaviours in team sports. *Journal of Sports Sciences, 31*(5), 546-553. https://doi.org/10.1080/02640414.2012.738926

Croft, H., Willcox, B., & Lamb, P. (2018). Using performance data to identify styles of play in netball: An alternative to performance indicators. *International Journal of Performance Analysis in Sport, 17*(6), 1034-1043. https://doi.org/10.1080/24748668.2017.1419408

Cupples, B., & O'Connor, D. (2011). The development of position-specific performance indicators in elite youth rugby league: A coaches perspective. *International Journal of Sports Science and Coaching, 6*(1), 125-141.

Elferink-Gemser, M., Kannekens, R., Huijgen, B., Tromp, Y., Jonker, L., Toering, T., & Visscher, C. (2010). Reading and writing the game: Tactical skills in team sports. In *Youth sports: growth, maturation and talent* (pp. 165-177). https://doi.org/10.14195/978-989-26-0506-7_11

Farrow, D. (2010). A multi-factoral examination of the develpment of skill expertise in high performance netball. *Talent Development and Excellence, 2*(2), 123-135.

Garcia, J., Ibanez, S., De Santos, R., Leite, N., & Sampaio, J. (2013). Identifying basketball performance indicators in regular season and play off games. *Journal of Human Kinetics, 36*, 163-170.

Garganta, J. (2009). Trends of tactical performance analysis in team sports: Bridging the gap between research, training and competition. *Portuguese Journal of Sport Sciences, 9*(1), 81-89.

Gonzalez-Villora, S., Serra-Olivares, J., Pastor-Vicedo, J. C., & da Costa, I. T. (2015). Review of the tactical evaluation tools for youth players, assessing the tactics in team sports: football. *SpringerPlus, 4*, 663. https://doi.org/10.1186/s40064-015-1462-0

Grehaigne, J. F., Bouthier, D., & David, B. (1997). Dynamic-system analysis of opponent relationships in collective actions in soccer. *Journal of Sports Sciences, 15*, 137-149.

Grehaigne, J. F., Godbout, P., & Bouthier, D. (2001). The teaching and learning of decision making in team sports. *Quest, 53*, 59-76.

Higham, D., Hopkins, W., Pyne, D., & Anson, J. (2014). Performance indicators related to points scoring and winning in international rugby sevens. *Journal of Sports Science and Medicine., 13*, 358-364.

Hsu, C., & Sandford, B. (2007). The delphi technique: Make sense of consensus. *Practical Assessment, Research and Evaluation, 12*(10), 1-8.

Hughes, M. D., & Bartlett, R. M. (2002). The use of performance indicators in performance analysis. *Journal of Sports Sciences, 20*(10), 739-754. https://doi.org/10.1080/026404102320675602

INF. (2016). *Rules of netball*. Retrieved 11/10/19, from https://netball.sport/game/the-rules-of-netball/

Keeney, S., Hasson, F., & McKenna, H. P. (2011). *The Delphi technique in nursing and health research* [Electronic document]: Wiley-Blackwell. Retrieved from http://ebookcentral.proquest.com/lib/AUT/detail.action?docID=624638

Lynn, M. (1985). Determination and quantification of content validity. *Nursing Research, 35*(6), 382-386.

Mclean, S., Hulme, A., Mooney, M., Read, G., Bedford, A., & Salmon, P. (2019). A systems approach to performance analysis in women's Netball: Using work domain analysis to model elite netball performance. *Frontiers in Psychology, 10*(201), 1-13. https://doi.org/10.3389/fpsyg.2019.00201/full10.3389/fpsyg.2019.00201

McLean, S., Salmon, P. M., Gorman, A. D., Read, G. J. M., & Solomon, C. (2017). What's in a game? A systems approach to enhancing performance analysis in football. *PloSOne, 12*(2), 1-15. https://doi.org/10.1371/journal.pone.0172565

Morley, D., Morgan, D., McKenna, J., & Nicholls, A. (2014). Developmental contexts and features of elite academy football players: Coach and player perspectives. *International Journal of Sports Science and Coaching, 9*(1), 217-232.

Mullen, P. M. (2003). Delphi: Myths and reality. *Journal of Health Organisation and Management, 17*(1), 37-52. https://doi.org/10.1108/14777260310469319

O'Donoghue, P., Mayes, A., Edwards, K., & Garland, J. (2008). Performance norms for british national super league netball. *International Journal of Sports Science and Coaching, 3*(2), 501-511.

Paul, L., & Donna, O. C. (2017). Talent identification and recruitment in youth soccer: Recruiter's perceptions of the key attributes for player recruitment. *PloS One, 12*(4), 1-15. https://doi.org/10.1371/journal.pone.0175716

Polit, D. F., & Beck, C. T. (2006). The content validity index: Are you sure you know what's being reported? Critique and recommendations. *Research in Nursing and Health, 29*(5), 489-497. https://doi.org/10.1002/nur.20147

Pulling, C., Eldridge, D., & Lomax, J. (2016). Centre Passes in the UK Netball Super League. *International Journal of Performance Analysis in Sport, 16*, 389-400.

