Manuscript title: Randomisation of simulated rugby match activity produces reliable movements and associated measures of subjective task load, cognitive and neuromuscular function

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Preferred Running Head: Reliability of a rugby simulation using randomised movements

Abstract Word Count: 196

Manuscript Word Count: 3698

Tables: 2

Figures: 1

Abstract

The study assesses the test-retest reliability of movement and physiological measures during a simulated rugby match that employed activities performed in a random order. Twenty male rugby players (21.4 ± 2.1 y) completed two trials of a 2 x 23 min rugby movement simulation protocol during which the order of events was randomised, with 7-10 days between trials. Movement characteristics, heart rate (HR), RPE, maximum voluntary contraction (MVC), voluntary activation (VA%) of the quadriceps, Stroop test and subjective task load rating (NASA-TLX) were measured. The most reliable measures of external load was relative distance (typical error [TE] and CV% = 1.5-1.6 $m \cdot min^{-1}$ and 1.4-1.5%, respectively), with all other movement characteristics possessing a CV% <5%. The most reliable measure of internal load, neuromuscular function and perceptual measures were for %HRmax (TE and CV% = 1.4-1.7% and 1-4-2.1%, respectively), MVC before (TE and CV% = 10.8-14.8 N·m and 3.8-4.6%, respectively), and average RPE (TE and CV% = 0.5-0.8 AU and 3.6-5.5%, respectively). The Stroop test, NASA-TLX and blood lactate produced the least reliable measures (CV% >5%). Future studies can confidently examine changes in several perceptual, neuromuscular, physiological and movement measures related to rugby activity using stochastic movements.

Introduction

Rugby movements vary considerably from match-to-match (e.g. ~15% for high-intensity running; Kempton, Sirotic & Coutts, 2014) and are reported to be different when compared to other teams sports such as soccer and Australian Rules Football (Varley, Gabbett, & Aughey, 2014). Such variation makes it difficult to establish meaningful changes in movement and physiological responses to a given intervention. Given the intermittent and stochastic nature of match-play, it is also logistically difficult to obtain physiological and perceptual data during matches, despite this information being valuable when examining the metabolic response to such exercise (Coutts, Reaburn & Abt, 2003). In an attempt to address these issues, exercise protocols based on time-motion analysis that can be performed in a controlled environment have been devised to replicate the movement and physiological characteristics for both whole match (rugby league match simulation protocol, RLMSP; Sykes et al, 2013) and interchange rugby players (rugby league movement simulation protocol for interchange players, RLMSP-i; Waldron, Highton & Twist, 2013).

The reliability (i.e. the test-retest consistency of measurements) of most internal (e.g. heart rate, rating of perceived exertion) and external load (e.g. total distance, high speed running) measures taken during rugby league simulations is sufficient (CV<5%, Sykes et al., 2013; Waldron et al., 2013) to detect meaningful changes that are due to, for example, nutritional or training interventions and not technical error or biological variation (Hopkins, 2000). Indeed, the RLMSP-i (Waldron et al., 2013) has been used to detect meaningful changes (6.5–13.4%) in running performance after nutritional supplementation (Clarke, Highton, Close & Twist, 2016), inclusion of physical contacts (Mullen, Highton & Twist, 2015), varying collision types (Norris, Highton, Hughes & Twist, 2016) and manipulated knowledge of task end-point (Highton, Mullen & Twist, 2017). The use of the RLMSP-i to examine changes in elements of rugby league performance offers a viable alternative compared to competitive matches.

Whilst the reliability of the RLMSP-i has been established, aspects of its validity has been questioned (Norris et al., 2016) that have led to studies altering the content of the protocol (e.g. Norris, Highton & Twist, 2018). A yet unexplored limitation of the existing RLMSP-i is the cyclic nature of the movement commands that do not replicate the more stochastic activity associated with actual match play (Waldron et al., 2013; Waldron, Twist, Highton, Worsfold & Daniels, 2011). A more random activity pattern might alter the vigilance required and the 'mental demand' associated with a task (Warm, Parasuraman & Matthews, 2008), which is known to have implications for players' perceived exertion (Greig, Marchant, Lovell, Clough & McNaughton, 2007). However, attempts to increase the external validity of simulations to better replicate match performance might have negative effects on the internal validity and associated reliability. For example, in the study of Norris and colleagues (2018) the improved validity after including a more appropriate contact element seemingly compromised the reliability of measures such as high speed running distance (CV% = 14.4%, Norris et al., 2018) compared to the original simulation (CV% = 5.5%, Waldron et al., 2013).

