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The effects of menstrual cycle phase on physical performance in female rugby athletes: A case-study

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A B S T R A C T

Limited research exists on the effects of menstrual phase on athletic performance in team sport athletes. In this case-study we investigated the potential effect of menstrual cycle phase on several physical qualities in rugby athletes. Four eumenorrhoeic female rugby athletes completed a battery of physical tests weekly for 5-9 weeks, including 10-m sprint, countermovement (CMJ) and drop (DJ) jumps, isometric mid-thigh pull (IMTP), and Bronco. Concurrently, athletes tracked their menstrual cycle with a smartphone application (FitrWoman™). To investigate differences in physical performance between phases, data were allocated into four different menstrual phases at the date of each weekly test. A mixed linear model was created for each physical quality of interest. Mean changes between phases were estimated using magnitude-based inferences with 90% confidence intervals. Individual differences between the average score for each menstrual phase with the value predicted by the trend of the other three phases were also assessed. At a group-level, possible greater performances were observed in the CMJ during the late luteal phase compared with menstruation, in the DJ during late luteal compared with luteal, and in the IMTP during late luteal compared with follicular to ovulation (Δ% = 4.9-7.0%). A variety of responses were observed between individuals for all the tests conducted. Understanding and accounting for individual responses during the menstrual cycle will likely be beneficial to training prescription and interpreting performance monitoring results.

1. Introduction

It is well known that the physiology of women is unique and largely influenced by the menstrual cycle (Mujika & Taipale, 2019). The menstrual cycle is a biological rhythm characterised by the cyclic fluctuations of endogenous sex hormones, such as oestrogen and progesterone. A typical menstrual cycle lasts 28–32 days and consists of a follicular phase (~12–14 days; low to rising levels of oestrogens and low levels of progesterone), ovulation (~1 day, preceded by an oestrogen surge) and a luteal phase (~12–14 days; high levels of oestrogens and progesterone) (Sims & Heather, 2018).

While the primary function of oestrogen and progesterone is to support reproduction, the changing concentrations of these hormones across the menstrual cycle have also been found to affect a number of physiological systems, which in turn could have implications on sport performance (Constantini et al., 2005; de Jonge, 2003). However, research findings on this topic are conflicting, with large variance between studies. These equivocal findings are likely attributable to differences in study design, participants' characteristics, number and definition of menstrual cycle phases, phase verification methods, variables measured, and relatively small sample sizes (de Jonge et al., 2019; Julian et al., 2017; McNulty et al., 2020).

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A limited number of studies have investigated the effects of menstrual cycle phase on physical performance in team sport athletes, with most of the research addressing individual sport athletes or untrained people. Previous studies conducted in female soccer athletes revealed unclear and non-significant differences in sprint, repeated sprint ability, and jumping performance between phases (Julian et al., 2017; Somboonwong et al., 2015; Tounsi et al., 2018); however, while Tounsi et al. (2018) observed no differences in the Yo-Yo Intermittent Recovery Test Level 1 between early follicular, late follicular, and luteal phases, Julian et al. (2017) reported possibly better performance in the Yo-Yo Intermittent Recovery Test Level 2 during the early follicular phase compared to mid luteal (effect size, ES = 0.56). The different aerobic and anaerobic contributions to the two tests (Bangsbo et al., 2008) might explain the contrasting results.

Rugby is a high-intensity, intermittent, field-based contact sport that requires players to possess a range of physical qualities, including speed, power, strength, and fitness (Ross et al., 2014). To date, only one study (Miskec et al., 1997) has evaluated the potential influence of menstrual cycle phases in rugby athletes. Specifically, these results highlighted no significant differences between early follicular and luteal phase on anaerobic power output during repeated high-intensity, intermittent exercise on a cycle ergometer. However, no further physical tests were conducted. There is a requirement for more ecologically valid research in this area, and specifically data that are relevant at an individual level. In support of this statement, a recent study addressing elite female rugby athletes has highlighted the importance to develop understanding on the menstrual cycle and considering its impact on training and competition on female rugby athletes (Findlay et al., 2020). Therefore, in this case-study we investigated the potential effect of menstrual cycle phase on several physical qualities in female rugby athletes. Due to the variability observed in the concentration of sex hormones and timing of cycle phases both between- and within-subjects (Haggstrom, 2014; Vescovi, 2011), participants' individual responses to cycle phases were assessed, in addition to average group responses.

2. Methods

2.1. Participants

Eighteen non-elite female rugby athletes (mean ± standard deviation: age, 23 ± 3 years; height, 1.67 ± 0.05 m; body mass, 80 ± 18 kg) from the same New Zealand Provincial Union were recruited to participate. Four athletes fulfilled all inclusion criteria (age, 23 ± 4 years; height, 1.69 ± 0.05 m; body mass, 67 ± 6 kg; menstrual cycle duration, 30 ± 4 days) and were included in the analysis (Figure 1). Inclusion criteria for participation were: being injury free, the absence from any form of contraception for at least six months, having a menstrual cycle duration of 24-35 days before the beginning of the study (Lebrun et al., 1995), and completing at least one testing session in each of the four menstrual cycle phases considered. Written informed consent was obtained from each participant and approval was obtained from the University of Waikato Human Research Ethics Committee (HREC#2018-10).

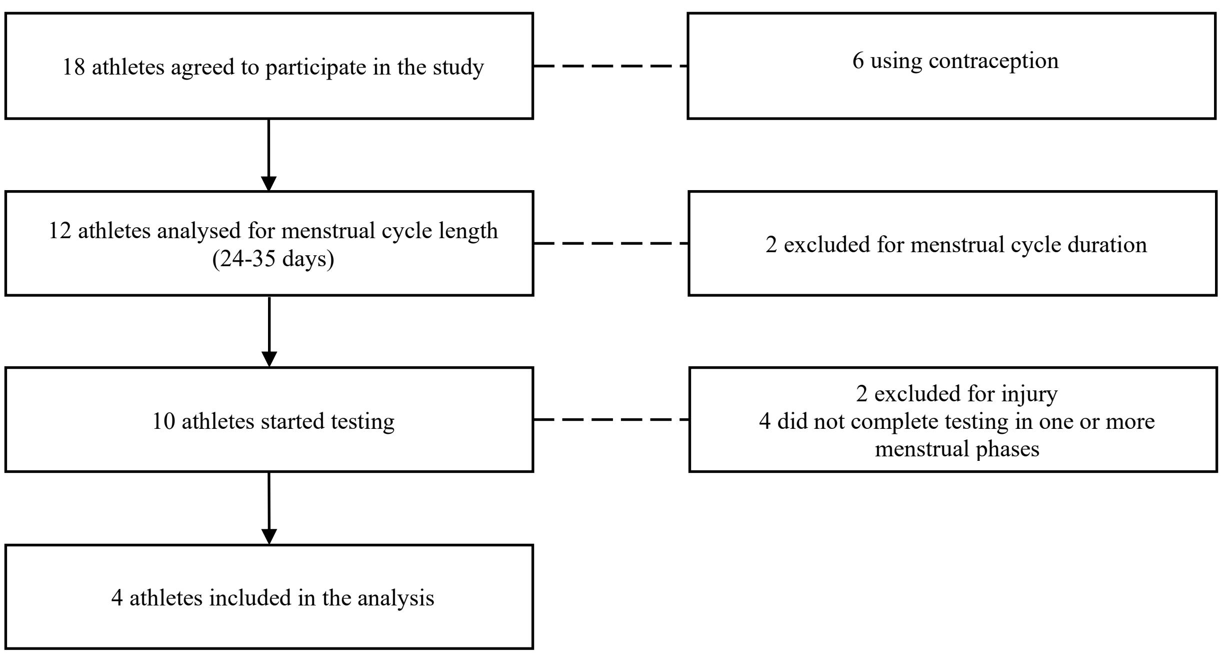

Figure 1: Participant flow chart

2.2. Study design

An observational study design with repeated measures was used. Participants completed a battery of physical tests weekly, for 5-9 consecutive weeks, during the preparation period. Concurrently, they tracked their menstrual cycle daily for the duration of the study.

Physical testing was performed weekly, irrespective of the menstrual phase for a given individual. Participants' data were de-identified to the principal investigators to maintain blinding of the menstrual cycle phase at the time of testing.

A familiarisation session was completed for all testing procedures before the start of the study. The physical assessments were conducted in the same order, on the same day of the week, at the same time of the day (Taylor et al., 2010; Teo et al., 2011) for the duration of the study. Participants were asked to standardise their dietary intake and to abstain from alcohol within the 24 hours before each test.

2.3. Physical tests

A 10-minute standardised warm up comprising of dynamic stretches, jogging, running drills, and stride outs was performed before starting the physical testing.

Acceleration. Acceleration abilities were assessed using a 10 m sprint with split times at 5 and 10 m. The test was completed indoor in running shoes using single beam timing lights (Brower Timing System, Utah, USA). The first gate was set at 0.5 m, while the remaining were set at a height of 0.75 m. Sprint times at each split were measured to the nearest 0.01 second. Participants started each sprint in a standing split position 0.5 m behind the first gate and were instructed to "run as fast as possible" past the last gate. Each participant was given one warm-up trial followed by three maximal sprints, separated by two min of rest. The repeatability for 10-m sprint times conducted under similar conditions is excellent (intraclass correlation coefficient, ICC = 0.90) (Goodale et al., 2016).

Lower-body power. Body weight countermovement jump (CMJ) and drop jump (DJ) were assessed using an optical measurement system (OptoJump Next, Microgate, Bolzano, Italy) sampling at 1000 Hz. For the CMJ, participants started from an upright standing position with their hands-on hips. Participants were instructed to "bend their knees to a self-selected depth and to jump as high as possible". For the DJ, participants stepped out and dropped off a 30 cm high box keeping their hands on their hips. Participants were instructed to "minimise time spent in contact with the ground and jump as high as possible as quickly as possible". For both jumps, one warm-up trial was given, followed by three maximal jumps separated by five seconds. CMJ height estimated from flight time and DJ reactive strength ratio (RSR) defined as the ratio between flight time and contact time were considered for analysis. These variables (CMJ height and RSR) have been shown reliable using similar equipment based on coefficient of variation values (CV = 2.2 and 4.2%, respectively) (Byrne et al., 2017; Glatthorn et al., 2011).

Strength. Maximal strength was measured via the isometric mid-thigh pull exercise (IMTP) using a force measurement system comprising of a strain gauge load cell and software package sampling at 1000 Hz (The Strength Assessment Tool, AUT University, Auckland, NZ). The load cell was anchored to a wooden platform and connected to handles via chains. Testing protocol and position were standardised in agreement with the guidelines of Comfort et al. (e.g., knee angle 125-145°, hip angle 140-150°) (Comfort et al., 2019) and kept consistent for each athlete throughout the study. Participants were instructed to pull "as hard and as fast as possible" for three seconds. Verbal encouragement was given throughout the pull. Two sub-maximal IMTP trials at increasing intensities were given, followed by three maximal efforts interspersed by two minutes of passive rest. Peak force (PF) determined as the maximum force generated during the three seconds pull was recorded and considered for the analysis. PF assessed with a similar device has been found to be reliable (ICC = 0.96 and CV = 3.1%) (James et al., 2017).

Fitness. The 1.2 km shuttle run test, also known as Bronco test (Kelly & Wood, 2013) was used as a measure of fitness. The test was performed outdoors, on the same surface, in running shoes. The protocol consists of a continuous 20, 40, 60 m straight shuttle run, completed five times at maximal intensity (i.e., 20 m and back, 40 m and back, 60 m and back) (Kelly & Wood, 2013). Total running time was recorded and used for analysis. Excellent test-retest reliability of Bronco times has been reported (ICC = 0.99) (Brew & Kelly, 2014).

2.4. Menstrual cycle monitoring

Menstrual cycle information was tracked daily with a smartphone application (FitrWoman™). Participants started the monitoring 10 weeks prior to the start of physical testing to determine their menstrual cycle duration as required by the inclusion criteria. Participants continued to monitor their cycle throughout the 9-week duration of the study.

The length of the menstrual cycle was calculated from the first day of menses to the day preceding the next menses. By inputting typical cycle length, period duration, and the date of their last period, FitrWoman™ estimates menstrual cycle phases. The application divides the menstrual cycle duration in four phases: Phase 1 (menstruation), Phase 2 (follicular to ovulation), Phase 3 (luteal), and Phase 4 (late luteal).

2.5. Training load and well-being

The internal training load for all training sessions completed by each participant during the 5 to 9-week period was calculated using the session-RPE method (Foster et al., 2001). This method quantifies internal training load as the product of the training session rate of perceived exertion (RPE) multiplied by session duration.

The Daily Analysis of Life Demands for Athletes (DALDA) questionnaire (Rushall, 1990) was employed as a measure of well-being. The questionnaire contains 34 items to evaluate the sources and symptoms of stress. Each question can be answered either as "worse than normal", "normal", or "better than normal". Participants filled the questionnaire at each testing session before the warm up.

2.6. Hydration status

To minimise the effects of hypohydration on physical performance outcome (McDermott et al., 2017), the hydration status of every participant was verified on each testing day before the warm up. Urine specific gravity (USG) was measured using urine test strips (Combur®-Test strip, Roche Diagnostics). This method has been shown to be valid and reliable ("Combur-Test® strip", 2020; Warren et al., 2018; Zubac et al., 2014). When the USG value was between 1.020 and 1.025, participants were asked to ingest a 5 ml/kg of body mass beverage (Na^+: 132 mg/100 ml, K^+: 78 mg/100 ml, CHO: 1.4 g/100 ml, mOsm/L: 230 mmol/L). With a USG of 1.030 or higher, 10 ml/kg of body mass of the same beverage was given (Sawka et al., 2007). Furthermore, if the pH value recorded was 7 or more, 0.005 was added to the USG score (Abbey et al., 2014).

2.7. Statistical analysis

At the end of the 9-week period, data were allocated into menstruation, follicular to ovulation, luteal, or late luteal phases at the date of each testing session. Except for the Bronco, the average of the best two scores achieved in the tests at every session was used for analysis.

To investigate differences in physical performance between menstrual phases, physical test scores were log-transformed and analysed using the mixed linear model procedure (Proc Mixed) in the Statistical Analysis System (University Edition of SAS Studio, version 9.4, SAS Institute, Cary NC). A model was created for each physical quality of interest. Menstrual cycle phase, the mean change over the duration of the study, and the weekly training load before each testing session were included in the model as fixed effects. The differences between athletes in the middle of the study and the individual differences in the overall change were entered as random effects with an unstructured covariance matrix to allow these two effects to be correlated.

Mean changes between phases were estimated using magnitude-based inferences with 90% CI (Hopkins, 2006) and are presented as a percent. Furthermore, the effects of training load on the physical tests results were quantified using the same approach. Quantitative chances of higher or lower differences were evaluated qualitatively as follows: <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. If the probabilities of the true value being substantially higher and lower were both >5%, the difference was termed as unclear.