Saavedra, J. M., Porgeirsson, S., Chang, M., Kristjánsdóttir, H., & García-Hermoso, A. (2018). Discriminatory power of women's handball game-related statistics at the Olympic games (2004-2016). *Journal of Human Kinetics, 62*(1), 221-229.

Silva, P., Garganta, J., Araújo, D., Davids, K., & Aguiar, P. (2013). Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports. *Sports Medicine, 43*(9), 765-772. https://doi.org/10.1007/s40279-013-0070-9.

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Warm-up strategies of elite triathletes competing in the International Triathlon Union World Triathlon Series and Paratriathlon events: A case study

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ABSTRACT

The use of a warm-up is a widely recommended and adopted strategy for athletes to optimise performance. However, limited recommendations about the optimal warm-up strategy for triathletes exist. Therefore, the purpose of this study was to investigate the warm-up strategies of elite triathletes in preparation for competition. Ten elite triathletes (n=6 female and n=4 male, age: 26.8±6.1 y) currently competing in the International Triathlon Union World Triathlon Series (n=8) or Paratriathlon Series (n=2) and including both Olympic and Paralympic medalists, completed a survey about their warm-up routine. For the World Series athletes, the range in total warm-up duration was 25-55 min, which included 8-20 min of swimming, 0-30 min of cycling, and 5-25 min of running. For the Paratriathlon athletes, the range of total warm-up duration was 15-25 min, which included 5-15 min of swimming, 0-10 min of cycling, and 0-10 min of running. Elite triathletes finished their warm-up 13±5 min prior to race start. The inclusion of additional warm-up strategies varied in frequency: dynamic activation drills (7/10; 70%), short sprints (7/10; 70%), static stretching (5/10; 50%), technique drills (5/10; 50%), static muscle activations (3/10; 30%), foam rolling (2/10; 20%) and massage (0/10; 0%). There is a large range in the duration and intensities of the warm-up strategies amongst elite triathletes, which highlights the individual needs of the athletes and/or a lack of scientific recommendations available. Future research should be based on current practice to begin to develop an optimal warm-up routine for triathletes. Developing athletes can experiment with modified versions of current practice during training in scenarios simulating competition.

1. Introduction

The use of a warm-up prior to competition is a widely recommended and adopted strategy for all athletes (Bishop, 2003). A range of different warm-up strategies have been beneficial to improve explosive performance for team sports (i.e. jumping, sprinting and agility tasks), including warm-up protocols involving repeated sprints, dynamic exercises, small-sided games and the application of heated garments (Silva, Neiva, Marques, Izquierdo, & Marinho, 2018). Warm-up strategies are also beneficial for swimming, cycling and running-based tasks, which has been attributed to temperature, metabolic, neural and psychological mechanisms (McGowan, Pyne, Thompson, & Rattray, 2015). However, much of the literature investigating warm-up has been criticised due to methodological issues, including: i) a low sample size, ii) untrained populations, iii) ecological difficulties of simulating competition scenarios (e.g. the delay caused by pre-competition marshaling), and iv) lack of and/or inappropriate statistical analyses (Bishop, 2003; McGowan et al., 2015). Hence, it has been suggested that warm-up routines of elite athletes are largely based on trial-and-error, rather than empirical evidence (Bishop, 2003).

Warm-up is considered to be important for elite triathletes due to the high physiological demands on the athlete at the start of the event as speed over the first 222 m of the swim leg was highly associated with finishing position (Vleck, Bentley, Millet,

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& Burgi, 2008). However, limited research on warm-up is available specifically for triathletes, with a single investigation demonstrating that a 10-minute swim or 10-minute run/swim warm-up did not significantly improve swim or triathlon performance (Binnie, Landers, & Peeling, 2012). Therefore, other strategies that may be effective require investigation. However, a challenge exists in research concerning triathlon where there are many possible amalgamations of warm-up (i.e. different durations of swimming, cycling, running, the distribution of intensity and the timing prior to race start), researchers need an appropriate starting point that is applicable to athletes who are currently competing. Therefore, the purpose of this case study is to describe the warm-up strategies of elite triathletes, with the view that these athletes are likely utilising sound warm-up practices, and the 'current practice' of these elite athletes represents an appropriate comparison for any new interventions that are to be investigated.

2. Methods

2.1. Approach

An online survey instrument was developed to elicit information relating to the pre-event warm-up strategies and beliefs of elite triathletes. A letter of invitation and guidelines for the online survey (surveymonkey.com, California, Palo Alto, USA) were distributed electronically to individual athletes that currently compete in the International Triathlon Union (ITU) World Triathlon Series and Paratriathlon events. Also, letters of invitation were provided to professional coaches to encourage the participation of their athletes who met this inclusion criterion. Athletes were asked to report their name and race results, which were verified at www.triathlon.org/results and then de-identified prior to analysis.

2.2. Participants

Ten elite triathletes (n=6 female and n=4 male, age: 26.8±6.1 y) who currently compete in the ITU World Triathlon Series (n=8) or Paratriathlon Series (n=2) volunteered for the study. Participants had competed at this level for 1-10 years. The sample included both Olympic and Paralympic medalists. The Human Research Ethics Committee at the University of Newcastle granted approval for the project (H-2015-0305) and participants provided written informed consent prior to commencing the survey. There was no incentive to participate.