Further studies to establish, or indeed re-establish the reliability of simulation protocols after the format or content is changed to improve external (i.e. the extent to which the loads observed replicate those of match play) and internal validity (i.e. the extent to which the simulation can be used to determined changes due to an intervention) are warranted. Given the protocol's more stochastic arrangement of movements, and its potential implications for mental demand and task vigilance, it is possible that physical and cognitive performance could be altered with after exercise (Warm et al., 2008). Understanding the extent to which cognitive and mentally orientated measures are altered would be useful during and in recovery after any modified RLMSP-i, yet the reliability of such measures remains unknown despite being reported after actual and simulated match play (e.g. Pointon & Duffield, 2012; Duffield, Murphy, Snape, Minett, & Skein, 2012). Therefore, the aim of this study was to

assess the test-retest reliability of internal and external measures during the modified simulation of rugby league match play designed for interchange players (RLMSP-i) performed in a random order of activity. A second aim was to assess the reliability of associated measures of subjective task load, cognitive and neuromuscular function.

Methods

Participants and design

Twenty male university rugby players (league and union; age = 21.4 ± 2.1 y, body mass = 83.2 ± 9.7 kg, stature = 1.80 ± 0.10 m, predicted maximal oxygen uptake [VO_{2max}] = 48.9 ± 3.9 $ml \cdot kg^{-1} \cdot min^{-1}$) completed two trials of a modified (random) rugby league movement simulation protocol for interchanged players (RLMSP-i; Waldron et al., 2013) in a repeated measures design. After baseline measurements of body mass, stature and neuromuscular function, participants completed two stochastic conditions of the RLMSP-i, at a similar time of day (± 2 h), with 7-10 days between trials. The modified protocol comprised the same total number of movement commands as the original RLMSP-i (Waldron et al., 2013); however, the order of events was randomised such that no repeated cycles of activity occurred. Participants were instructed to refrain from strenuous activity, and avoid caffeine and alcohol consumption, in the 24 h before each trial. A self-reported food diary for the 48 hours immediately before trial one was completed and replicated in the 48 hours before the remaining trial, to control for effects of pre-exercise dietary intake on performance (Waldron et al., 2013). All participants provided written informed consent and completed a pre-test

health questionnaire. Ethics approval for this study was given by the Faculty of Life Sciences Research Ethics Committee (1011-15-TM-SES).

Experimental overview

On the first visit, participants performed the multistage fitness test (Brewer Ramsbottom & Williams, 1998) to estimate VO_{2max} before being habituated with all experimental procedures. The inclusion criteria required participants to obtain a VO_{2max} of >45 $ml \cdot kg^{-1} \cdot min^{-1}$ (>level 9 of the test), to replicate values reported for professional rugby league players (Gabbett, Jenkins & Abernethy, 2011). Throughout both protocols, movement characteristics using a global positioning system device with an integrated accelerometer (GPS), heart rate (HR) and rating of perceived exertion (RPE) were recorded. Before, at half time and immediately after the protocol reaction time and blood lactate concentration were measured. In addition, maximum voluntary contraction (MVC) and voluntary activation (VA%) of the quadriceps were measured before and within 10-15 min of completing the protocol. Subjective task load rating (NASA-TLX; Hart & Staveland, 1988) were also reported on completion of the simulation protocol.