Individual differences between the mean score for each menstrual phase with the mean predicted by the trend of the other three phases were assessed for each physical quality (Hopkins, 2017). Specifically, the residual obtained from the mixed linear model was used as typical error in percent units. The smallest worthwhile change (SWC = 0.2 x between-subjects SD) calculated from previous data collected in our lab was used to establish the smallest important change in percent units. Quantitative chances of higher or lower differences were evaluated qualitatively as follows: <10%, very unlikely; 10−90%, possible; >90%, very likely. If the probabilities of the true value being substantially higher and lower were both >10%, the difference was termed as unclear.

With regards to wellness, DALDA responses were coded as 1 = "worse than normal", 2 = "normal", and 3 = "better than normal" and summed across the 34 items. The total score obtained in the questionnaire by each athlete was then rescaled to range from 0 to 100. Individual differences in the average scores between phases were interpreted as small, moderate, large, very large, and extremely large when reaching thresholds of 10, 30, 50, 70, and 90%, respectively.

3. Results

All data are presented as mean ± SD, unless otherwise indicated. The maximum variation in cycle length throughout the study was five days. Individual average physical performance results specific to menstrual cycle phase and the number of testing sessions completed in every phase by each participant are reported in Table 1.

Mean differences in physical performance between menstrual cycle phases are reported in Table 2. At a group-level, possible lower CMJ performance was observed in the menstruation phase compared to late luteal (Δ% = -4.9%). Possible lower DJ performance was observed in the luteal phase compared to late luteal (Δ% = -7.0%). Furthermore, possible lower IMTP performance was observed in the follicular to ovulation phase compared to late luteal (Δ% = -6.0%). All other phase differences were possible to very likely trivial or unclear.

Individual differences in physical performance are reported in Table 3. One participant had very likely slower 5-m time in the luteal phase compared with the trend of the other three phases. Another athlete displayed possible greater IMTP performance in the menstruation phase compared with the trend of the other three phases. With regards to the Bronco test, one athlete showed very likely trivial differences between the follicular to ovulation phase with the trend of the other three phases, and between the luteal phase with the trend of the other three phases; furthermore, another athlete displayed a possible trivial difference between the late luteal phase with the trend of the other three phases. The remaining comparisons were unclear or were scored both as a possible substantial increase or decrease and a possible trivial difference.

Training load had a possible to very likely trivial effect on Bronco, CMJ, DJ, 5-m, and 10-m speed scores. An unclear effect was registered for the IMTP. Trivial to small differences were observed in well-being (DALDA) between phases at an individual level (Figure 2).

4. Discussion

This is the first study investigating the effects of menstrual cycle phase on several physical qualities in rugby athletes over multiple testing sessions. The inclusion and analysis of participants' individual responses to cycle phase, in addition to the group average responses, also represent a novelty.

Table 1: Individual average physical performance results specific to menstrual cycle phase across 5 to 9 weeks.

Test	Phase[a]	Participants 1	2	3	4
5-m time (s)	Phase 1 (*n*)	1.14 ± NA (*1*)	1.08 ± NA (*1*)	1.12 ± NA (*1*)	1.06 ± 0.00 (*2*)
	Phase 2 (*n*)	1.15 ± 0.02 (*4*)	1.08 ± 0.00 (*2*)	1.12 ± 0.03 (*4*)	1.07 ± 0.01 (*2*)
	Phase 3 (*n*)	1.14 ± 0.03 (*3*)	1.07 ± 0.01 (*2*)	1.11 ± 0.03 (*3*)	1.12 ± 0.05 (*2*)
	Phase 4 (*n*)	1.16 ± NA (*1*)	1.07 ± 0.01 (*2*)	1.12 ± NA (*1*)	1.07 ± 0.01 (*2*)
10-m time (s)	Phase 1 (*n*)	1.96 ± NA (*1*)	1.82 ± NA (*1*)	1.95 ± NA (*1*)	1.85 ± 0.01 (*2*)
	Phase 2 (*n*)	1.94 ± 0.01 (*4*)	1.82 ± 0.02 (*2*)	1.93 ± 0.04 (*4*)	1.87 ± 0.01 (*2*)
	Phase 3 (*n*)	1.94 ± 0.04 (*3*)	1.83 ± 0.02 (*2*)	1.92 ± 0.07 (*3*)	1.89 ± 0.05 (*2*)
	Phase 4 (*n*)	1.95 ± NA (*1*)	1.81 ± 0.02 (*2*)	1.93 ± NA (*1*)	1.84 ± 0.01 (*2*)
CMJ height (cm)	Phase 1 (*n*)	34.0 ± NA (*1*)	35.7 ± 5.4 (*2*)	29.7 ± NA (*1*)	35.5 ± 1.9 (*2*)
	Phase 2 (*n*)	34.9 ± 1.7 (*4*)	38.7 ± NA (*1*)	29.2 ± 2.3 (*4*)	35.2 ± 2.6 (*2*)
	Phase 3 (*n*)	33.9 ± 1.2 (*3*)	38.4 ± 0.3 (*2*)	30.0 ± 0.6 (*3*)	33.3 ± 4.5 (*2*)
	Phase 4 (*n*)	36.7 ± NA (*1*)	37.8 ± 0.0 (*2*)	27.9 ± NA (*1*)	36.4 ± 2.9 (*2*)
DJ RSR (ratio)	Phase 1 (*n*)	1.37 ± NA (*1*)	1.65 ± NA (*1*)	1.37 ± NA (*1*)	1.41 ± 0.07 (*2*)
	Phase 2 (*n*)	1.32 ± 0.17 (*3*)	1.55 ± NA (*1*)	1.24 ± 0.14 (*3*)	1.39 ± 0.16 (*2*)
	Phase 3 (*n*)	1.28 ± 0.11 (*3*)	1.70 ± 0.09 (*2*)	1.30 ± 0.08 (*3*)	1.27 ± NA (*1*)
	Phase 4 (*n*)	1.39 ± NA (*1*)	1.69 ± 0.06 (*2*)	1.23 ± NA (*1*)	1.50 ± 0.09 (*2*)
IMTP PF (N)	Phase 1 (*n*)	1702 ± NA (*1*)	1833 ± NA (*1*)	1850 ± NA (*1*)	1750 ± 198 (*2*)
	Phase 2 (*n*)	1588 ± 218 (*3*)	1506 ± 415 (*2*)	1628 ± 106 (*3*)	2091 ± 521 (*2*)
	Phase 3 (*n*)	1630 ± 113 (*3*)	1538 ± 136 (*2*)	1599 ± 123 (*3*)	1949 ± NA (*1*)
	Phase 4 (*n*)	1615 ± NA (*1*)	1748 ± 74 (*2*)	1745 ± NA (*1*)	1772 ± 592 (*2*)
Bronco time (s)	Phase 1 (*n*)	360 ± NA (*1*)	310 ± NA (*1*)	335 ± NA (*1*)	338 ± 21 (*2*)
	Phase 2 (*n*)	353 ± 4 (*4*)	303 ± NA (*1*)	346 ± 13 (*4*)	333 ± 4 (*2*)
	Phase 3 (*n*)	355 ± 5 (*3*)	319 ± NA (*1*)	342 ± 19 (*3*)	338 ± 1 (*2*)
	Phase 4 (*n*)	352 ± NA (*1*)	318 ± 1 (*2*)	339 ± NA (*1*)	331 ± 6 (*2*)

Note: [a] Phase 1, menstruation; Phase 2, follicular to ovulation; Phase 3, luteal; Phase 4, late luteal. Data are presented as mean ± SD.
CMJ, countermovement jump; DJ, drop jump; IMTP, isometric mid-thigh pull; *n,* number of testing sessions completed; NA, not applicable; PF, peak force; RSR, reactive strength ratio.

Table 2: Mean differences between menstrual cycle phases.

Test	Phases[a]	Difference (%)	90% confidence limits		Inference[b]
			Lower	Upper	
5-m time (s)	Ph1 – Ph2	-0.6	-2.5	1.4	6/68/26, Unclear
	Ph1 – Ph3	-0.5	-2.5	1.4	6/68/26, Unclear
	Ph1 – Ph4	0.0	-2.2	2.0	14/70/16, Unclear
	Ph2 – Ph3	0.0	-1.4	1.5	8/85/7, Unclear
	Ph2 – Ph4	0.5	-1.3	2.3	23/72/5, Unclear
	Ph3 – Ph4	0.5	-1.4	2.3	23/71/6, Unclear
10-m time (s)	Ph1 – Ph2	-0.1	-1.6	1.3	5/86/9, Unclear
	Ph1 – Ph3	0.2	-1.4	1.7	11/83/6, Unclear
	Ph1 – Ph4	0.5	-1.1	2.1	19/77/4, Likely ↔
	Ph2 – Ph3	0.3	-0.8	1.4	7/92/1, Likely ↔
	Ph2 – Ph4	0.6	-0.8	2.0	21/78/1, Likely ↔
	Ph3 – Ph4	0.3	-1.2	1.8	14/82/4, Likely ↔
CMJ height (cm)	Ph1 – Ph2	-2.2	-6.3	2.1	1/78/21, Likely ↔
	Ph1 – Ph3	-2.6	-6.7	1.6	0/74/26, Possibly ↔↓
	Ph1 – Ph4	-4.9	-9.2	-0.4	0/39/61, Possibly ↓↔
	Ph2 – Ph3	-0.4	-3.8	3.1	2/94/4, Likely ↔
	Ph2 – Ph4	-2.7	-6.8	1.5	0/72/28, Possibly ↔↓
	Ph3 – Ph4	-2.3	-6.5	2.0	1/76/23, Likely ↔
DJ RSR (ratio)	Ph1 – Ph2	1.5	-6.2	9.6	15/79/6, Unclear
	Ph1 – Ph3	3.0	-4.4	11.0	24/74/2, Possibly ↔
	Ph1 – Ph4	-4.2	-11.6	3.7	2/63/35, Possibly ↔↓
	Ph2 – Ph3	1.5	-4.7	8.1	11/86/3, Likely ↔
	Ph2 – Ph4	-5.6	-12.1	1.4	1/53/46, Possibly ↔↓
	Ph3 – Ph4	-7.0	-13.2	-0.3	0/39/61, Possibly ↓↔
IMTP PF (N)	Ph1 – Ph2	5.1	-4.3	15.5	59/35/6, Unclear
	Ph1 – Ph3	3.0	-6.2	13.0	44/45/11, Unclear
	Ph1 – Ph4	-1.1	-10.5	9.2	20/47/33, Unclear
	Ph2 – Ph3	-2.1	-9.2	5.4	10/55/35, Unclear
	Ph2 – Ph4	-6.0	-13.6	2.4	3/29/68, Possibly ↓↔
	Ph3 – Ph4	-4.0	-11.9	4.7	7/41/52, Unclear
Bronco time (s)	Ph1 – Ph2	0.4	-7.8	9.3	14/74/12, Unclear
	Ph1 – Ph3	0.2	-2.3	2.7	3/95/2, Very likely ↔
	Ph1 – Ph4	-0.4	-3.8	3.1	5/87/8, Likely ↔
	Ph2 – Ph3	-0.2	-5.2	5.0	8/84/8, Unclear
	Ph2 – Ph4	-0.8	-3.1	1.5	1/94/5, Likely ↔
	Ph3 – Ph4	-0.6	-3.1	1.9	1/94/5, Likely ↔

Note: [a] Phase 1 (Ph1), menstruation; Phase 2 (Ph2), follicular to ovulation; Phase 3 (Ph3), luteal; Phase 4 (Ph4), late luteal. [b] Likelihood (%): increase/trivial/decrease. ↔ Trivial; ↓ Substantial decrease. CMJ, countermovement jump; DJ, drop jump: IMTP, isometric mid-thigh pull; PF, peak force; RSR, reactive strength ratio.

Table 3: Individual menstrual cycle phase differences.

Test	Phases[a]	Participants			
		1	2	3	4
		Inference[b]	Inference[b]	Inference[b]	Inference[b]
5-m time (s)	Ph 1 - Trend	20/38/42, Unclear	38/45/17, Unclear	41/42/17, Unclear	7/39/54, Possible ↓↔
	Ph 2 - Trend	12/49/39, Unclear	33/54/14, Unclear	31/51/17, Unclear	39/41/20, Unclear
	Ph 3 - Trend	13/61/26, Unclear	12/60/29, Unclear	13/56/31, Unclear	96/3/0, Very likely ↑
	Ph 4 - Trend	41/43/16, Unclear	12/61/27, Unclear	22/35/43, Unclear	7/35/58, Possible ↓↔
10-m time (s)	Ph 1 - Trend	39/47/14, Unclear	32/54/15, Unclear	52/40/8, Possible ↑↔	13/61/26, Unclear
	Ph 2 - Trend	17/59/24, Unclear	21/65/14, Unclear	20/51/29, Unclear	51/44/5, Possible ↑↔
	Ph 3 - Trend	2/71/27, Possible ↔↓	19/70/11, Unclear	17/62/21, Unclear	69/30/1, Possible ↑↔
	Ph 4 - Trend	26/55/19, Unclear	6/67/27, Possible ↔↓	26/38/37, Unclear	1/32/67, Possible ↓↔
CMJ height (cm)	Ph 1 - Trend	5/37/59, Possible ↓↔	0/28/72, Possible ↓↔	21/60/19, Unclear	15/67/18, Unclear
	Ph 2 - Trend	23/63/14, Unclear	6/36/58, Possible ↓↔	2/83/15, Possible ↔↓	1/36/62, Possible ↓↔
	Ph 3 - Trend	2/52/45, Possible ↔↓	72/28/1, Possible ↑↔	29/62/9, Possible ↔↑	5/56/39, Possible ↔↓
	Ph 4 - Trend	73/26/1, Possible ↑↔	21/66/13, Unclear	19/49/32, Unclear	76/24/0, Possible ↑↔
DJ RSR (ratio)	Ph 1 - Trend	11/41/48, Unclear	32/55/13, Unclear	50/43/7, Possible ↑↔	23/55/22, Unclear
	Ph 2 - Trend	31/61/8, Possible ↔↑	7/44/49, Possible ↓↔	3/70/27, Possible ↔↓	12/52/36, Unclear
	Ph 3 - Trend	3/44/53, Possible ↓↔	20/62/18, Unclear	34/42/23, Unclear	2/23/75, Possible ↓↔
	Ph 4 - Trend	72/26/2, Possible ↑↔	17/74/9, Possible ↔↑	26/44/29, Unclear	85/15/0, Possible ↑↔
IMTP PF (N)	Ph 1 - Trend	44/24/32, Unclear	44/26/30, Unclear	89/8/3, Possible ↑	4/18/79, Possible ↓↔
	Ph 2 - Trend	14/37/50, Unclear	10/17/73, Unclear	13/35/52, Unclear	56/26/19, Unclear
	Ph 3 - Trend	27/37/36, Unclear	32/31/37, Unclear	10/21/68, Unclear	51/26/22, Unclear
	Ph 4 - Trend	42/28/31, Unclear	81/16/3, Possible ↑↔	47/24/29, Unclear	44/27/29, Unclear
Bronco time (s)	Ph 1 - Trend	27/66/7, Possible ↔↑	15/71/14, Unclear	4/53/43, Possible ↔↓	17/79/3, Possible ↔↑
	Ph 2 - Trend	5/94/2, Very likely ↔	5/53/42, Possible ↔↓	27/66/7, Possible ↔↑	3/60/37, Possible ↔↓
	Ph 3 - Trend	5/90/4, Very likely ↔	21/70/9, Possible ↔↑	13/75/12, Unclear	42/56/3, Possible ↔↑
	Ph 4 - Trend	10/72/18, Unclear	5/85/10, Possible ↔	18/53/30, Unclear	5/72/23, Possible ↔↓

Note: [a] Phase 1 (Ph1), menstruation; Phase 2 (Ph2), follicular to ovulation; Phase 3 (Ph3), luteal; Phase 4 (Ph4), late luteal. [b] Likelihood (%): increase/trivial/decrease. ↑ Substantial increase; ↔ Trivial; ↓ Substantial decrease. CMJ, countermovement jump; DJ, drop jump; IMTP, isometric mid-thigh pull; PF, peak force; RSR, reactive strength ratio; Trend, value predicted by the trend of the other three phases.