2.3. Procedure

Participants completed 11 major items related to their pre-event warm-up strategies. Participants were asked to indicate if they complete a warm-up and the average duration and intensity of that warm-up separately for swimming, cycling, and running. Intensities were defined as "very light-comfortable (low intensity)," "somewhat hard-hard (moderate intensity)" and "very hard-maximal (high intensity; greater than anaerobic threshold)." Only three intensity zones were included in order to minimise confusion and create a consistent definition of intensity between participants. Participants were asked how long prior to an event they aim to finish their warm-up and whether they include a range of common additional strategies, including: dynamic activations, short sprints, static stretching, technique drills, static muscle activations, foam rolling and massage. Further, participants were asked why (or why not) they complete a warm-up and if any factors influence their normal routine.

2.4. Statistical approach

As the present study is a descriptive cross-sectional survey design, the analysis and presentation of data are descriptive, and presented as ranges, proportions, and percentages.

3. Results

The individual warm-up durations and intensity distributions of the triathletes are illustrated in Figure 1.

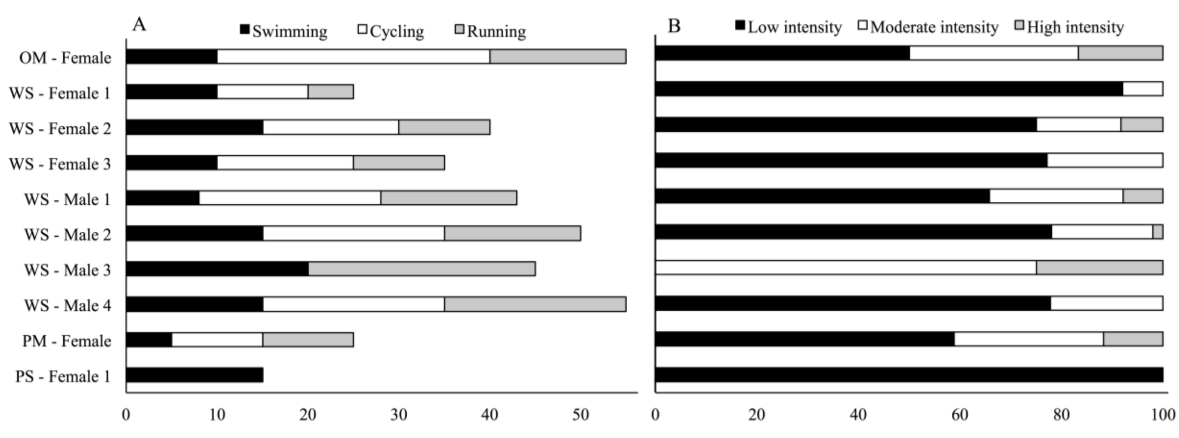

Figure 1: Individual triathlon-specific warm-up duration (A) and intensity distribution (B) for elite ITU world series triathletes (n=8) and paratriathletes (n=2).

For the ITU World Series athletes, the total warm-up duration ranged from 25-55 min, which included 8-20 min of swimming, 0-30 min of cycling and 5-25 min of running. The intensity distribution of these warm-ups ranged from 0-92% at a low intensity, 8-75% at moderate intensity, and 0-25% at high intensity. For the ITU Paratriathlon athletes, the range of total warm-up duration was 15-25 min, which included 5-15 min of swimming, 0-10 min of cycling and 0-10 min of running. The intensity distribution of these warm-ups included 59-100% at low intensity, 0-29% at moderate intensity and 0-12% at high intensity.

Elite triathletes aimed to finish their warm-up 5-20 min prior to the race start. Additional strategies included in the warm-up were: dynamic activation drills (7/10; 70%), short sprints (7/10; 70%), static stretching (5/10; 50%), technique drills (5/10; 50%), static muscle activations (3/10; 30%), and foam rolling (2/10; 20%). No triathlete reported the use of massage in their warm-up routine. Commonly reported reasons to perform a warm-up included: to perform better (6/10; 60%), to increase blood flow (5/10; 50%), to increase energy production (4/10; 40%), to increase concentration (4/10; 40%) or to increase body temperature (3/10; 30%). Most triathletes noted that they would decrease the duration of their warm-up in the heat (8/10; 80%), however fewer triathletes would increase the duration in the cold (4/10; 40%). Time (8/10; 80%) and space (6/10; 60%) were factors that would influence a triathlete's warm-up strategy.

4. Discussion

This case study has identified that all elite triathletes surveyed perform a pre-event warm-up, however, an important finding was the variation of the total warm-up duration and the intensity distribution of the triathlon specific warm-up activities. The varied approach to the warm-ups can be attributed to several factors. Firstly, these warm-up routines were likely developed specifically for the individual, to help prepare them physically and mentally. Secondly, there is limited research on triathlon specific warm-up protocols and subsequently, there are no empirical recommendations available about the effectiveness of different warm-up strategies for triathletes. Hence, the individual routines were likely developed through trial-and-error rather than on the basis of empirical research (Bishop, 2003).