Procedures

Rugby League Movement Simulation Protocol

Participants completed a simulation protocol for rugby league match play (RLMSP-i) designed to replicate the mean movement speeds, distances and playing times of interchanged players (Waldron et al., 2013). Participants performed a standardised 10 min warm-up comprising a self-paced jog, high knees, heel flicks and near maximal running. Participants then performed the RLMSP-i on an artificial synthetic grass surface (3G all-weather surface). Environmental temperature and humidity were recorded (THG810, Oregon Scientific Ltd.,

Berkshire, UK) during each RLMSP-i, and did not differ between trials (pooled data, 12.4 ± 2.9°C and 38.4 ± 9.1%, respectively). Near nude body mass (shorts and underwear) was recorded immediately before and after the RLMSP-i using balance beam scales (Seca, 712, Hamburg, Germany) and fluid intake was recorded to estimate fluid loss and did not differ between trials (pooled data, 0.19 ± 0.35%; change in body mass including fluid intake). Participants ran alone, following the instruction of an audio signal (CD player) that dictated the speed of movement between various coloured cones. The RLMSP-i lasted 46 min, comprising two 23 min bouts separated by 20 min passive recovery. For each quartile of the first and second bout (5.45 min) the movement characteristics were matched with the order of events randomised, meaning no repeated 'cycles' of activity. The simulation was designed to reproduce total relative running ~100 $m \cdot min^{-1}$, ~1 contact per minute and mean HR response of 85-90% of HR_{max}. The number of each movement and distances covered during one quartile of the simulation (5.45 min) is reported in Figure 1.

Movement demands and heart rate

Before performing the RLMSP-i (~10 min), participants were pre-fitted with a custom designed and appropriately sized vest housing the GPS unit (10 Hz MinimaxX S5, firmware 6.75, Catapult Innovations, Melbourne, Australia) between the scapulae. The satellites available and horizontal dilution of precision (HDOP) for all testing visits was 14.2 ± 0.7 (range 12 – 17) and 0.67 ± 0.11 AU (range 0.5 – 1.5), respectively. Previously reported speed zones were utilised for low intensity activity (<14 $km \cdot h^{-1}$) and high speed running (≥14 $km \cdot h^{-1}$; Waldron et al., 2013). Participants' HR was collected throughout performances of the RLMSP-i using a HR monitor (Polar Electro Oy, Kempele, Finland) wirelessly connected to the GPS unit. Data were later downloaded and analysed, reporting relative distance covered in total, low intensity activity and high speed running ($m \cdot min^{-1}$), peak speed ($km \cdot h^{-1}$; 20.5 m

sprint), sprint to contact speed ($km \cdot h^{-1}$; 8 m sprint), PlayerLoad^{TM} (AU) and time spent at high metabolic power >20 $W \cdot kg^{-1}$ (s).

Blood lactate concentration

Blood was collected and immediately analysed for lactate concentration (Lactate Pro, Arkray, Japan) from a fingertip capillary sample 5 min before and immediately after the first and second bout of the RLMSP-i.

Perceptual measures

Participants' rating of perceived exertion (RPE, 6-20 scale; Borg, 1985) was recorded every quartile (5.45 min) of the first and second bout during each trial. Session RPE (*s*RPE, 0-10 scale; Foster et al., 2001) was recorded within 20 min of completing each trial.

Neuromuscular function

Isometric force of the knee extensors in the dominant leg was measured using an isokinetic dynamometer (Biodex 3, Biodex Medical Sytems, Shirley, NY, USA) after a standardised warm up consisting of 5 min cycling at 80 W (no warm up was provided immediately after the simulation). With participants seated in an upright position and 90° flexion in the hip and knee, straps were tightly secured across the thorax and hip to minimise extraneous body movements from the dynamometer (Newman, Jones & Newham, 2003). Participants were then instructed to perform five isokinetic contractions at 60 $deg \cdot s^{-1}$, followed by two isometric contractions at 50, 80 and 100% of their maximum voluntary contraction (MVC). After the warm up, participants performed four MVCs (each 4 s duration) with 2 min rest between efforts (Newman et al., 2003). Strong verbal encouragement was provided and real-time visual feedback on force production was used to encourage maximal efforts (McNair,