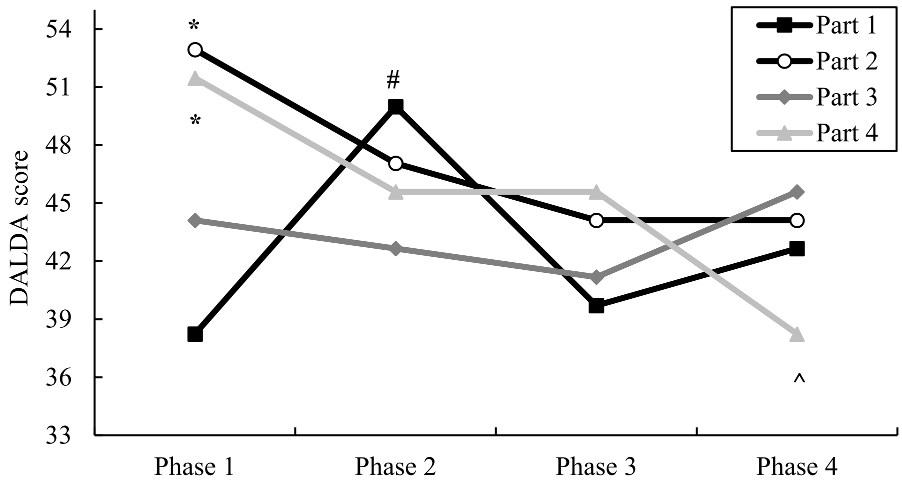

Figure 2: DALDA score specific to each participant. Data are presented as rescaled mean scores for each menstrual cycle phase. Phase 1, menstruation; Phase 2, follicular to ovulation; Phase 3, luteal; Phase 4, late luteal. * = Small difference with Phase 2, Phase 3, and Phase 4. # = Small difference with Phase 1, Phase 3, and Phase 4. ^ = Small difference with Phase 2 and Phase 3.

In female rugby athletes, possibly greater CMJ performance was observed in the late luteal phase compared with the menstruation phase, with possible to likely trivial changes observed between the other phases. Previous research conducted on female soccer athletes reported unclear differences in CMJ height between early follicular and mid luteal phase (Julian et al., 2017). The different study design, menstrual cycle phases considered, and phase verification methods might explain the conflicting results. In the current study, possibly greater DJ performance was observed in the late luteal phase compared with the luteal phase, with the remaining phase comparisons showing possible to likely trivial or unclear differences. No other studies have investigated the effects of menstrual cycle performance on DJ in team sport athletes. However, previous research reported no significant differences in the five-jump test (Tounsi et al., 2018) between the early follicular, late follicular, and luteal phase in female soccer athletes.

Possible greater peak force was observed in the IMTP in the late luteal phase compared with the follicular to ovulation phase in rugby athletes. Unclear differences were observed in other phase comparisons. To the authors' knowledge, no other study has evaluated the influence of menstrual cycle on maximal isometric strength in team sport athletes using multi-joint exercises (i.e., IMTP). A study (dos Santos Andrade et al., 2017) performed on female soccer athletes found the hamstring/quadriceps peak torque strength balance ratio for the non-dominant limb was significantly lower ($p = 0.01$) during follicular phase compared to the luteal phase, which might have implications in terms of lower-limb and anterior cruciate ligament injury risk. In contrast, previous research (Hertel et al., 2006) assessing isokinetic concentric strength in female college students (i.e., soccer and cheerleading) found no substantial fluctuations in hamstring and quadriceps muscle strength across the menstrual cycle at group-level.

Unclear differences were observed across the menstrual cycle in 5-m sprint time in rugby athletes. Furthermore, unclear differences and likely trivial differences were observed between phases in 10-m sprint time. While the trivial differences highlight the absence of a substantial change in performance between phases, the unclear differences are likely attributed to the small sample size employed in this study (Buchheit, 2018). When considering the existing research on team sports, previous studies addressing female soccer athletes showed unclear and non-significant differences between early follicular and mid luteal phases in 5, 10, 30 m sprint times (Julian et al., 2017), and in 40-yard (~37 m) sprint time (Somboonwong et al., 2015). Furthermore, in female soccer athletes, no significant differences were observed between early follicular, late follicular, and luteal phase in a repeated shuttle-sprint ability test (Tounsi et al., 2018).

Likely to very likely trivial or unclear menstrual phase differences characterised the Bronco test. No significant differences in fitness performance were reported between phases in female rugby (Miskec et al., 1997) and soccer athletes (Julian et al., 2017; Tounsi et al., 2018) in previous research. However, in the study of Julian et al. (2017), female soccer athletes covered possibly greater distance in the Yo-Yo Intermittent Recovery Test Level 2 during the early follicular phase compared to mid luteal (ES = 0.56). These findings contrast the results of this study, and may be explained by the different menstrual phases considered and the different tests employed (Sella et al., in press).

To date, most of the research in this area has focused on the average effects of menstrual cycle on physical performance at group-level, without considering and analysing the individual responses. However, it is known that a large inter- and intra-individual variability exist in the concentration of sex hormones and timing of cycle event (Haggstrom, 2014; Vescovi, 2011) that could potentially affect women differently. Therefore, tracking individual performance changes across the different phases of the cycle proves to be critical for athletes and coaches. For example, in this study, no clear differences were observed in 5-m sprint time across the menstrual cycle at group-level. However, one athlete showed very likely slower 5-m time in the luteal phase compared with the trend of the other three phases. These observations suggest impairment in her short acceleration abilities in the luteal phase, which in turn could affect game performance (Clarke et al., 2017). Another athlete displayed possibly greater peak force in the IMTP exercise in the menstruation phase compared with the trend of the other phases, despite no clear differences were observed at group-level between the menstruation phase with the other phases; therefore, further highlighting the need to account for individual performance differences across the menstrual cycle. In collision-based sports such as rugby, high levels of muscular strength are thought to be important to success (Ross et al., 2014); in particular, peak force assessed in the IMTP appears to be associated with performance in numerous athletic tasks in a variety of athletes (Comfort et al., 2019).

It is worth noting that several phase comparisons at group-level and at individual-level, resulted both as a possible substantial increase or decrease and a possible trivial difference. These findings are explained by the magnitude of the SWCs and typical errors (TEs) of the physical tests conducted (TE ~ SWC or TE > SWC), and indicate that the ability to make firm conclusions is limited unless the probability of a substantial change is high. Throughout the study, the weekly training load completed before each testing session did not substantially affect test scores. Trivial to small differences were observed between phases in well-being on the day of testing.

It is important to highlight some limitations of the present study. Firstly, because of the long duration of the investigation, we did not measure oestrogens and progesterone concentrations to verify menstrual cycle phase and no ovulation testing was conducted. Instead, we opted for a designated smartphone application. Compared to direct hormones measurements, this method is a practical, time-efficient and cost-effective alternative to monitor the menstrual cycle (i.e., duration and phase prediction) in a team environment. However, it does not allow distinguishing between ovulatory and anovulatory or luteal phase-deficient cycles, nor does it allow for monitoring the daily variation of hormones between individuals (de Jonge et al., 2019). In addition, knowledge of hormones concentration specific to menstrual cycle phase could have also assisted in explaining performance differences at individual-level between- and within-menstrual cycle phases. Therefore, additional research is required to investigate the validity of this alternative method to monitor menstrual cycle (Julian & Sargent, 2020). While not addressed in the current study, recovery post-exercise may also differ between phases and impact on overall training outcomes.

Out of the participants that were screened for eligibility (n = 18), only 4 completed the study (22%, Figure 1). Large degrees of drop-out rates (75 and 82%) were also observed in previous research conducted in soccer athletes (Julian et al., 2017; Julian et al., 2020), highlighting one of the challenges in conducting this type of research with athletic population in applied settings.

To improve the quality of menstrual cycle research, further studies are required to address the above limitations. In addition, similar to the study of Julian et al. (2020) in soccer, future research is needed to assess the influence of menstrual cycle directly on rugby and other sports' match activities and determinants of success. Lastly, given the high prevalence of contraception in female athletes (Rechichi et al., 2009), the effects of different hormonal profiles should be also considered.

5. Conclusions

In female rugby athletes, possibly greater performances were observed in the CMJ, DJ, and IMTP in the late luteal phase compared with the menstruation, luteal, and follicular to ovulation phases. However, a large variety of responses were observed at an individual-level.

Including menstrual cycle monitoring and understanding the potential effects of cycle phase on physical performance in rugby and other team sports could be of interest for coaches and practitioners. In particular, assessing and accounting for athletes' individual changes during menstrual cycle phases will likely be beneficial for interpreting monitoring results and training prescription.

Conflict of Interest

The authors declare no conflict of interests.

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Manipulating training activities to simulate physical match demands in rugby sevens

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ABSTRACT

Rugby sevens is a demanding sport that requires extensive physical preparation. Coaches often have limited contact time with players, but must ensure adequate physical, technical and tactical preparation. Playing form approaches (e.g., small-sided/conditioned games and phase of play activities) for training team sports are effective for improving tactical awareness and decision-making, but little information is available to guide the specific formats required to achieve adequate physical conditioning. To investigate what playing form approaches were able to meet and/or exceed physical match demands, microtechnology devices were used to measure total distance, high-speed distance, maximum velocity, acceleration load density, PlayerLoad and collisions in a group of international rugby sevens players (n = 22) during four tournaments and two training camps. Differences in the mean and duration specific demands of matches and different training session types (volume, quality, speed, collision) were determined using linear mixed models and effect sizes (ES) with 95% confidence intervals. Volume and quality training types simulated mean and peak match demands effectively. Speed training exceeded the peak high-speed running demands of matches over durations from 1 to 5 minutes (ES range 1.8 to 2.5). These results demonstrate that appropriately prescribed playing form activities are able to simulate the physical demands of rugby sevens competition.

1. Introduction

Rugby sevens is a physically demanding team sport that requires players to engage in large volumes of high-intensity running and frequent collisions (Ross, Gill, & Cronin, 2014). Rugby sevens is most frequently played in a tournament format, with five to six matches played over a two to three day period (Ross et al., 2014). The total workload accumulated by players over the course of a tournament typically exceeds that of a full 15-a-side rugby match and objective markers of fatigue remain elevated for up to six days following tournament participation (West et al., 2014). As such, adequate physical preparation for rugby sevens is essential (Schuster et al., 2017).

Research has shown that training sessions for both rugby sevens (Higham, Pyne, Anson, Hopkins, & Eddy, 2016) and rugby union (15 players) (Campbell, Peake, & Minett, 2018; Hartwig, Naughton, & Searl, 2011; Phibbs et al., 2018; Tee, Lambert, & Coopoo, 2016a) typically fail to emulate the physical intensity of match play. This suggests that training approaches can be improved and that research into improved training prescription is required. Playing form activities are a popular contemporary approach to training in team sports, and rugby in particular.

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Playing form activities are small-sided games, conditioned games and phase of play activities that are based on game scenarios and are specific to performance problems players are likely to encounter in competition. (Ford, Yates, & Williams, 2010). Evidence suggests that playing form activities effectively develop decision-making and tactical understanding (McKay & O'Connor, 2018; Miller et al., 2017).

Preparing players for international rugby sevens competition is subject to a number of logistical challenges that make the use of playing form activities advantageous. Sub-elite players typically play both sevens and fifteen man rugby (Ross et al., 2014), attending infrequent rugby sevens training camps in order to prepare for tournaments which take place three to six times per year. Full-time professional players on the World Rugby Sevens Series (WRSS) often live in different locations across their respective countries and cannot remain in camp continuously due to the long periods between competition events (Meir, 2012). This restricted access to players places unique demands on coaches who must quickly and efficiently impart their 'game model' and operationalize team tactics within limited timeframes (Richards, Collins, & Mascarenhas, 2012). As a result, training camps typically focus on developing player skill and team cohesion through a range of playing form activities (Meir, 2012).

This overt focus on tactical outcomes often limits the time that strength and conditioning (S&C) coaches have with players for physical preparation. Recently, it has been suggested that S&C coaches could collaborate with technical and tactical coaches to manipulate aspects of playing form training such as pitch size, work:rest intervals and player numbers to improve the quality of physical stimulus received in a process designated *tactical periodisation* (Tee, Ashford, & Piggott, 2018). While this approach is theoretically promising, little information is available regarding the specific manipulations that would elicit appropriate training intensity. Therefore, the primary aims of this study are to determine the whole and peak match demands of rugby sevens match play at an international, sub-elite level of competition, and subsequently to determine the parameters necessary to meet or exceed these demands through playing form activities. It is anticipated that this information will be useful to rugby coaches that make use of playing form activities in their own practice.

In addition to the primary aims, a further aim of this study it to provide important novel normative data for practitioners working in the field. Previous research in rugby sevens has described the described the peak running demands of competition over periods of 1 and 2 minutes (Furlan et al., 2015; Granatelli et al., 2014; Murray & Varley, 2015), however the mean ball in play time is 30.9 seconds (Ross et al., 2014). This study reports peak running, acceleration and collision demands over durations from 30 seconds to 5 minutes to support improved training prescription. Further to this, this study explores the use of acceleration load density (Delaney, Cummins, Thornton, & Duthie, 2018) and a novel collision algorithm (Hulin, Gabbett, Johnston, & Jenkins, 2017) to quantify the physical demands of rugby sevens.

2. Methods

2.1. Experimental approach to the problem

The action research concept informed the experimental approach to this study. Action research is a process through which an intervention or change program is implemented, and managed by, the participant(s) and situated in their practice (Carr & Kemmis, 1983). The coach and strength and conditioning coach of the team were the principal investigators in this project which aimed to devise more effective methods of training within the constraints of their environment. Microtechnology device (global positioning system (GPS) and accelerometer) data were collected during training camps and international tournaments to establish the specificity of playing form activities as a physical training stimulus.