The majority of the warm-ups for both World Series and Paratriathlon Series athletes are made up of low intensity activities, and 4/10 of the athletes do not include any high intensity activity in their warm-up. Previously, the inclusion of high intensity activity has significantly improved 100 m swim time (Neiva et al., 2014) and 800 m run time (Ingham, Fudge, Pringle, & Jones, 2013), however reducing the amount of high intensity activity has been shown to be beneficial for sprint cycling (Tomaras & MacIntosh, 2011). Furthermore, researchers have also reported the benefits of a low intensity warm-up compared with no warm-up at all (Zourdos et al., 2017). With these mixed findings, there are no clear evidenced-based guidelines for triathletes to use to prescribe their warm-up. However, warm-up recommendations exist for explosive performance, which include 10-15 minutes of cardiovascular exercise that gradually increases in intensity (to 50-90%), and the use of heated garments afterwards to maintain muscle temperature (Silva et al., 2018). Further, 2 minutes of re-warm-up including sprints is needed when the rest period is longer than 15 minutes. Hence, such a strategy may also be useful for triathletes who are required to perform an explosive swim start, which allows them to move to the front of the field and later position themselves in the front group during the bike leg.

The majority of elite triathletes surveyed also perform dynamic activation drills and short sprints, which have been described as ergogenic (McGowan et al., 2015; Yamaguchi, Takizawa, & Shibata, 2015) and half practiced some form of technique drill as a part of their warm-up routine. The majority of triathletes also followed current recommendations to reduce the warm-up duration in hot conditions (McGowan et al., 2015). However, half of the triathletes employed the out-dated strategy of static stretching, which is not recommended prior to endurance exercise (Lowery et al., 2014; Peck, Chomko, Gaz, & Farrell, 2014; Wilson et al., 2010). Finally, two of the triathletes performed foam rolling and none received massage, which suggests that most of the triathletes do not feel that they gain benefits from these strategies.

The data presented should not be considered as an optimal warm-up. Empirical research is needed to determine if the warm-up strategies presented here are beneficial, and to identify how these strategies could be improved to optimise triathlon performance. Examples of potential future comparative studies to optimise triathlon specific warm-up are illustrated in Table 1. In Table 1, Trial 1 represents 'current practise', which can be guided by the results of the current study and Figure 1. The other trials represent altered versions of current practice across five different variables to be examined individually, which may be useful warm-up interventions for future researchers to investigate. This research should apply a randomised cross-over design to investigate the effect of warm-up duration, intensity, timing and modality with foundations around current practice. The additional strategies incorporated by the athletes such as drills, sprints and foam rolling also warrant investigation. Finally, future researchers should ensure that their performance tests are both reliable and valid, by implementing time-trial protocols, race specific hydration practices and incorporating appropriate facing wind speed (Stevens & Dascombe, 2015). Cycling ergometers that allow triathletes to use their own bikes (Novak, Stevens, & Dascombe, 2015) and treadmills that permit subconscious pacing strategies (Stevens et al., 2015) are also available to maximise external validity in the laboratory.

Due to the limited literature regarding the effects of warm-up on triathlon performance, and the likely individualised trial-and-error approach adopted by most athletes, developing triathletes should not blindly copy the practices of the elite athletes reported within this study. Instead, they should consider these strategies relative to what is practical in their situation, but they should ultimately work with their coach to optimise their individual regime when training in simulated competition scenarios. An example of a suitable warm-up based on the Olympic medal winning athlete in the current study (OM Female, Figure 1) would be 30 min of cycling, 15 min of running and 10 min of swimming, where 50% of each activity is completed at low intensity, 35% at moderate intensity and 15% at high intensity. An alternative recommendation provided by a Triathlon Australia Sports Scientist would be 10 min of cycling including 3 x sprints, optional 3-5 min of running at low

Table 1. Potential research projects needed to optimise triathlon specific warm-up where each variable to be optimised is to be investigated separately.

Variable to be Optimised	Trial 1 (Current Practice)	Trial 2 (Novel Strategy 1)	Trial 3 (Novel Strategy 2)	Trial 4 (Control)
Duration	Swim/bike/run durations generally consistent with current practice	Swim/bike/run durations generally shorter than current practice	Swim/bike/run durations generally longer than current practice	No warm-up
Intensity	Combination of low intensity, moderate intensity and high intensity	Low intensity activity only	Combination of low intensity and moderate intensity only	No warm-up
Timing	Warm-up completed shortly before race start (e.g. 10-15 min)	Warm-up completed very close to race start (e.g. within 5 min)	Warm-up completed well before race start (e.g. >20 min)	No warm-up
Modality	Include swim, bike and run	Include swim only	Include swim and bike only	No warm-up
Additional strategies	Include dynamic drills	Include static activation drills	Include foam rolling	No warm-up

intensity and then 15 min of swimming including drills and 4x50 s high intensity with 20 s rest. It is recommended to complete the warm-up in the order of cycling, running then swimming as this is the most practical format to meet bike-racking requirements and maximise preparedness for the swim. It is recommended to finish the warm-up 10-15 minutes prior to race start.

The current study is limited by a small sample size, as a trade off exists between quality (i.e. elite level) and quantity of recruitment. Other elite triathletes not included here may perform different warm-up routines, however, the current case study does provide a snapshot of the current practice of some elite ITU triathletes. The study is also limited by the participant's interpretation of our descriptors of the intensity categories used. Three categories were chosen with perceived exertion descriptors to assist with understanding and to minimise confusion.