Depledge, Brettkelly & Stanley, 1996). Force output was A/D converted at a sampling frequency of 1,000 Hz. Signal analysis was conducted using a commercially designed data acquisition software programme (AcqKnowledge III, Biopac Systems, Massachusetts). The highest recorded torque of the four contractions was used for analysis. Transcutaneous electrical stimulation of the quadriceps muscle was delivered using a constant-current stimulator (Digitimer DS7, Hertfordshire, UK) to determine voluntary activation. Two rectangle self-adhesive surface electrodes (5 × 13 cm; Axelgaard Manufacturing Co. Ltd., Lystrup, Denmark) were applied. One electrode was placed distally, 5 cm above the patella covering the vastus lateralis, vastus medialis and rectus femoris muscles. The other electrode was positioned proximally close to the insertion of the quadriceps muscle, avoiding activation of the antagonist (Shield & Zhou, 2004). The skin was prepared by shaving and light abrasion for each electrode site. The outline of both electrodes was drawn on to the skin using a permanent marker to minimise variability of electrode placement between sessions (Keogh, Wilson & Weatherby, 1999). Two paired electrical stimuli (100 Hz) produced by means of square wave impulses (200 Ks) were delivered during a 6 s sampling period. One impulse was delivered to the relaxed muscle pre-contraction (un-potentiated control twitch), after which participants were instructed to contract maximally. The second impulse was delivered 4 s after the control twitch, during the MVC (superimposed twitch). The amperage was optimised for participants during each testing visit by progressively increasing by 25 mA until there was no further increase in peak twitch torque. The amplitude of the superimposed twitch was calculated at 20% above which peak twitch torque was achieved. Voluntary activation (VA%) was later calculated according to the interpolated twitch technique (Merton, 1954), with the ratio of superimposed twitch relative to the twitch response of the relaxed muscle expressed as a percentage (1- [superimposed twitch/control twitch] ×100).

Peak MVC was calculated as the mean torque 50 ms before the superimposed stimulation delivery.

Stroop Test

Cognitive function was assessed using a commercially available Stroop test application (EncephalApp Stroop; Bajaj et al., 2013) on a tablet computer (Apple iPad Air 2, California, USA). The test was administered 5 min before and immediately after the first and second bouts of the RLMSP-i. The test required participants to react 80 times as quickly as possible by touching the corresponding colour at the bottom of the screen to various coloured words (red, blue and green) that appeared on the screen. The outcomes of the test were twofold: 1) reaction time (total time in seconds to complete 80 correct reactions) and, 2) accuracy (number of attempts required to complete 80 correct reactions).

Subjective Task Load

Subjective task load was measured ~20 min after each trial of the RLMSP-i, using the National Aeronautics and Space Administration Task Load Index (NASA-TLX; Hart & Staveland, 1988). Participants rated six subscales of task load (mental demand, physical demand, temporal demand, frustration, effort, and performance), with written definitions of the subscales available throughout. Each subscale was presented as a 10 cm line with visual anchors at either end (e.g. low/high). Numerical values were not displayed, but the scale ranged from 0-100 AU. Data was recorded to the nearest 5 AU. A weighted scoring of the six subscales was also performed using 15 pairwise comparisons (e.g. mental demand cf. effort) between each subscale. Participants were instructed to circle the descriptor that represents the most important contributor to task load during the RLMSP-i. The weighted score corresponds to the number of times each subscale is selected as being the most important contributor to

global task load. A task load (weighted rating) score is then calculated by multiplying the weighted score by the rated score for each individual subscale. Finally, a global task load score is then produced by summing the weighted rating for each descriptor, and dividing by the total weights (n=15).

Statistical analysis

Reliability was determined using the coefficient of variation (CV%) and typical error (TE). The TE was calculated as the standard deviation of the differences between trial one and two divided by √2; the CV was then calculated as the TE divided by the grand mean test-retest score, multiplied by 100. The smallest worthwhile change (SWC%) in each measure was calculated as 0.2 multiplied by the pooled SD of the repeated trials. The SWC was multiplied by 3, 6, and 10 to determine a moderate (MC), large (LC) and very large change (VLC), respectively (Hopkins, Marshall, Batterham & Hanin, 2009; Hopkins, 2000). These values were then used as 'analytical goals' against which the TE could be compared (e.g. a moderate change in a variable for a given sample could be confidently established providing the TE is lower than the MC; Atkinson & Nevill, 1999; Pyne, 2003).