2.2. Participants

Twenty-two male players representing an international rugby sevens team competing in the Rugby Europe Trophy competition between 2017 and 2019 were included in the study. The physical performance characteristics of these players are presented in Table 1. The Rugby Europe Trophy is the third tier of international rugby sevens competition (after the WRSS and Rugby Europe Grand Prix) and teams competing at this level are ranked between 13 and 26 in Europe. Players were informed of the study procedures and provided written informed consent. Ethical approval was granted by the Local Research Ethics Committee of Leeds Beckett University and the recommendations of the Declaration of Helsinki were respected. Procedures

2.2.1. Match and training exposures

Data were collected across four international rugby sevens tournaments (23 total matches) and two international training camps (10 individual training sessions). Tournaments were played under World Rugby laws and as such the data collected were purely observational. Training camp activities were designed by the coaches with the intention of maximising the development of tactical understanding, while simultaneously providing a highly specific physical training stimulus. Each training camp consisted of five training sessions over two days with each individual session organized around particular tactical themes (Table 2). Individual training sessions consisted of a warm up, followed by a skill development activity, followed by playing form activities, and a cool down comprised of an individual skill development task. The playing form activity blocks were structured to replicate the duration of a match half (7 mins), with 2-3 min recovery between each block. Activities within these blocks were organized around specific tactical '*moments of the game*' (Tee et al., 2018) (e.g., attack from midfield rucks, kick off defence, etc.).

Table 1: Physical performance characteristics of players representing an international rugby sevens team participating in the Rugby Europe Trophy competition.

	All players (n = 22)	**Forwards (n = 10)**	**Backs (n = 12)**	***p*-value**	**Effect size, ±95%CI**
Body mass (kg)	87.0 ± 7.2	91.6 ± 4.0*#	83.1 ± 7.1	0.002	1.1 ±0.7
1RM squat (kg)	141 ± 18	146 ± 20	137 ± 16	0.312	0.5 ±1.0
1RM bench press (kg)	108 ± 14	114 ± 16	104 ± 12	0.139	0.7 ±0.9
10m sprint (s)	1.82 ± 0.08	1.86 ± 0.09	1.80 ± 0.07	0.161	0.7 ±1.1
40m sprint (s)	5.45 ± 0.21	5.56 ± 0.16*	5.36 ± 0.20	0.046	0.9 ±0.9
Momentum ($kg.m^{-1}.s^{-1}$)	472 ± 40	486 ± 26	462 ± 47	0.217	0.5 ±0.8
Counter movement jump (CMJ) height (cm)	40.9 ± 4.8	38.8 ± 2.8	42.8 ± 5.5	0.121	0.7 ±0.9
CMJ peak power (Watt)	4394 ± 359	4419 ± 302	4373 ± 425	0.822	0.1 ±0.9
CMJ Relative peak power ($Watt.kg^{-1}$)	50.3 ± 3.9	48.5 ±1.8	52.2 ± 4.7	0.124	0.7 ±0.8
Bronco Run (s)	297 ± 11	300 ± 13	295 ± 9	0.406	0.4 ±1.0

Note: Testing procedures for all variables are detailed in the supplementary document. * indicates a significant difference between backs and forwards ($p < 0.05$) (independent samples t-test). # indicates that there is a greater that 75% likelihood that the differences observed were practically meaningful at an effect size threshold of 0.6 (moderate). Effect size represents the standardized mean difference between forwards and backs with 95% confidence intervals

Within these playing form activities, coaches attempted to manipulate the constraints of training to achieve particular physiological stimulus. Sessions were broadly categorized as either '*volume*' or '*quality*' type sessions. *Volume* sessions attempted to expose players to higher work rates than they would typically be exposed to during matches. The aim of *quality* sessions was to execute tactical movements successfully under physical demands similar to those experienced under match conditions. Quality sessions were utilized when new tactical approaches needed to be learned to allow time for brief periods of communication, feedback and reflection between playing bouts. In order to achieve these outcomes, work:rest ratios were manipulated to influence physical demands. *Volume* sessions were constructed with ball in play periods >45 seconds in duration and half as much rest provided (i.e work:rest ~ 2:1). *Quality* sessions were constructed with short ball in play periods <35 seconds in duration and longer rest periods up to 60 seconds in duration (work:rest ~ 1:2). This reflects the average ball in play time of 28-33 seconds during international competition (Ross et al., 2014).

In cases where play broke down before the required playing time interval had elapsed, coaches introduced another ball into the game and allow play to continue immediately from unstructured situations. Pitch dimensions were never altered and all sessions took place on a full size rugby pitch. Rugby sevens has one of the largest player to pitch area ratios of all team sports (at least 515 m^2/player), and as such pitch area is unlikely to be a limiting constraint on player movement patterns. Sample sessions are provided in Table 3 for clarity.

It was anticipated that even though session types could be manipulated to influence physical demands, it would be not be possible to manipulate game conditions sufficiently to provide consistent exposure to maximal velocity running or frequent high-intensity collisions, both of which are key determinants of performance (Ross et al., 2014). Therefore, specific game form drills were developed to emphasise either maximal velocity running or collision exposure and included in training sessions as skill development activities (Table 2). Due to the intensity of these activities each drill was typically only utilized once per training camp (Table 2).

2.2.2. *Quantification of match and training demands*

During training camps and tournaments players wore microtechnology devices (S5 Optimeye, Catapult Innovations, Melbourne, Australia) that sample GPS data at a frequency of 10Hz and contain a tri-axial accelerometer sampling at 100Hz. Players used the same microtechnology device for the duration of the data collection period. Devices were positioned between the shoulder blades, in a custom-designed undergarment provided by the manufacturer. The validity of these units for measuring team sports movements has been previously established (Johnston et al., 2012; Varley, Fairweather, & Aughey, 2012). Following the completion of each match or training session, data were downloaded to the manufacturer's software (OpenField 1.14, Catapult Innovations, Melbourne, Australia) and trimmed to only include playing time. Playing time was considered to be the beginning to the end of each half or playing block (inclusive of ball out of periods) for matches and training respectively. For training sessions, only playing form activities (volume, quality, collision or speed) were retained for analysis. Start and finish times of these activities were recorded by direct observation and then used to ensure that only relevant training periods were included in the data. Data were then exported as .csv files before

Table 2: Example training schedule from a two-day international rugby sevens training camp.

	TRAINING CAMP SCHEDULE			
	Day 1		**Day 2**	
07:00 to 08:00	STRENGTH AND POWER TESTING		-	
08:00	BREAKFAST		BREAKFAST	
08:30 to 09:30	TEAM MEETING		TEAM MEETING	
09:30 to 10:30	PREPARATION: Physio, taping, foam rolling and mobility work		PREPARATION: Physio, taping, foam rolling and mobility work	
10:30 to 12:00	TRAINING SESSION #1 Tactical Theme: Defence		TRAINING SESSION #4 Tactical Theme: Attack from broken play	
	Session type: Quality		**Session type: Volume**	
	Session content	Timing and detail	Session content	Timing and detail
	• Warm-up	10 minutes	• Warm-up	10 minutes
	Skill development • Collision – 2 vs 2 tackle drill	10 minutes Emphasis – repeat effort ~ 2-3 tackles/min	Aerobic capacity test • Bronco	10 minutes
	Tactical development • High D drill into game situation #1 • High D drill into game situation #2 • Game situation start from ruck#1 • Game situation start from ruck #2	4 x 7 minutes Work: up to 30s Rest:up to 60s Ratio ~ 1:2	Tactical development • Red zone attack #1 • Red zone attack #2 • Mid-field ruck attack #1 • Mid-field ruck attack #2	4 x 7 minutes Work: more than 45s Rest: less than 30s Ratio ~ 2:1
	Individual skills • Warm down Kick off skills	10 minutes	Individual skills • Warm down Passing skills	10 minutes
12:00 to 13:00	LUNCH		LUNCH	
13:00 to 14:00	PREPARATION: Physio, taping, foam rolling and mobility work		PREPARATION: Physio, taping, foam rolling and mobility work	
14:00 to 15:00	TRAINING SESSION #2 Tactical Theme: Kick off		TRAINING SESSION #5 Tactical Theme: Match simulation	
	Session type: Quality		**Session type: Quality**	
	Session content	Timing and detail	Session content	Timing and detail
	• Warm up	15 minutes	• Warm up (as per tournament)	10 minutes
	Skill development • Speed - testing OR speed games	15 minutes Emphasis – maximum velocity	Skill development • Wrestling and collision skills	15 minutes
	Tactical development • Game situation from kick off scenarios	3 x 7 minutes Work: up to 30s Rest:up to 60s	Tactical development • Full match simulation	3 x 7 minutes Work: up to 30s Rest:up to 60s
	Individual skills • Warm down Kick skill game	Ratio ~ 1:2 10 minutes	Individual skills • Warm down Penalty moves	Ratio ~ 1:2 10 minutes
15:00 to 16:00	RECOVERY: Snack, mobility, foam roller		TEAM MEETING	
16:00 to 17:00	TRAINING SESSION #3 Tactical Theme: Attack from set piece		ONE ON ONE MEETINGS AND CLEAN UP	
	Session type: Volume			
	Session content	Timing and detail		
	• Warm up	10 minutes		
	Skill development • Long passing	10 minutes		
	Tactical development • Attack from mid field scrums • Attack from wide scrums • Attack from lineouts	3 x 7 minutes Work: more than 45s Rest: less than 30s Ratio ~ 2:1		
	• Warm down	10 minutes		

being further analysed in R (version R-3.1.3, R Foundation for Statistical Computing, Vienna, Austria). GPS files were excluded from the data set if the mean number of satellites connected was <10, or the horizontal dilution of precision was >2.0. In total, 378 match halves and 379 training bouts (221 quality, 125 volume, 20 collision, 13 speed) were analysed.

The variables of interest were total distance, high speed distance (distance >5m.s^{-1}), acceleration load density, PlayerLoad, maximal velocity and collision count. These variables were selected because they are representative of the various physical demands of the game and have been previously reported, providing a basis for comparison (Ross, Gill, & Cronin, 2015a, 2015b). Where appropriate, data were normalized to activity duration to account for differences in playing time (e.g., starters vs. substitute players) and thus total distance (m.min^{-1}), high speed distance (m.min^{-1} >5m.s^{-1}), PlayerLoad (AU.min^{-1}) and collisions (n.min^{-1}) are all presented as per minute values, while acceleration (m.s^{-2}) is presented as the mean value over the relevant time period and maximal velocity (m.s^{-1}) as the maximum value over the relevant time period.

PlayerLoad is a measure derived from the accumulation of data from all axes of the triaxial accelerometer, and is considered to be a representation of the mechanical load that athletes are exposed to (Barrett, Midgley, & Lovell, 2014). Collision count was determined using the 'tackle' algorithm provided by the manufacturer, which derives collision events from the interaction between accelerometer and gyroscope data. Collision data were exported and all collisions less than 1 PlayerLoad (AU) and or lasting less than 1 second were excluded from the analysis in order to improve the accuracy of the detection (Hulin et al., 2017). While it is acknowledged that this method has only been validated for use in rugby league, in the absence of a validated and commercially available application for determining collision counts in rugby sevens, this method was deemed to be representative of collision exposure.

Match and training exertions are described as both the overall mean (average exertion over the entire playing period) and duration specific (maximal mean exertion over specified time periods) values (Whitehead, Till, Weaving, & Jones, 2018). Specifically, time-series files detailing players instantaneous speed every 0.1s were exported from the proprietary software to RStudio. A custom algorithm was built using the *zoo* package (Zeileis & Grothendieck, 2005)to calculate the maximal mean of each player's instantaneous speed across different durations (30s, 1 min, 2 min, 3 min, 4 min, 5 min) using a shifting time window according to the methods of Delaney et al. (2015) (Delaney et al., 2015). The same time series files were used to derive acceleration load density by calculating the absolute value of all acceleration/deceleration data, before being averaged over the duration of the defined period. Acceleration load density provides a reliable assessment of the total acceleration and deceleration demands of an activity (Delaney et al., 2018; Delaney et al., 2019).

2.3. Statistical analysis

All data were log transformed prior to analysis to reduce non-uniformity of error. Differences in physical characteristics between backs and forwards were assessed using independent samples t-tests. Linear mixed models were constructed using the *lme4* package (Bates, Maechler, Bolker, & Walker, 2015) to assess the difference between match exertions and different training session types. Separate models were built for each measured variable and duration. Match or training session type were designated as fixed effects, while player identity, match or training session identity, player position (back or forward), period (half 1 or 2 for matches and interval 1 to 5 for training sessions) and season were all included as random effects. These random effects were included to address the non-independence of data (i.e., repeated measures on the same participants) and to account for differences in exertions that may occur as results of pacing and fatigue (Higham, Pyne, Anson, & Eddy, 2011; Tee, Lambert, & Coopoo, 2016b, 2019). Pairwise comparisons were made between training session types and match exertions using the least-squares mean test provided in the *emmeans* package (Lenth, 2019). Cohen's *d* effect sizes (ES) and 95% confidence intervals were then calculated for these pairwise comparisons using the *psych* package (Revelle, 2018). ES magnitudes were interpreted as 0.00-0.19, *trivial*; 0.20-0.59, *small*; 0.60-1.19, *moderate*; 1.20-1.99, *large*; and >2.0 *very large* (Hopkins, Marshall, Batterham, & Hanin, 2009).

Due to the applied nature of this study, it was important to assess whether differences were practically meaningful, rather than just significantly different. As such, percentage likelihood that observed effects exceeded a minimum threshold for practical importance were derived from the p-values of the least-squares mean tests (Hopkins et al., 2009). It has been previously demonstrated that mean running speed and acceleration are highly variable in team sports, and that as a result of this variability small effects may lie within the typical error of measurement of these metrics (Duthie, Thomas, Bahnisch, Thornton, & Ball, 2019). On this basis, an effect size of 0.6 was designated as the threshold for practical importance. Accordingly, differences were considered practically meaningful if there was a >75% likelihood of the effect being moderate (ES > 0.6).

3. Results

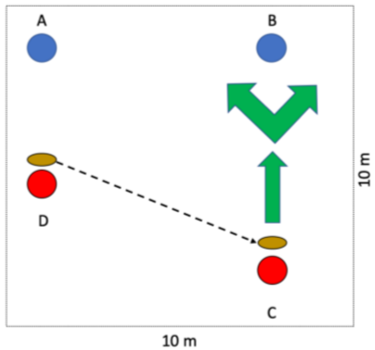
The mean movement demands of rugby sevens match play and the various playing form training structures are presented in Table 4. Figure 1 shows the magnitude of difference (ES ± 95%CI) from match-play of the various training structures for all of the movement variables.

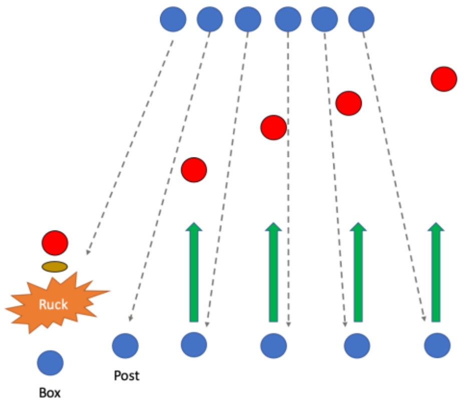
Both the *volume* and *quality* type training structures simulated the demands of match play well. There were no practically important differences between match play and *volume* type training for any of the performance parameters measured. The only meaningful difference between match play and *quality* type training was a *moderate* difference in PlayerLoad (ES -1.0, -1.1 to -0.8; $p < 0.001$; 85% likelihood).