This study has identified that all of the elite triathletes surveyed perform a pre-event warm-up, but variations exist within the total warm-up duration and the intensity distribution of the warm-up activities, likely due to a lack of empirical evidence and recommendations available. Approximately half of the athletes incorporate high intensity activities, while half perform low-moderate intensities only. Most of the athletes follow recommendations to incorporate dynamic activations and short sprints in their warm-up. Future research should aim to provide specific recommendations for triathletes that are relevant to elite athletes by incorporating current practice into original research. Researchers investigating the effects of warm-up in triathletes should make comparisons to the current practice of elite athletes, as well as experiment with variations of current practice (as per Table 1). Until this research is available, coaches with developing athletes should experiment with various versions of current practice (as per Figure 1) in training scenarios that simulate competition. It is vital that the chosen warm-up routine is thoroughly tested and deemed effective by the athlete to maximise the belief and confidence gained prior to the event.

Conflict of Interest

The authors declare no conflict of interests.

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References

Binnie, M. J., Landers, G., & Peeling, P. (2012). Effect of different warm-up procedures on subsequent swim and overall sprint distance triathlon performance. *The Journal of Strength and Conditioning Research*, *26*(9), 2438-2446. doi:10.1519/JSC.0b013e31823f29c6.

Bishop, D. (2003). Warm up II: Performance changes following active warm up and how to structure the warm up. *Sports Medicine*, *33*(7), 483-498.

Ingham, S. A., Fudge, B. W., Pringle, J. S., & Jones, A. M. (2013). Improvement of 800-m running performance with prior high-intensity exercise. *The International Journal of Sports Physiology and Performance*, *8*(1), 77-83.

Lowery, R. P., Joy, J. M., Brown, L. E., Oliveira de Souza, E., Wistocki, D. R., Davis, G. S., . . . Wilson, J. M. (2014). Effects of static stretching on 1-mile uphill run performance. *The Journal of Strength and Conditioning Research*, *28*(1), 161-167. doi:10.1519/JSC.0b013e3182956461.

McGowan, C. J., Pyne, D. B., Thompson, K. G., & Rattray, B. (2015). Warm-Up strategies for sport and exercise: Mechanisms and applications. *Sports Medicine, 45*(11), 1523-1546. doi:10.1007/s40279-015-0376-x.

Neiva, H. P., Marques, M. C., Fernandes, R. J., Viana, J. L., Barbosa, T. M., & Marinho, D. A. (2014). Does warm-up have a beneficial effect on 100-m freestyle? *The International Journal of Sports Physiology and Performance, 9*(1), 145-150. doi:10.1123/ijspp.2012-0345.

Novak, A. R., Stevens, C. J., & Dascombe, B. J. (2015). Agreement between LeMond Revolution cycle ergometer and SRM power meter during power profile and ramp protocol assessments. *Journal of Science and Cycling, 4*(3), 37.

Peck, E., Chomko, G., Gaz, D. V., & Farrell, A. M. (2014). The effects of stretching on performance. *Current Sports Medicine Reports, 13*(3), 179-185. doi:10.1249/jsr.0000000000000052.

Silva, L. M., Neiva, H. P., Marques, M. C., Izquierdo, M., & Marinho, D. A. (2018). Effects of Warm-Up, Post-Warm-Up, and Re-Warm-Up Strategies on Explosive Efforts in Team Sports: A Systematic Review. *Sports Medicine, 48*(10), 2285-2299. doi:10.1007/s40279-018-0958-5.

Stevens, C., & Dascombe, B. (2015). The reliability and validity of protocols for the assessment of endurance sports performance: An updated review. *Measurement in Physical Education and Exercise Science, 19*(4), 177-185.

Stevens, C. J., Hacene, J., Sculley, D. V., Taylor, L., Callister, R., & Dascombe, B. (2015). The reliability of running performance in a 5 km time trial on a non-motorized treadmill. *International Journal of Sports Medicine, 36*(9), 705-709. doi:10.1055/s-0034-1398680.

Tomaras, E. K., & MacIntosh, B. R. (2011). Less is more: Standard warm-up causes fatigue and less warm-up permits greater cycling power output. *Journal of Applied Physiology, 111*(1), 228-235. doi:10.1152/japplphysiol.00253.2011.

Vleck, V. E., Bentley, D. J., Millet, G. P., & Burgi, A. (2008). Pacing during an elite Olympic distance triathlon: comparison between male and female competitors. *Journal of Science and Medicine in Sport, 11*(4), 424-432. doi:10.1016/j.jsams.2007.01.006.

Wilson, J. M., Hornbuckle, L. M., Kim, J. S., Ugrinowitsch, C., Lee, S. R., Zourdos, M. C., . . . Panton, L. B. (2010). Effects of static stretching on energy cost and running endurance performance. *The Journal of Strength & Conditioning Research, 24*(9), 2274-2279. doi:10.1519/JSC.0b013e3181b22ad6.