The activities designed to emphasise either speed or collision exposure displayed some large differences from match activity. *Speed* type sessions resulted in less total distance being covered (ES -0.9, -1.5 to -0.2; $p = 0.001$; 91% likelihood) and less PlayerLoad (ES -2.3, -3.0 to -1.7; $p < 0.001$; 100% likelihood)

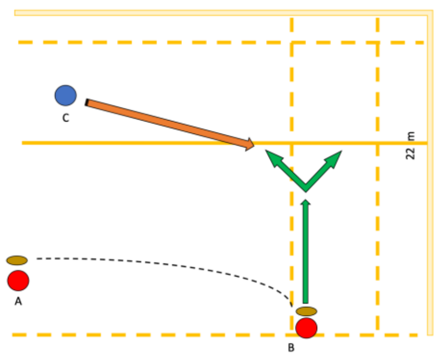
Table 3: Sample session plan focused on defensive organization, illustrating the incorporation of tactical periodization principles into session planning.

TRAINING SESSION #1		
Date: N/A	Phase: Pre-competition	Total time: 1 hour
Tactical Theme – Defence from rucks **Game moments**: Transition from first phase or turnover to 'high-D' structure **Tactical scenario:** Defending a ruck after slowing the ball down **Sub-principle:** Remove attack's time and space as quickly as possible **Sub-sub-principles:** Line speed depends on prior organization – get position + width quickly		
Technical: Organisation from box and post defenders when arriving at rucks. NB roles and responsibilities	**Physical:** - "Quality" emphasis – Work periods ~ 30 seconds/3-4 phases, with up to a minute between bouts. Work:rest 2:1 - Adequate rest ensure that learning occurs at game speed.	**Mental:** Quickly switch roles – transitions are normally preceded by an error – adjust quickly to new scenario

Activity	**Duration**	**Structure**	**Key coaching points**
Warm up	10 minutes	**Raise:** Passing grid with submaximal running **Activation and mobilization:** Running technique drills **Potentiate:** Wrestle in prep for contact exposure	- 'Rifles' – finish the pass - Control hips to dominate contact
<u>**Skill development**</u> 2 vs 2 tackle area drill	15 minutes	**2 vs 2 tackle area drill**  Player D pass to player C, Player C attempts to beat player B. Players D provide support and clean ruck. Player A make decision about whether to contest ruck or set defence.	Attackers - Agility before contact. Try to free arms for offload/long place. Support player 45 degrees on the inside and 2-3 m depth. Available for offload or clean. Defenders – Close space quickly! Settle prior to contact = feet ready to react to agility. Foot into contact zone. Wrap and leg drive after contact. Return to feet quickly. Catch up defender – Keep alignment. Awareness of offload. Identify opportunity for turnover or slow possession, or set defence quickly

<u>Tactical development</u> High D – work together to reduce attack time and space	4 x 7-minute blocks	**High D drill into game play** – 2 x 7 minutes  Attacking and defending players start 10 – 15m ahead of the ruck. Ruck contains 2 attacking and 1 defending player. On the signal, both groups of players advance to the ruck and set to play – this simulates game situation following a ruck especially if we manage to slow down the ball. Defensive players KPI's – 1. Set box, 2. Set post, 3. achieve width/alignment, 4. Work rate – achieve line speed, while maintaining connection. - Second block – defence two players in ruck = one less player in the line. **Game situations starting from ruck defence** – 2 x 7 minutes Defence starts flat, but from various ruck positions (left, right, middle). Principles of High D to be demonstrated in dynamic game play.	***Tactical:*** 1. Box and post most NB – must set to avoid blindside attack 2. Post must advance quickly to stop first attacker stepping back and attacking blind 3. Retreating defenders work hard to achieve with/alignment and be ready 4. Aggressive linespeed! Move fast when the ball is in the air, settle when ball is in hands. 5. Maintain alignment. ***Technical:*** 1. Shoulders remain square even if sliding to avoid being beaten on the weak shoulder. 2. Maintain connection with inside and outside defenders 3. Positioning – inside, inside shoulder ***Mental:*** 1. Agitated/angry coaching behaviours to increase pressure 2. Deliberately unfair refereeing during some bouts to develop resilience.
<u>Warm down</u> Kick off receipt skills	2 x 5 minute blocks	**Catching in the air** Players to pair off – one feeding, other catching. Feeder throws balls in the air requiring the catcher to move a few steps before jumping and catching overhead **Supported catches** As previous, but catchers now work as catching pods (1 lifter/1 catcher)	***Technical:*** 1. Move early, watch ball to the peak of its arc before settling 2. Hands above head and in the air to catch.

TRAINING SESSION #2		
Date: N/A	**Phase: Pre-competition**	**Total time: 50 minutes**
Tactical Theme – Kick off recovery **Game moments**: Kick off to recovery possession or kick off to exert pressure **Tactical scenarios:** Leading/chasing game – One or two score differences **Sub-principle:** Pressure on catcher – no time to look/assess options – create a contact point **Sub-sub-principles:** Chase line – wide players ahead to cut of wider attack options.		
Technical: Kick quality – predictable height and positioning Kick chase – contestable = 1 competing player, 1 past the ball + organized line - Deep kick = 6 in a line, pressure into the corner	**Physical:** - Maximum velocity and high speed running volume - “Quality” emphasis – Work periods ~ 30 seconds/3-4 phases, with up to a minute between bouts. Work:rest 2:1 - Adequate rest ensure to ensure running intensity is maintained	**Mental:** Decision making regarding score line scenarios, and reacting to opposition strength/weaknesses.

Activity	Duration	Structure	Key coaching points
Warm up	10 minutes	<u>**Max velocity preparation**</u> **Raise:** Long passing grid with submaximal running **Activation and mobilization:** Running technique and plyometric drills **Potentiate:** Gradual acceleration into 10 – 15 VMax	- Stay straight – don’t run sideways to deliver long pass - Postures and shapes – accel vs Max V.
<u>**Skill development**</u> Speed weapons	15 minutes	**‘Finish in the corner’** drill ~ 5 attacks per player  Player A kick/pass to player B. Player C is the last defender and may start moving as soon as player A passes. Player C must receive the ball and use speed and agility skills to beat player C and score anywhere over the try line.	Attackers – Don’t allow defenders to close space before using your ‘weapons’. Vary speed and try to get defender to turn his shoulders. Defenders – Close space quickly! Shepard attacker, try to provide only one shoulder to attack and minimize the ability to use ‘weapons’.

Tactical development Kick offs	3 x 7-minute blocks	**Game play from kickoff starts** Block 1: Contestable kick – 1 x 7 minutes Block 2: Deep kick – 1 x 7 minutes Block 3: Variable (scenarios) – 1 x 7 minutes	***Tactical:*** 1. Contestable: Player in the air to compete with catcher – react to errors! 2. Deep kick: Pressure through high line speed and organized shape. Lock them in! ***Technical:*** 1. Kick quality 2. Timing arrival into jump zone ***Mental:*** 1. Decision making around kick type – when/why
Warm down Kick skills game	5 minutes	**Cover the field** Players kick to gain ground – if ball hits grass they receive another kick from where it landed. When close enough attempt drop goal.	***Technical:*** ***1.*** No pressure catch – set and execute 2. Kick skill – control fall of ball, head down.

Table 4: Mean movement demands of international rugby sevens matches and tactical periodisation training structures.

		Training type			
	Match	**Quality**	**Volume**	**Speed**	**Collision**
Total distance ($m.min^{-1}$)	107 ± 37	93 ± 17	102 ± 14	76 ± 7*	41 ± 5*,§,#,%
High speed distance ($m.min^{-1}$)	16 ± 11	10 ± 5	10 ± 4	22 ± 3§	0.6 ± 0.4*,§,#,%
Maximum velocity ($m.s^{-1}$)	7.2 ±1.0	6.9 ± 0.9	7.2 ± 0.8	7.8 ± 0.9	4.1 ± 0.4*,§,#,%
Acceleration load density ($m.s^{-2}$)	0.35 ± 0.10	0.40 ± 0.07	0.41 ± 0.05	0.27 ± 0.09§,#	0.32 ± 0.06
PlayerLoad ($AU.min^{-1}$)	10.7 ± 1.3	9.0 ± 1.8*	10.2 ± 1.2	6.7 ± 0.8*,§,#	4.5 ± 0.5*,§,#,%
Collisions ($N.min^{-1}$)	1.5 ± 2.4	1.0 ± 0.9	1.1 ± 0.9	-	1.4 ± 0.3

Note: *,§,# and % designate practically meaningful differences (> 75% likelihood of a moderate or greater effect) from match, quality, volume and speed type training respectively.

than matches. *Collision* training was the training type that was most similar to match play for collisions (ES -0.04, -0.6 to 0.5; *p* = 0.263; 100% likelihood of trivial effect), but was meaningfully lower for total distance, high speed distance, maximum velocity and PlayerLoad measures (*large* to *very large* effects, $p < 0.001$, 100% likelihood). Despite the intention to create overload, none of the training structures implemented lead to physical exertions that were meaningfully greater than match play.

When comparing between different training types, it is clear that *collision* type training is atypical, displaying practically important differences from all other training types for all measures except acceleration load density and collisions. *Speed* type training had meaningfully lower acceleration load density demands than both *volume* (ES -2.5, -3.3 to -1.7; $p = 0.062$; 89% likelihood) and *quality* (ES -2.2, -2.9 to -1.5; $p = 0.079$; 86% likelihood) type training. *Speed* training lead to more high speed running than *intensity* (ES 1.0, 0.3 to 1.6; $p = 0.040$; 87% likelihood) and *volume* (ES 1.2, 0.5 to 1.8; $p = 0.381$; 69% likelihood) type training, but only *intensity* presented a clear difference. No collisions occurred during *speed* training.

Based on the evidence of the previous analysis, *collision* training data was not carried forward to peak demands analysis due to being so clearly different. The averaged peak values for total distance, high speed distance and acceleration over time periods ranging from 30 seconds to 5 minutes are presented in Figure 2. There were no practically meaningful differences between matches and *quality* or *volume* training types over any duration. *Speed* sessions exceeded the average peak high speed running demands of matches over durations ranging from 1 to 5 minutes (*large* to *very large* effects, $p < 0.05$, > 89% likelihood).

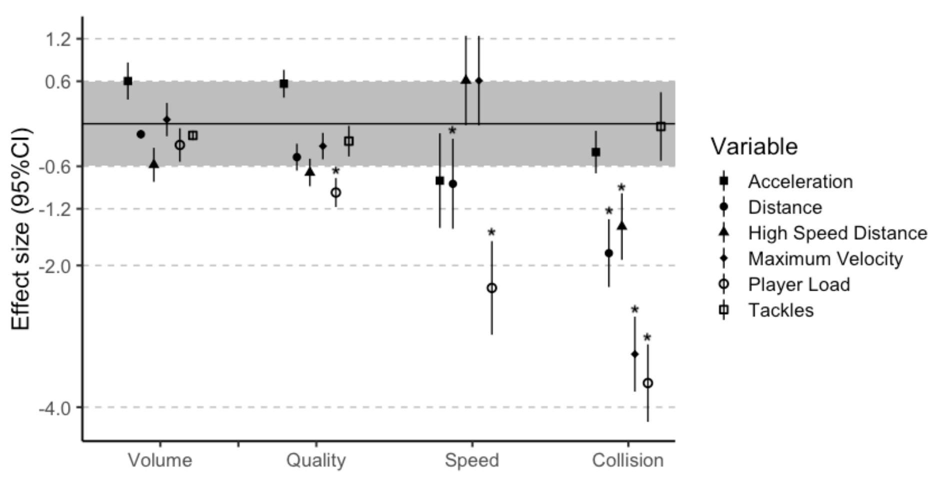


Figure 1: Comparison of standardized effect sizes with 95% confidence intervals of movement characteristics between international rugby sevens match-play and tactical periodization training activities. Positive values indicate outputs greater than match play.
Note: * designates a practically meaningful difference (> 75% likelihood of a moderate or greater effect) from matches.

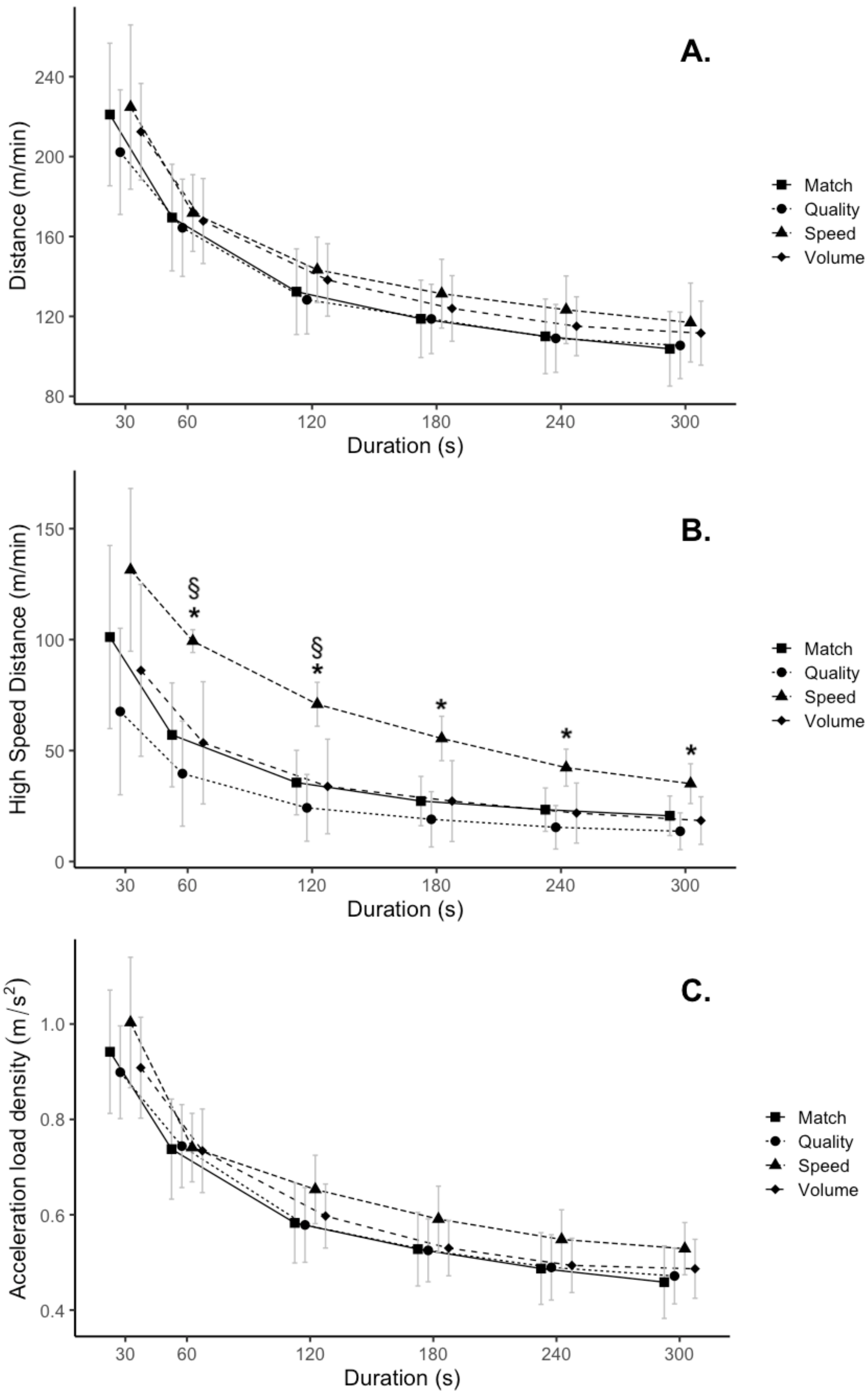


Figure 2: Peak (maximal mean) demands of international rugby sevens matches and tactical periodisation training types for A) total distance, B) high speed distance and C) acceleration load density over 30, 60, 120, 180, 240 and 300 second time periods. Data are presented as mean ± SD.

Note: * and § designate practically meaningful differences (> 75% likelihood of a moderate or greater effect) from matches from matches and *intensity* type training sessions. Positive values indicate outputs greater than match play. Absolute values are provided in the supplementary file.

Speed training was not practically different to matches for total distance or acceleration load density any time period. *Speed* training also exceeded the high speed running demands of *quality* training over durations of 1 and 2 minutes (*very large* effects, p = 0.013, > 87% likelihood). *Speed* training was also not practically different to *volume* training for any variable.

4. Discussion

The main finding of this study is that it was possible to provide a training stimulus similar to the physical demands of international rugby sevens match play through the use of playing form activities in training. These results contrast directly with previous examinations of rugby sevens training where training drills failed to reproduce the movement demands of matches (Higham et al., 2016). This study therefore presents novel findings, demonstrating that playing form activities can be highly specific to the physical demands of rugby sevens match play.

This study is also the first to provide a full range of peak duration specific demands for rugby sevens match play. Previous analysis of the peak demands of rugby sevens match play provided data over periods of 1 to 2 minutes (Furlan et al., 2015; Granatelli et al., 2014; Murray & Varley, 2015). The data provided here extend this analysis, considering both shorter (30 s) and longer periods of play (5 min). This is important because the mean ball in play time for international rugby sevens is approximately 30 seconds (Ross et al., 2014), thus the data provided here give a more accurate reflection of the ball in play demands. Understanding the peak intensities typical of longer game periods is essential for evaluating the effectiveness of training prescription (Delaney et al., 2017). There appears to be very little difference between rugby sevens, international rugby union (Delaney et al., 2017) and professional rugby league (Johnston et al., 2019; Weaving et al., 2019) when comparing the peak running intensities across all durations.

An interesting finding of this study was that the manipulation of work:rest ratios had relatively minor effects on the physical demands of training. Previous research demonstrates that following the highest intensity periods of play team sports players temporarily reduce their levels physical exertion (Bradley & Noakes, 2013; Peeters, Carling, Piscione, & Lacome, 2019).This suggests that players regulate their levels of exertion to ensure adequate reserves for future periods of play (Waldron & Highton, 2014). On this basis, the lack of differentiation between training structures may indicate that both types are sufficiently physically demanding that players are forced to regulate their efforts. Further consideration needs to be given to how to effectively differentiate training types to ensure variation in training stimulus.

In contrast, the manipulations applied within the playing form activities designed to maximise *speed* and *collision* exposures allowed for those particular movement challenges to be emphasised, but equally resulted in these activities becoming quite different from the generalised demands of match play. On this basis, it seems pragmatic to prescribe a combination of activity types to ensure that players are generally conditioned for match play, but are also regularly exposed to more intense sessions focused on developing particular physiological qualities. In this sense, the *speed* session was highly specific as a stimulus for maximal velocity and high speed running.

The match data provided here is the first to examine the physical demands in the third tier of international rugby sevens competition. In general, the total and high speed distance outputs were similar to those reported for tier 1 (sevens world series) players (Ball, Halaki, & Orr, 2019; Higham et al., 2016; Murray & Varley, 2015; Ross et al., 2015a, 2015b), with the exception of mean maximal velocity (tier 1 players (range 7.5 to 8.4 $m.s^{-1}$) (Higham et al., 2016; Ross et al., 2015b) vs. tier 3 players (7.2 ± 1.0 $m.s^{-1}$)). The peak running demands reported here and for tier 1 players were also similar (Furlan et al., 2015; Murray & Varley, 2015). Collectively these results suggest that there is very little difference in the movement demands between these distinct levels of competition. If the physical demands of play at different levels of competition are not meaningfully different, it is likely that the differences in performance ability lie in superior technical skills, effective tactical operationalisation and improved decision making. This observation underlines the value of playing form type training which maximise opportunities to develop these attributes.

This study presents a number of analyses that are novel in rugby sevens. Previous rugby sevens research has quantified the acceleration demands of the game using frequencies of entries into different acceleration thresholds (Ball et al., 2019). This approach is problematic because the discretization of time series data reduces the reliability of the measurement (Delaney et al., 2018). A more appropriate method is to report the acceleration load density for the period in question (Delaney et al., 2018). To the authors knowledge, this study is the first to apply this approach in mens rugby sevens. The peak acceleration load density of match play and training determined here are lower than those that have been previously reported for field hockey (Duthie et al., 2019), rugby union (Delaney et al., 2017), rugby league (Delaney et al., 2016) and women's international rugby sevens (Henderson, Chrismas, Stevens, Coutts, & Taylor, 2020). This may signify a difference in the physical performance of sub-elite vs elite team sport athletes, but further investigation is required.

A challenge for researchers working in the rugby codes is that although most microtechnology devices estimate collision exposure in some form, these estimations often don't correspond to actual collisions (McLellan, Lovell, & Gass, 2011). This study is the first to use the Hulin et al (2017) method to estimate collision exposure (Hulin et al., 2017). This measure has not been validated in rugby sevens, but unlike the majority of collision estimation metrics applied in rugby sevens, the measure was validated in professional rugby league against observable video criterion and displayed high levels of sensitivity (97.6%) and specificity (92.7%). Results showed that during matches players are exposed to 3 collisions every two minutes, which is similar to the peak collision frequency observed in professional rugby league players (Johnston et al., 2019).

A major limitation of this study is that no direct measures of technical or tactical skill were made and only physical performance was assessed. Anecdotally, the team in question performed well in the seasons studied, achieving their highest ever ranking in the European trophy competition in one of the seasons. Future studies should aim to assess technical and tactical outcomes alongside physical performance in matches and training.

In conclusion, this study has demonstrated that through use of appropriate manipulations of practice conditions, playing form activities can simulate the physical demands of match play in rugby sevens. This is useful because it confirms that highly specific physical preparation can be achieved while focusing on the development of technical, tactical and mental skills for competition. Playing form activities can be manipulated to emphasise particular aspects of conditioning (e.g., high speed running or collision exposure).

Conflict of Interest

The authors declare no conflict of interests.

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Supplementary Material 1

Mean peak movement demands of international rugby sevens matches and tactical periodisation training structures over time periods or 30 seconds to 5 minutes.

Session type	30 sec	1 min	2 min	3 min	4 min	5 min
			Total distance ($m.min^{-1}$)			
Match	221 ± 36	169 ± 27	132 ± 21	119 ± 19	110 ± 19	104 ± 19
Intensity	202 ± 31	164 ± 24	128 ± 17	119 ± 17	109 ± 17	104 ± 17
Volume	212 ± 24	168 ± 21	138 ± 18	124 ± 16	115 ± 15	112 ± 16
Speed	225 ± 41	172 ± 19	143 ± 16	131 ± 17	123 ± 17	117 ± 20
			High speed distance ($m.min^{-1}$)			
Match	101 ± 41	57 ± 23	36 ± 15	27 ± 11	23 ± 10	21 ± 9
Intensity	68 ± 38	40 ± 24	24 ± 15	19 ± 12	15 ± 10	14 ± 8
Volume	86 ± 39	53 ± 28	34 ± 21	27 ± 18	22 ± 14	18 ± 11
Speed	131 ± 37	99 ± 5$^{*,\#}$	71 ± 10$^{*,\#}$	55 ± 10*	42 ± 8*	35 ± 9*
			Mean Acceleration ($m.s^{-2}$)			
Match	0.94 ± 0.13	0.74 ± 0.10	0.58 ± 0.08	0.53 ± 0.07	0.49 ± 0.08	0.46 ± 0.08
Intensity	0.90 ± 0.10	0.74 ± 0.09	0.58 ± 0.08	0.53 ± 0.07	0.49 ± 0.07	0.47 ± 0.06
Volume	0.91 ± 0.11	0.73 ± 0.09	0.60 ± 0.07	0.53 ± 0.06	0.49 ± 0.06	0.49 ± 0.06
Speed	1.00 ± 0.14	0.74 ± 0.07	0.65 ± 0.07	0.59 ± 0.07	0.55 ± 0.06	0.53 ± 0.05

Note: *,§,$^{\#}$ and $^{\%}$ designate practically meaningful differences (> 75% likelihood of a moderate or greater effect) from match, quality, volume and speed type training respectively.

Supplementary Material 2

Procedures for collection of data describing the physical performance characteristics of the participant group.

Participants

Twenty-two players representing an international rugby sevens team that competed in the Rugby Europe Trophy competition between 2017 and 2019 were included in the study. Players were informed of the study procedures and provided written informed consent. Ethical approval was granted by the Local Research Ethics Committee of Leeds Beckett University and the recommendations of the Declaration of Helsinki were respected. The physical attributes of players at this level of competition have not been previously reported and therefore a broad assessment of physical characteristics was conducted.

Testing procedure

Testing batteries were completed over the course of weekend training camps. Participants were instructed to rest for a full 24 hours before attending a training camp. Typically, jump testing followed by strength tests (1RM back squat and bench press) were completed on the first morning of the camp prior to any other training taking place. Following jump and strength testing, players completed an on field training session of 60 minutes in duration. Players then rested for at least 2 hours (during which time they ate lunch) before completing the sprint test protocol. Players then completed two more on field training sessions during the afternoon before resting over night. The bronco run was completed as the first activity on day two of the camp following a thorough warm up. Players then completed two further training sessions. As reflects the ecological nature of this testing battery adjustments to this protocol were necessitated by aspects such as weather, access to appropriate facilities and player fatigue. Despite this all players completed the test battery on multiple occasions. Supplementary Table 1 presents the mean of the best scores for all players across the three season observation period.

Strength

1 repetition maximum (1RM) strength for back squat and bench press were determined according to the National Strength and Conditioning Association’s 1RM Testing Protocol (Haff & Triplett, 2015). Participants completed submaximal repetitions of each exercise at approximately 50–80% 1RM to serve as both warm-up and determination of 1RM load. With each exercise, subjects were then given 6 attempts, with progressively increasing load to achieve 1RM. 3 – 5 minutes rest was used in between each attempt. Both test protocols were completed using a 2.13m (7ft) Olympic bar and free weights. Participants were required to back squat until the top of the thigh was parallel with the ground, which was visually determined by the lead researcher. Players then had to return to a standing position with adequate technique to record a 1-RM score. For the bench press, athletes lowered the barbell to touch the chest and then pushed the barbell until elbows were locked out while keeping the head, upper back and buttocks on the bench and feet firmly planted on the floor. The largest successful weight achieved in each exercise was recorded.

Speed

10 meter and 40 meter sprint times were measured using a single beam photocell timing system (Brower timing systems, IR Emit, USA) on a grass rugby field with gates positioned at 10 & 40 meters. Players wore rugby boots during testing. Following a standardized warm-up consisting of light jogging, dynamic stretches, and submaximal sprint efforts, participants performed 2 maximal sprint efforts, from a start point of 0.5 m behind the first timing gate with 3 minutes passive rest between each attempt. The best split time over the two attempts was recorded for analysis. The reliability of this method has previously been determined as acceptable (CV for 10m and 40 = 3.1% and 1.3% respectively) (Darrall-Jones et al., 2015). Momentum was calculated by multiplying 10 meter sprint velocity by body mass.

Power

Counter movement jump (CMJ) height was assessed using the MyJump 2 (Version 1.0.11) smart device application, which measures jump height using flight time determined using the high-speed camera contained within the device (iPhone SE, iOS 12.4.1, camera resolution 1080p/60fps). The MyJump application has been shown to be appropriately valid (ICC = 0.997) and reliable (CV = 3.4%) for the determination of jump height (Balsalobre-Fernandez et al., 2015). CMJ tests were conducted as per the manufacturer instructions (Balsalobre-Fernandez et al., 2015). Players were given three opportunities to complete the test, with the best performance recorded. Attempts were separated by 60 seconds of passive rest. Peak power and relative peak power were calculated from jump height according to the methods of Sayers et al., (1999) (Sayers et al., 1999).

Aerobic Capacity

Aerobic capacity was assessed as the time to complete the 1 200 m shuttle run (Bronco) test (Kelly et al., 2014). The validity of this test for rugby athletes has been assessed against both the 30-15 intermittent fitness test (ICC = 0.73)(Kelly & Wood, 2013), and the yo-yo intermittent recovery level 1 test (ICC = 0.87) (Deuchrass et al., 2019). The test has appropriate reliability (TE = 2.4%) (7).

Supplementary Table 1: Physical performance characteristics of players representing an international rugby sevens team participating in the Rugby Europe trophy competition.

	All players (n = 22)	*Forwards (n = 10)*	*Backs (n = 12)*	*p-value*	*Effect size, ±95%CI*
Body mass (kg)	87.0 ± 7.2	91.6 ± 4.0*#	83.1 ± 7.1	0.002	1.07, ±0.65
1RM squat (kg)	141 ± 18	146 ± 20	137 ± 16	0.312	0.46, ±0.97
1RM bench press (kg)	108 ± 14	114 ± 16	104 ± 12	0.139	0.66, ±0.90
10m sprint (s)	1.82 ± 0.08	1.86 ± 0.09	1.80 ± 0.07	0.161	0.73, ±1.08
40m sprint (s)	5.45 ± 0.21	5.56 ± 0.16*	5.36 ± 0.20	0.046	0.87, ±0.86
Momentum ($kg.m^{-1}.s^{-1}$)	472 ± 40	486 ± 26	462 ± 47	0.217	0.47, ±0.76
Counter movement jump (cm)	40.9 ± 4.8	38.8 ± 2.8	42.8 ± 5.5	0.121	0.66, ±0.87
Peak power (Watt)	4394 ± 359	44.9 ± 302	4373 ± 425	0.822	0.11, ±0.93
Relative peak power ($Watt.kg^{-1}$)	50.3 ± 3.9	48.5 ±1.8	52.2 ± 4.7	0.124	0.69, ±0.84
Bronco Run (s)	297 ± 11	300 ± 13	295 ± 9	0.406	0.41, ±1.03

Note: * indicates a significant difference between backs and forwards ($p < 0.05$) (independent samples t-test). # indicates that there is a greater that 75% likelihood that the differences observed were practically meaningful at an effect size threshold of 0.6 (moderate). Effect size represents the standardized difference between forwards and backs with 95% confidence intervals.