Yamaguchi, T., Takizawa, K., & Shibata, K. (2015). Acute Effect of Dynamic Stretching on Endurance Running Performance in Well-Trained Male Runners. *The Journal of Strength & Conditioning Research, 29*(11), 3045-3052. doi:10.1519/jsc.0000000000000969.

Zourdos, M. C., Bazyler, C. D., Jo, E., Khamoui, A. V., Park, B. S., Lee, S. R., . . . Kim, J. S. (2017). Impact of a submaximal warm-up on endurance performance in highly trained and competitive male runners. *Research Quarterly for Exercise and Sport, 88*(1), 114-119. doi:10.1080/02701367.2016.1224294.

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

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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

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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.

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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.

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Movement and physiological demands of amateur mixed martial art fighting

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ABSTRACT
To quantify in-competition physiological loads of amateur mixed martial arts (MMA), we recruited 10 male MMA athletes (Age: 27.3 ± 3.3 y; mass: 79.5 ± 0.5 kg; height: 1.77 ± 0.04 m) training 9 ± 4 h.wk. Athletes were filmed during 3 x 5 min competitive rounds while notational analysis was performed post-fight using referee head-mounted camera video-recordings. Standing punches including elbows thrown, kicks attempted and landed, and accumulated time-fighting while standing, clinching and grappling (wrestling on the ground) were quantified. Athletes' heart rates were measured between rounds, while athletes' earlobe sampled blood lactate and perceived exertion (RPE) were recorded immediately post-fight. Results demonstrated 39 ± 18 punches were thrown/round, but only 20 ± 11 (47 ± 20%) of these were landed. In comparison, each round, 11 ± 7 kicks were attempted, and 5 ± 5 (48 ± 20%) of these struck the opponent. Similar proportions of the fight were spent wrestling on the ground (40 ± 23 %). and standing while punching/kicking (39 ± 18 %). Blood lactate was 12.0 ± 2.8 mmol.L^{-1} and the athletes' RPE indicated fights were hard or very hard (16 ± 2 a.u.). Similar heart rates were achieved after each round (176 ± 7, 175 ± 14, 177 ± 11 beats.min). The proportionally higher amount of time spent grappling on the floor and fighting while standing indicates a higher training priority for these fight components. This research will assist coaches in developing training protocols replicating or exceeding demands of amateur MMA.

1. Introduction

One of the major challenges faced by coaches in sport is to determine how their athletes' training equates to expected competition demands. While quantification of training demands is relatively easy, the practicalities of some sports such as Mixed Martial Arts (MMA) limit both the measurement devices available and the opportunities to collect data during actual competition. As a compromise, many researchers have simulated game demands to estimate what would likely be found in competition and have used less than optimal measurement techniques, for instance Crisafulli et al. (2009) used a preset routine of strikes and movements with a compliant opponent to obtain measures of oxygen uptake with a portable gas analyzer. Other researchers have focused on measuring physiology of participants outside of the competitive environment with tests purported to relate to the competition demands (Schick et al., 2010). However, there is no doubt that time motion analysis combined with physiological measurements taken during competition is a superior method for defining competition demands (Abdelkrim, et al., 2007).

Obtaining unobstructed video footage of MMA fighting presents unique challenges as the athletes are constantly moving and fixed cameras outside of the ring are likely to miss recording some fight details. The referee is within the ring and is the closest to the fight. Therefore, the referee has the optimal view from which to record the fight. Fortunately, the miniaturization and improved stabilization of technology has enabled cameras to be mounted on officials to provide researchers with this perspective.

In order to establish the effectiveness of training methods it is imperative coaches have good understanding of a sport's demands. Therefore, to help address the relative lack of MMA in-competition data, the current study employed a referee head-mounted camera to capture time-motion analysis data while also getting permission to access the ring during and immediately post fight to collect physiological data. Hence, the objective of our study was two-fold: Firstly, to provide strength and conditioning coaches with physiological and fight reference data to help design more effective training programs. Secondly, and

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more importantly to provide field practitioners with an example of how to collect this data for their own athletes.

2. Methods

2.1. Participants

Ten elite amateur MMA athletes volunteered for the study (age: 27.3 ± 3.3 years; mass: 79.5 ± 0.5 kg; height: 1.77 ± 0.04 m), with a combined MMA record of 4 ± 3 wins and 2 ± 2 losses (mean ± SD). The experimental protocol was approved by the University of Canterbury Human Ethics Committee (Christchurch, New Zealand), and all participants were informed of the risks involved in the study before their written consent was obtained.

2.2. Apparatus

Within the one minute inter-round rest period and post-fight, each athlete's heart rate was recorded using a Polar FS1 heart rate monitor (Polar, Finland) and Polar T31 heart rate chest belt attached to a handheld swimbar (Polar, Finland) that was pushed against the athletes chest. The use of the T31 is common for both exercise evaluations and medical research, and it has been shown to be both accurate and reliable (Montes and Navalta, 2019). Immediately post fight, (athletes provided a perceived rating of exertion (RPE) and had an earlobe blood lactate sample taken (within 3 minutes) using a Lactate Pro analyser (Lactate Pro, Arkray, Japan). The Lactate Pro has been shown to display good reliability and accuracy compared with a criterion laboratory analyser (Tanner et al., 2010).