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No relationship between nutritional knowledge and rapid weight loss in male amateur boxers

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ABSTRACT

Amateur boxing is a weight-categorized combat sport in which rapid weight loss (RWL) is prevalent prior to competition. Although many boxers believe such practices enhance perceived size and relative strength, potential benefits must be considered against the risks to performance and health. It is unknown whether RWL behaviours are related to nutritional knowledge. Accordingly, the Nutritional Knowledge Questionnaire for Athletes (NKQA) and the Rapid Weight Loss Questionnaire (RWL-Q) were administered to 63 male amateur boxers (mean ± SD; age 23 ± 3 years, body mass 69.6 ± 10.0 kg). Respective scores were analysed descriptively and assessed for correlation. All 63 boxers (100 %) had lost weight to compete, with pre-competition weight loss characterised by a 2.9 ± 1.0 kg (4.2 ± 1.4 %) average reduction in 8 – 10 days. Fluid restriction and the use of sweat suits were the most prevalent methods of RWL (87 % each) with 'extreme' methods (diuretics, laxatives, diet pills and self-induced vomiting) having been used by 21 % of boxers. Total scores for NKQA (52 ± 13 %) compared unfavorably to athletes previously studied. No relationships were observed between NKQA and RWL-Q for either total scores ($r = -0.044$, $p = 0.731$) or any NKQA subsection (r from 0.001 to - 0.127, $p > 0.05$). While coaches (49 %) and other boxers (40 %) exerted the greatest influence on weight loss behaviours, medical professionals had the lowest influence ($p < 0.05$). Nutritional knowledge was not related to weight loss behaviours. Furthermore, amateur boxers should be encouraged to seek professional advice for safe and reliable information.

1. Introduction

Amateur boxing is a weight-categorized combat sport contested over either 3 x 3 min (elite), 3 x 2 min or 4 x 2 min (novice) rounds. Victory is awarded either by knockout (whereby a boxer knocks down their opponent for 10 seconds), by the referee deeming one boxer unable to continue, or to the boxer who has scored the greater "number of *quality blows* on the target area" at the conclusion of the bout (England Boxing, 2019). Accordingly, strength and power are key determinants of success (Chaabène et al., 2015).

Combat athletes frequently aim to compete in a weight category below their habitual body mass to maximise perceived advantages in size and strength, or to be "big for the weight" (Pettersson, Ekström, & Berg, 2013; Reale, Slater, & Burke, 2017b). As championship weigh-ins must occur at least three hours before amateur boxing competition (England Boxing, 2019), boxers frequently "make weight" to achieve a particular weight class, before regaining body mass by the time they box (Reale, Cox, Slater, & Burke, 2017a).

England Boxing currently has no limit for weight regain before competition, potentially encouraging the use of rapid weight loss (RWL) methods (England Boxing, 2019; Reale, Slater, & Burke, 2017c). Indeed, although amateur boxers weigh-in on the day of competition, magnitudes of RWL and subsequent regain commonly range from 2 – 5 % body mass (Barley, Chapman, & Abbiss, 2018a; Reale, Slater, & Burke, 2018). However, RWL practices frequently involve severe dehydration and dietary restriction (Reale et al., 2017b), which are likely to impair performance (Franchini, Brito, & Artioli, 2012). As weight-making practices in amateur boxing are constantly evolving (Reale et al., 2017c), it is essential to frequently evaluate

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the prevalence of RWL in amateur boxing to inform educational strategies.

Existing literature suggests that improved nutritional knowledge may impact sporting performance. For example, while greater nutritional knowledge is associated with improved body composition, strength and dietary practices in young team sport athletes (Debnath, Chatterjee, Bandyopadhyay, Datta, & Dey, 2019), insufficient dietary knowledge may compromise athletes' fueling and recovery strategies (Trakman, Forsyth, Hoye, & Belski, 2018). The need to manipulate body mass may make nutritional knowledge even more important for amateur boxers (Reale et al., 2017a). However, weight loss and nutritional knowledge are more frequently informed by coaches and other athletes than by qualified health professionals, which may lead to false beliefs and inappropriate practices (Artioli et al., 2010b). It is currently unknown whether the prevalence of RWL is related to nutritional knowledge in amateur boxers.

No data exists on the nutritional knowledge of competitive, senior amateur boxers. Furthermore, no study has yet investigated the relationship between nutritional knowledge and RWL behaviours in weight-categorized athletes. Accordingly, this study was designed to examine the relationship between nutritional knowledge and RWL, as well as to investigate the sources of nutritional information used by amateur boxers. It was hypothesized that nutritional knowledge would be negatively associated with the prevalence and severity of RWL behaviours. These findings could be used to guide future education strategies with the aim of moderating potentially dangerous RWL behaviours, whilst maintaining the health and performance of amateur boxers.

2. Methods

2.1. Participants

Following ethical approval, 63 competitive male amateur boxers (mean ± SD; age 22 ± 3 years, self- reported body mass 69.6 ± 10.0 kg, height 177 ± 9 cm, age started boxing 13 ± 4 years-old) were recruited and provided informed consent. Participants were recruited following gatekeeper approval from club coaches, in person and via email. Inclusion criteria were aged >18 years, >2 years' boxing experience, >5 contests. Female boxers were excluded from the investigation due to limited numbers. Boxers were asked for their England Boxing championship weight division (46-49, 49-52, 52-56, 56-60, 60-64, 64-69, 69-75, 75-81, 81-91, 91+ kg) and competition experience (5-10 bouts novice, 11-20 bouts intermediate, 21+ bouts open class) for grouping analysis and categorisation purposes (England Boxing, 2019).

2.2. Instruments

The Nutritional Knowledge Questionnaire for Athletes (NKQA) (Furber, Roberts, & Roberts, 2017) and Rapid Weight Loss Patterns Questionnaire (RWL-Q) (Artioli et al., 2010c) were utilised.

The NKQA tests respondents on their knowledge of the nutritional contents of food, as well as consensus guidelines in sports nutrition. The questionnaire was scored out of a maximum possible 136 marks, which are distributed as follows: Protein (19 marks), Carbohydrates (21 marks), Fats (23 marks), General (31 marks), Fluid (14 marks) and Sport (28 marks). Higher scores indicate superior nutritional knowledge, with the original authors reporting a test-retest Pearson's correlation of 0.98, ($p < 0.05$).

The RWL-Q was originally developed in judo and quantifies the frequency with which specified RWL techniques are used; assigning greater scores to more severe methods and higher rates of weight loss. Furthermore, this questionnaire distinguishes between 'rapid weight loss methods' (training in sweat suits or in heated rooms, sauna use, wearing additional clothing, various methods of manipulating fluid/food intake) and 'extreme rapid weight loss methods', defined as the use of diuretics, laxatives, diet pills and self-induced vomiting (Artioli et al., 2010c). A continuous scoring system is used to attain numeric scores for anthropometrics, competition history and previous RWL patterns. For example, when asked if they had used sweat suits in training for rapid weight loss, boxers' answers were scored as follows: 'Always' = 3 points, 'Sometimes' = 2 points, 'Almost never' = 1 point, 'Not anymore' = 0.5, 'Never used it' = 0 points. The length of time over which boxers lose weight prior to weigh-in is scored as follows: '>15 days' = 0 points, '11 – 14 days' = 1 point, '8 – 10 days' = 2 points, '6 – 7 days' = 3 points, '4 – 5 days' = 4 points, '1 – 3 days' = 5 points. The RWL-Q also questions athletes on the extent to which various sources of information (e.g., coach, other boxer, social media etc.) influence their nutritional knowledge and weight loss behaviours ('none', 'little', 'some', 'high'). Higher scores for RWL-Q indicate more aggressive rapid weight loss behaviours. The validation of the original questionnaire (Artioli et al., 2010c) demonstrated excellent reliability from a highly significant correlation between test-retest scores ($r = 0.92$, $p < 0.05$).

2.3. Task

A cross-sectional questionnaire-based study was carried out across 10 amateur boxing clubs, nationwide.

2.4. Procedure

Questionnaires were administered using the Bristol Online Survey (JISC Software, Bristol, UK). Sport-specific questions referring to track and field in the NKQA and Judo specific questions in the RWL-Q were amended to suit amateur boxing. Data was collected following pilot work, conducted to ensure that all questions were easily understood by the population. Participants were asked to complete the online questionnaires alone, with no assistance from other sources.

2.5. Statistical Approach

Descriptive statics are presented as means and standard deviations. Data were analysed using statistical software (SPSS Statistics 25, IBM, New York, USA). Pearson's correlation coefficient was used to investigate the relationships between RWL-Q and NKQA scores in the whole cohort, as well as in subgroups defined by weight category and competitive experience. Repeated measures ANOVA was used to identify differences in NKQA subsection scores, which were reported as percentages to allow comparisons with existing literature. Where appropriate, differences are given as Cohen's d effect sizes (Cohen, 1988), alongside the 95 % confidence interval (ES ± [LCL, UCL], where LCL and UCL are the lower and upper confidence limits, respectively). Frequency analysis was used to examine the magnitude of influence on athletes' current nutritional knowledge and weight loss behaviours from external sources, before Friedman's test was used to assess differences between sources ($p < 0.05$). Significant differences were investigated with *post hoc* analyses, using the Bonferroni correction.

3. Results

3.1. Boxer demographics

Complete data-sets were obtained from 63 boxers (Table 1), representing 10 clubs from five of the 11 geographical regions sanctioned by England Boxing. Of the 39 open class boxers included, 20 had previously won regional championships, of which nine had gone on to become national champions.

3.2. Relationships between scores on the Rapid Weight Loss Questionnaire and the Nutrition Knowledge Questionnaire for Athletes

No relationships were found between RWL-Q scores and either total NKQA (r = -0.044, p = 0.731) or any subsection scores (r lowest = 0.001, greatest = - 0.127, p > 0.05).

3.3. Nutrition Knowledge Questionnaire for Athletes scores

Total NKQA scores (Table 1) averaged 52 ± 13 % and did not vary with experience (novice = 48 ± 13 %, n = 13; intermediate = 51 ± 15 %, n = 11; open class 54 ± 13 %, n = 39; F = 0.960, p = 0.389; ES = -0.16 ± [-0.82, 0.51] to 0.45 ± [-0.16, 1.06]). There was a significant difference between NKQA subsection scores (F = 3.27, p < 0.001; Figure 1). Scores for protein (62 ± 16 %) were greater than all other sub-sections (p < 0.05; ES = 0.46 ± [0.11, 0.81] to 0.95 ± [0.58, 1.32]). Fluid (43 ± 19 %) and carbohydrate (47 ± 21 %) represented the lowest scoring sub-sections (Figure 1), and were not significantly different from each other (p = 0.214; ES = 0.18 ± [-0.17, 0.53]).

3.4. Rapid Weight Loss scores

Total RWL-Q scores (30 ± 10), showed no significant difference (F = 1.534, p = 0.224) between experience levels (Table 1). All 63 boxers (100 %) had lost weight to compete, with mean pre-competition weight loss was 2.9 ± 1 kg, commencing on average "8 - 10 days" prior. Significant differences were observed in the frequencies of RWL methods previously or still used by boxers ($\chi 2$ = 220; p < 0.001), with 'Restricting fluid intake' (87 %; mean rank 9.17), 'Training in sweat suit' (87 %; mean rank 8.90) and 'Skipping meals' (78 %; mean rank 7.82) the most popular methods (Figure 2). Descriptive statistics showed that an 'extreme' method was used by at least 21 % of boxers, with diuretics (21 % with history of use) being the least used RWL method (Figure 2).

Table 1: Participant characteristics

	Novice n = 13	Intermediate n = 11	Open class n = 39	Total n = 63
Age (y)	22 ± 3	22 ± 2	22 ± 3	22 ± 3
Body mass (kg)	72.0 ± 10.2	72.8 ± 10.0	69.7 ± 10.0	69.6 ± 10.0
Height (cm)	180 ± 8	177 ± 10	176 ± 9	177 ± 9
NWLPS	1 ± 1	3 ± 4	4 ± 3	3 ± 3
Usual WL (kg)	3.6 ± 1.0	3.0 ± 1.0	3.0 ± 1.0	2.9 ±1.0
ΔBM (kg)	8.5 ± 4.0	5.6 ± 2.0	6.5 ± 4.0	7.0 ± 4.0
$NKQA_{RAW}$	65 ± 17	70 ± 21	73 ± 18	71 ± 18
NKQA (%)	48 ± 13	51 ± 15	54 ± 13	52 ± 13
ES_{NKQA}	-0.28 ± [-1.07, 0.51]$^{+}$	-0.16 ± [-0.82, 0.51]$^{\Delta}$	0.45 ± [-0.16, 1.06]$^{\#}$	
RWL-Q	26 ± 10	30 ± 10	31 ± 10	30 ± 10
ES_{RWL-Q}	-0.39 ± [-1.18, 0.41]$^{+}$	-0.17 ± [-0.84, 0.50]$^{\Delta}$	0.55 ± [-0.07, 1.17]$^{\#}$	

Note: NWLPS = number of weight loss bouts in previous season; Usual WL (kg) = self-reported weight loss usually undertaken prior to competition; ΔBM (kg) = difference between off-season body mass and championship weight limit; NKQA = Total scores on the Nutritional Knowledge Questionnaire for Athletes (given both as raw scores and percentages). ES = effect size (Cohen's d); $^{+}$ = versus intermediate; $^{\Delta}$ = versus open class; $^{\#}$ = versus novice; RWL-Q = Total scores on the Rapid Weight Loss Patterns Questionnaire

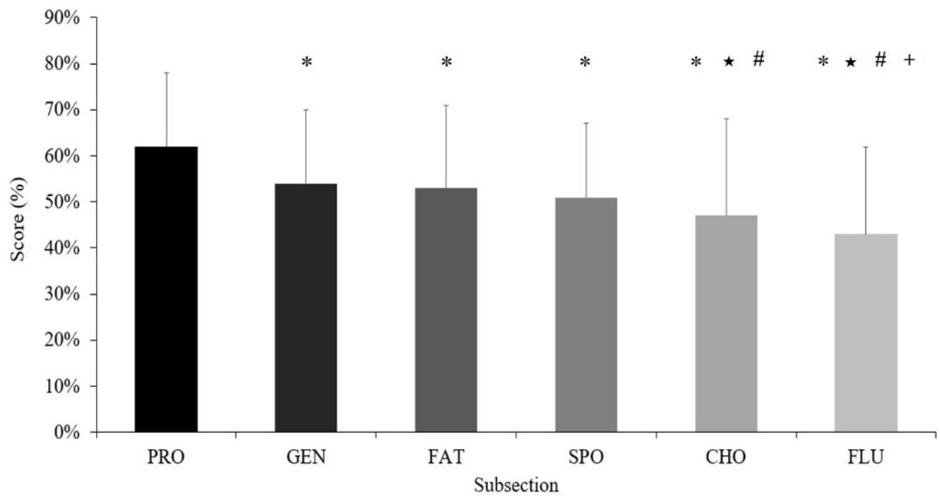

Figure 1: Results of the Nutritional Knowledge Questionnaire for Athletes, divided into subsections. PRO = Protein. GEN = General nutrition knowledge. FAT = Fat. SPO = Sports nutrition. CHO = Carbohydrate. FLU = Fluid.

Note: * = significantly lower than PRO (Cohen's d effect sizes from -0.46 ±, [-0.81, -0.11] to -0.95 ± [-1.32, -0.58]), ★ = significantly lower than GEN (Cohen's d effect sizes from -0.40 ± [-0.75, -0.04] to -0.60 ± [-0.97, -0.25]), # = significantly lower than FAT (Cohen's d effect sizes from -0.31 ± [-0.66, 0.04] to -0.51 ± [-0.87, -0.16]), + = significantly lower than SPO (Cohen's d effect size = -0.45 ± [-0.8, -0.1])

The influence of each source of nutritional knowledge differed significantly ($\chi 2 = 71$; $p < 0.001$). The percentages of athletes influenced by different sources of information are shown in Figure 3A, while statistical analysis revealed mean ranks as follows; coach = 5.06, other boxer = 4.71, parent = 3.75, social media = 4.42, doctor = 2.60, dietitian/nutritionist = 3.48, strength and conditioning coach = 3.98. Post hoc analysis (Figure 3) revealed that doctors exerted significantly lower influence than all other sources, bar dietitians/nutritionists and parents ($p < 0.05$). Conversely, coaches exerted more influence than doctors, dietitians/nutritionists and parents ($p < 0.05$). Other boxers exerted more influence than both doctors and dietitians/nutritionists ($p < 0.05$).

The relative influence on weight loss behaviours (Figure 3B) also varied significantly between sources ($\chi 2 = 119$, $p = 0.001$). Statistical analysis revealed mean ranks as follows; coach = 5.66, other boxer = 5.09, parent = 3.48, social media = 3.73, doctor = 2.56, nutritionist = 3.42, strength and conditioning coach = 4.06. Post hoc analysis revealed that doctors exerted significantly lower influence than coaches, other boxers and social media ($p < 0.05$). Conversely, coaches exerted more influence than all other sources (Figure 3B) except other boxers ($p = 1.0$). Other boxers also exerted more influence than parents, doctors, dietitians/nutritionists and strength and conditioning coaches ($p < 0.05$).

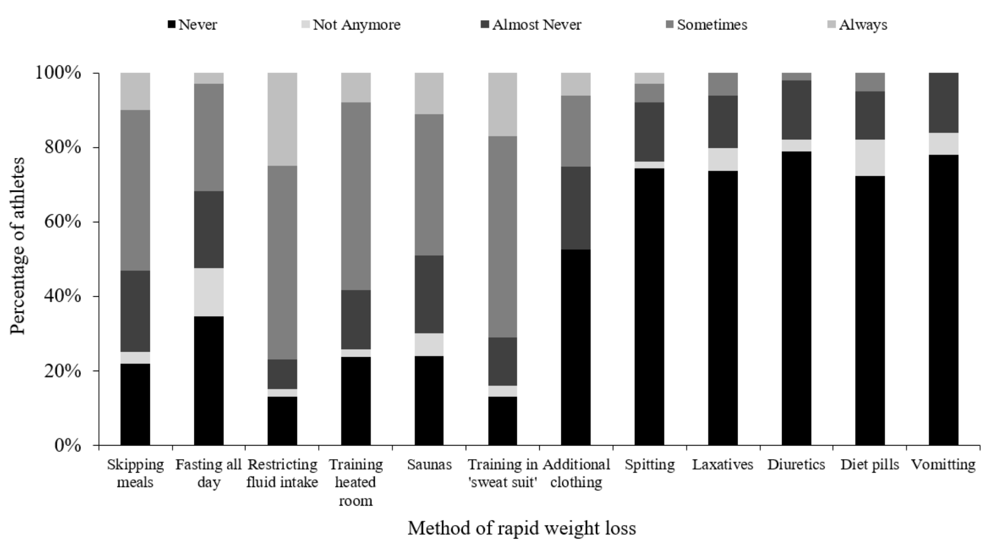

Figure 2: Frequency of rapid weight loss methods used by amateur boxers (percentage of boxers). A significant difference was apparent between the frequencies of methods used ($p < 0.001$).

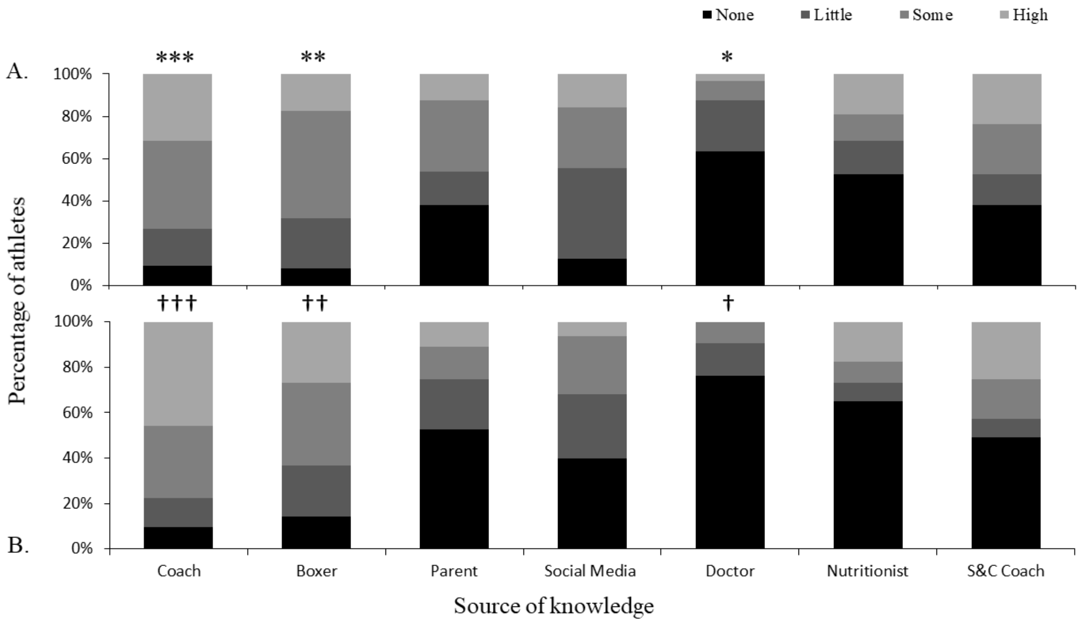

Figure 3: Relative influence of external sources of information for A. Nutritional knowledge, and B. Weight loss behaviours, represented as the percentage of athletes who received different levels of influence from each source (n = 63). Boxer = other boxer; Nutritionist = dietitian/nutritionist; S&C Coach = strength and conditioning coach.

Note: * = less than coach, other boxer, social media, strength and conditioning coach ($p < 0.05$); ** = greater than doctor, dietitian/nutritionist ($p < 0.05$); *** = greater than parent, doctor, dietitian/nutritionist ($p < 0.05$); † = less than coach, other boxer, social media ($p < 0.05$); †† = greater than parent, doctor, dietitian/nutritionist, strength and conditioning coach ($p < 0.05$); ††† = greater than parent, social media, doctor, dietitian/nutritionist, strength and conditioning coach ($p < 0.05$)

4. Discussion

This is the first study to investigate the relationship between nutritional knowledge and RWL in amateur boxers. Importantly, contradicting our hypothesis, nutritional knowledge was not associated with improved RLW practices. Such a finding may appear to contradict previous findings in Australian Rules football and soccer players, in whom a moderate correlation was reported between nutritional knowledge and body composition (Devlin, Leveritt, Kingsley, & Belski, 2017). However, as there is a strong motivation for combat athletes to avoid conceding size and strength to their opponents (Pettersson et al., 2013), RWL behaviours may be independent of nutritional knowledge. Indeed, evidence in mixed martial arts (Coswig et al., 2018), and judo (Reale, Cox, Slater, & Burke, 2016), sports in which combatants weigh-in the day before competition, suggests that weight regain may actually correlate with subsequent success. While a recent study in elite MMA athletes concluded there was no difference in weight regain between winners and losers (Kirk, Langan-Evans, & Morton, 2020), it must be noted that this was in the context of both groups increasing body mass by around 10 % following weigh-in. However, it should be noted that post weigh-in increases in body mass have not correlated with success in amateur boxing, where athletes weigh-in on the day of competition (Reale et al., 2017a). While it seems unlikely that nutrition education alone will improve boxers' weight loss behaviours, future research is required to explore the perceived advantages associated with RWL in boxers of different competitive levels.

All participants in the current study reported having to reduce body mass to compete in their specific weight class, with total RWL-Q scores similar to those observed recently in other combat sports (Reale et al., 2018). Similarly to previous studies on amateur boxers, the athletes studied used both gradual and acute weight loss methods prior to competition (Reale et al., 2018). Of concern, the average rate of pre-competition weight loss (4.2 % body mass in 8 - 10 days) surpasses recommended safety guidelines of 1.5 % body mass per week (Artioli et al., 2010a), therefore necessitating RWL. Such practices may increase the loss of functional mass, reduce aerobic and anaerobic capacity, and increase the perception of discomfort in athletes (Franchini et al., 2012). Tragically, a fatality associated with RWL was recently reported after an athlete lost 6.8 kg from sauna bathing, before subsequently suffering from exertional rhabdomyolysis (Zhuo, Li, & William, 2019). Furthermore, higher rates of weight loss are also associated with psychological consequences such as disordered eating behaviours (Williams, 2016), while hormonal disturbances from weight loss have been observed to disrupt appetite regulation (Dulloo, Jacquet, Montani, & Schutz, 2015). Such effects could potentially add to difficulties in maintaining body mass between contests (Dulloo et al., 2015).

The use of "extreme" RWL methods (Furber et al., 2017) was particularly prevalent in the current population (Figure 2), being used more frequently (21 – 27 %) than in judoka (6.5 – 20 %) studied previously (Artioli et al., 2010b). Despite not qualifying as "extreme" on the RWL-Q, and being linked to multiple fatalities (Control & Prevention, 1998; Zhuo et al., 2019), sauna use is popular across combat sports (Reale et al., 2018) and was used by 75 % of the current population. Whilst dehydration by any means is likely to impair performance (Barley, Iredale, Chapman, Hopper, & Abbiss, 2018b; Walsh, Noakes, Hawley, & Dennis, 1994), "passive" methods like sauna bathing may impair thermoregulatory responses more severely to increase the likelihood of heat injury (Walsh et al., 1994). The present findings indicate a high prevalence of RWL in amateur boxing, which may pose risks to health and performance.

The current study found no differences between competitive standard for RWL, with a high prevalence of RWL observed across all competition levels. These findings are in contrast to existing evidence which suggests that international standard combat athletes report higher RWL-Q scores than those competing at regional level (Artioli et al., 2010b; Reale et al., 2016). This conflict may be explained by cultural differences between combat sports, as well as the fact that any potential benefits of RWL would be highly sport-specific. For example, the study of Artioli et al. (2010b) was carried out in judo, while Reale, Slater, and Burke (2018) included judoka and wrestlers; sports in which athletes weigh-in the night before competition. This schedule may give athletes more time to recover from the harmful effects RWL, which necessitates at least some degree of glycogen depletion and muscular dehydration (Barley et al., 2018a; Reale et al., 2017c). Accordingly, such combat sports have reported associations between weight regain and competitive success (Coswig et al., 2018; Reale et al., 2016). In contrast, no such correlation has been observed in amateur boxers (Reale et al., 2017a), who weigh-in on the day of competition. Of note, it is frequently grappling sports where weight regain has been associated with success, potentially due to the greater relative importance of absolute strength than in striking sports (Davis, Connorton, Driver, Anderson, & Waldock, 2018; Reale et al., 2017c). The current findings demonstrate a high prevalence of RWL globally across all competition levels in amateur boxers, despite a lack of evidence to show a performance benefit from such practices.

This is the first cross-sectional analysis to investigate the nutritional knowledge of senior amateur boxers. Mean NKQA scores (52 ± 13 %) were similar to those from individuals with no previous nutritional training (50 ± 7 %) (Furber et al., 2017), with a large range of nutritional knowledge apparent (16 % to 78 %). Such a spread may reflect diversity in amateur boxing, with boxers coming from a wide range of educational and cultural backgrounds (Agirbas, Keyf, Aggon, & Ozan, 2018; Chaabène et al., 2015; Morton, Robertson, & Sutton, 2010). However, not only were the NKQA scores of the boxers studied descriptively lower than those of the nutrition experts assessed in the original validation of this instrument (80 ± 7 %), but they were also lower than those of track and field athletes (61 ± 11 %) reported in the same paper (Furber et al., 2017).

Of note, NKQA subsections on carbohydrate and fluid were the lowest scoring (43 % for each), which may have serious implications for performance (Davis et al., 2018). Both gradual weight loss methods and RWL are dependent on manipulating nutrient intake (Morton et al., 2010; Reale et al., 2017b), while the requirement for consecutive daily weigh-ins throughout boxing tournaments further increases the importance of knowledge relating to refueling and rehydration (Reale et al., 2017a; Spronk, Kullen, Burdon, & O'Connor, 2014). Accordingly, the poor nutritional knowledge shown in this sample highlights a need for nutrition education in amateur boxers, especially considering the importance of carbohydrate intake, fueling, recovery and hydration for performance in a weight-categorized sport (Folasire, Akomolafe, & Sanusi, 2015; Reale et al., 2018). However, it is also important to note the general nature of the NKQA, which may not assess the specific knowledge required by weight categorized athletes. For example, while the questionnaire assesses knowledge on appropriate dietary options for weight loss, there are no questions on the optimal rates, or adverse consequences of weight loss.

Coaches and other boxers were the most influential sources of knowledge on nutrition and weight loss in the current population (Figure 3). This finding is consistent throughout combat sports, both within amateur and professional settings (Artioli et al., 2010b; Park, Alencar, Sassone, Madrigal, & Ede, 2019). Weight loss practices are known to be passed on to successive generations by former athletes who transition into coaching, thus perpetuating a culture of RWL (Reale et al., 2018). However, mixed martial artists who have previously engaged with a dietitian showed reduced RWL behaviours compared to individuals consulting coaches and other athletes (Park et al., 2019). Limited interactions with nutrition professionals may explain the low NKQA scores and high prevalence of RWL reported in the current study.

5. Conclusions

The current findings are the first to demonstrate that nutritional knowledge has no relation to RWL practises in male amateur boxers, despite a high prevalence of RWL in this population. However, nutritional knowledge was lower than that previously reported in athletes, particularly regarding carbohydrates and fluid intake. This highlights the need for nutrition education in amateur boxers to support training and performance.

5.1. Practical applications

- Future educational strategies are required to inform amateur boxers on the potentially harmful effects of RWL and the lack of performance benefits so far reported in this population. Further research is needed to ascertain whether such education would be effective for mitigating the prevalence and severity of RWL.
- Amateur boxers should be encouraged to seek professional advice to ensure they are receiving safe and reliable information on nutrition and weight loss.
- Amateur boxers may benefit from nutritional education to support optimal fuelling, recovery and hydration practises.

Conflict of Interest

The authors declare no conflict of interests.

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