After the contest, notational analysis was performed on the video recordings from a referee head-mounted camera (Go Pro™, San Mateo, CA, USA). This quantified fight variables including both attempted and successful standing punches and kicks as well as the proportion of time spent in various fighting components.

2.3. Task

As MMA athletes, all participants adhered to a controlled diet to meet a specified weight to compete as directly by their coach and adhered to other pre-fight preparations provided by their manager. This included refraining from any form of exercise 24 hours prior to the contest. Each participant was weight matched with an opponent in a full-contact contest lasting three rounds of 5 min each. MMA fights often do not last the full scheduled duration. Therefore, in the present study if a participant received a lesion or any form of concussion that was deemed too dangerous to continue with (diagnosed by a clinical physician onsite), the contest was halted immediately. However, to gain a complete understanding of the physiological stress accompanying a longer length contest, barring a medical intervention, the entire contest duration was completed where possible.

2.4. Statistical Approach

Descriptive data was analyzed (mean ± SD) for each round of the fight. The magnitude and direction of the difference between winning and non-winning fighters was also calculated using a standardized effective size statistic ± 90% confidence limit. The criteria employed for interpreting effect size were: <0.2 *trivial*, 0.2-0.6 *small*, 0.6-1.2 *moderate*, and 1.2-2.0 *large* (Hopkins, 2002). A one-tailed paired *t* test was performed between groups of winning and losing fighters for all variables.

3. Results

Four of the five fights completed all three rounds, and went to the judges decision. One fight was stopped on advice from the ringside physician for medical reasons in the third round. Of the total fight time, similar proportions were spent wrestling on the ground and standing while punching/kicking with the least time spent clinching when standing (Table 1). Winning fighters landed more punches particularly in the first two rounds, and this is highlighted by the large magnitude of difference in punches landed when compared to those fighters that lost their fight. Heart rate data varied little between rounds and between winning and losing fighters, while the overall perceived exertion was rated between hard and very hard and was similar between winning and non-winning fighters. Nonetheless, blood lactate measured post fight was moderately (~2.3 $mmol{\cdot}L^{-1}$) higher in losing fighters (see Table 2).

Table 1: Mean time and percentage (± SD) of fight spent in different activities

	Round 1	Round 2	Round 3	Mean
Standing (s)	116 ± 44	94 ± 77	121 ± 38	110 ± 54
(%)	40 ± 15	37 ± 30	41 ± 13	39 ± 18
Grappling (s)	63 ± 29	50 ± 42	71 ± 45	61 ± 35
(%)	21 ± 10	20 ± 16	24 ± 15	21 ± 12
Wrestling (s)	114 ± 72	113 ± 68	100 ± 23	109 ± 64
(%)	39 ± 25	44 ± 26	34 ± 23	40 ± 23

4. Discussion

Our primary study objective was to provide strength and conditioning coaches with physiological and fight reference data to help design more effective training programs. The current MMA athletes rated their perceived exertion as being between hard and very hard, physiologically they had sustained high heart rates across all three rounds, and had a moderately high lactate reading post-competition. These measures all fell within the wide range of results previously reported by Amtmannet et al. (2003). Therefore, our findings agree with Braswell et al. (2010) who found a high level of physical fitness is essential for performance in MMA. Overall compared to this first round ~40% less kicks were performed in the second and third rounds. Yet, the greatest magnitude of difference between winning and losing fighters were the number of punches landed especially in the first two rounds.

The physiological and notational demands that we have highlighted above help explain recent findings that MMA induces significant fatigue and muscle damage that persists for greater than 24 hours after a competition (Ghoul et al., 2019). Therefore if using this data to replicate competition demands during training, it is advisable that strength and conditioning coaches also consider incorporating post training recovery interventions especially leading into a fight (Lindsay, et al., 2017).

A major limitation of this study was that no female MMA athletes were included so there is no evidence of what their physiological competition demands may entail. With the popularity of MMA growing (Spanias, et al., 2019), it is important that female data is captured to provide specific training guidelines. Nevertheless, this study addresses Cronin and the late Gordon Sleivert's challenge to sport scientists to formulate research designs that result in meaningful and practical information that assists coaches and strength and conditioning practitioners in the development of their athletes (Cronin & Sleivert, 2005). In this respect, the findings of the present study highlight the importance of landing punches in the first two rounds for this sample of amateur MMA athletes. Furthermore, we highlight the time spent in different fight components and detail the typical heart rate and lactate response of competitive fighting, thereby providing reference data upon which to monitor and modify training intensities. Future studies should consider further refining the notational analysis to include aspects such as whether punches are thrown whilst on the ground or from a standing position.

Finally, in addressing our second objective, this study provides coaches working with MMA athletes a valuable example of how to incorporate novel technology (head mounted camera) to collect data for notational analysis on their own athletes to assess key performance indicators relevant to their athlete's competitive level. Additionally, coaches are encouraged to collect physiological data during training enabling them to judge the extent to which their training matches competition demands.

Table 2: Physiological and MMA specific contest variables, with P-value and effect sizes between winning and losing fighters

Variable	All fighters (n = 10)	Winners (n = 5)	Losers (n = 5)	P-value	Effect size ± 90% CI	Interpretation
Round 1						
Heart rate (beats·min^{-1})	176 ± 7	176 ± 6	176 ± 9	*0.19*	0.03 ± 0.00	*Trivial*
Punches thrown (#)	42 ± 17	49 ± 7	36 ± 22	*0.15*	0.92 ± 0.07	*Moderate*
Punches landed (#)	22 ± 12	28 ± 10	16 ± 11	*0.07*	1.22 ± 0.12	*Large*
Kicks (#)	15 ± 9	18 ± 11	11 ± 5	*0.10*	0.94 ± 0.07	*Moderate*
Kicks connecting (#)	8 ± 6	11 ± 8	5 ± 2	*0.12*	1.14 ± 0.11	*Moderate*
Round 2						
Heart rate (beats·min^{-1})	175 ± 14	175 ± 11	174 ± 17	*0.39*	0.10 ± 0.00	*Trivial*
Punches thrown	31 ± 15	37 ± 10	24 ± 18	*0.09*	0.89 ± 0.06	*Moderate*
Punches landed	15 ± 11	23 ± 8	8 ± 8*	*0.01*	1.81 ± 0.27	*Large*
Kicks (#)	9 ± 6	10 ± 7	8 ± 6	*0.27*	0.22 ± 0.00	*Small*
Kicks connecting (#)	3 ± 2	3 ± 2	3 ± 2	*0.21*	0.33 ± 0.01	*Small*
Round 3						
Heart rate (beats·min^{-1})	177 ± 11	176 ± 11	179 ± 13	*0.35*	-0.19 ± 0.00	*Trivial*
Punches thrown	45 ± 19	49 ± 7	42 ± 27	*0.30*	0.45 ± 0.02	*Small*
Punches landed	22 ± 12	26 ± 12	18 ± 12	*0.26*	0.69 ± 0.04	*Moderate*
Kicks (#)	9 ± 4	10 ± 4	8 ± 4	*0.15*	0.60 ± 0.03	*Small*
Kicks connecting (#)	4 ± 2	5 ± 3	4 ± 2	*0.16*	0.83 ± 0.06	*Moderate*
Post Fight						
RPE (a.u)	16.3 ± 1.5	16.4 ± 1.9	16.2 ± 1.1	*0.44*	0.13 ± 0.00	*Trivial*
Post Lactate (mmol·L^{-1})	12.0 ± 2.8	10.8 ± 3.1	13.1 ± 2.0	*0.16*	-0.89 ± 0.07	*Moderate*

* Statistically significantly different between winning and losing fighters at the $P < 0.05$ level of significance

Conflict of Interest

The authors declare no conflict of interests.

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References

Abdelkrim, N.B., Fazaa, S.E., & Ati, J.E. (2007). Time–motion analysis and physiological data of elite under-19-year-old basketball players during competition. *British Journal of Sports Medicine, 41,* 69-75.

Amtmann, J.A., Amtmann, K.A., & Spath, W.K. (2003). Lactate and rate of perceived exertion response of athletes training for and competing in mixed martial arts event. *Journal of Strength and Conditioning Research*, *22,* 645-647.

Braswell, M.T., Szymanski, D.J., Szymanski, J.M., Dixon, E.E., Gilliam, S.T., Wood, R.J., ... Cicciarella, C.F. (2010). Physiological differences in mixed martial artists and traditional martial artists: A pilot study. *Journal of Strength and Conditioning Research, 24,* 1.

Cronin, J., & Sleivert, G. (2005). Challenges in understanding the influence of maximal power training on improving athletic performance. *Sports Medicine*, *35*, 213-234.

Crisafulli, A., Vitelli, I.C., Cappai, I., Milia, R., Tocco, F., Melis, F., & Concu, A. (2009). Physiological responses and energy cost during simulation of a Muay Thai Boxing match. *Applied Physiology, Nutrition, and Metabolism*, *34*, 143-150.

Ghoul, N., Tabben, M., Miarka, B., Tourny, C., Chamari, K., & Coquart, J. (2019). Mixed martial arts induces significant fatigue and muscle damage up to 24 hours post-combat. *Journal of Strength and Conditioning Research*, *33*, 1570-1579.

Hopkins, W.G. (2002). A scale of magnitudes for effect statistics. In: A new view of statistics. Retrieved from newstats.org/effectmag.html.

Lindsay, A., Carr, S., Cross, S., Petersen, C., Lewis, J.G., & Gieseg, S.P. (2017). The physiological response to cold-water immersion following a mixed martial arts training session. *Applied Physiology, Nutrition, and Metabolism, 42*, 529-536.

Montes, J., & Navalta, J. (2019). Reliability of the Polar T31 uncoded heart rate monitor in free motion and treadmill activities. *International Journal Exercise Science, 12*, 69-76.

Schick, G.M., Brown, L.E., Coburn, J.W., Beam, W.C., Schick, E.E., & Dabbs, N.C. (2010). Physiological profile of mixed martial artists. *Medicina Sportiva, 14*, 182-187.

Spanias, C., Nikollaidis, P.T., Rosemann, T., & Knechtle, B. (2019). Anthropometric and physiological profile of mixed martial art athletes: A brief review. *Sports, 7*, E146.

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