**** Insert Figure 1 about here ***

Results

Movement and physiological demands

The most reliable measures of external load during the stochastic simulation were relative distance during bout 1 (TE and CV% = 1.6 $m \cdot min^{-1}$ and 1.5%, respectively) and bout 2 (TE and CV% = 1.5 $m \cdot min^{-1}$ and 1.4%, respectively), average peak speed during bout 1 (TE and CV% = 0.7 $km \cdot h^{-1}$ and 2.9%, respectively) and bout 2 (TE and CV% = 0.7 $km \cdot h^{-1}$ and 3.0%,

respectively), and average PlayerLoad™ during bout 1 (TE and CV% = 5.3 AU and 2.3%, respectively) and bout 2 (TE and CV% = 5.3 AU and 2.3%, respectively). The only movement variable to demonstrate a TE lower than the SWC was PlayerLoad™ (AU) during bout 1 and 2 with all other variables demonstrating a TE at least smaller than the MC. All movement data are shown in Table 1.

The most reliable measure of internal load was %HRmax during bout 1 (TE and CV% = 1.7% and 2.1%, respectively) and bout 2 (TE and CV% = 1.4% and 1.8%, respectively) and average RPE during bout 1 (TE and CV% = 0.8 AU and 5.5%, respectively) and bout 2 (TE and CV% = 0.5 AU and 3.6%, respectively). All physiological data are shown in Table 2.

Neuromuscular function

MVC before (TE and CV% = 14.8 N·m and 4.6%, respectively) and after the simulation (TE and CV% = 10.8 N·m and 3.8%, respectively) demonstrated a TE lower than the SWC (Table 2).

**** Insert Table 1 here ****

**** Insert Table 2 here ****

Discussion

Previous studies reporting the reliability of rugby league simulation protocols have demonstrated the highest variability in movement demands for high speed running, with CV% of 5.5% (Waldron et al., 2013), 10.6% (Sykes et al., 2013) and 14.4% (Norris et al., 2018) for interchange, whole match and modified simulations, respectively. The data herein

show that the inclusion of stochastic movement characteristics has no detrimental effect on the reliability of high speed running during the RLMSP-i. More importantly, the test-retest variability of high speed running (TE = 1.9 km·h^{-1}; CV% = 6.4 - 7.1%) is less than previously described changes during the protocol associated with altered nutritional supplementation (-9 m·min^{-1}; Clarke et al., 2016), inclusion of physical contacts (-3 m·min^{-1}; Mullen et al., 2015) and manipulated knowledge of task end-point (-3.4 m·min^{-1}; Highton et al., 2017).

The reliability of average sprint to contact speed has not been described previously, yet this information would be useful when describing altered pacing or fatigue during the protocol due to intervention strategies. Indeed, based on typical changes (~8%) associated with altered contact types during the RLMSP-i (Norris et al., 2016), the current version of the protocol would allow detection of moderate changes in sprint speeds to contact during first (CV% = 2.7%) and second (CV% = 2.4%) bouts. The time spent at high metabolic power has also emerged to describe external loads associated with team sport performance (Oxendale, Highton & Twist, 2017; Gaudino et al., 2014; Kempton, Sirotic, Rampinini & Coutts, 2015), the reliability of which during the RLMSP-i has not been described before. For the first time the test-retest reliability of this external load measure during stochastic simulated rugby league movements suggests that high metabolic power is reliable enough to detect moderate changes in performance (CV% = 3.9 - 4.0%) associated with increasing the number of directional changes during an intermittent simulation protocol (e.g. 5.8% increase; Oxendale et al., 2017).

Although less reliable than other measurements, CV% relating to B[la] were comparable to the original RLMSP-i, with 12.3-16.3% cf. 13.4-19.7% for the RLMSP-i and the stochastic RLMSP-i, respectively. However, the reliability was sufficient to detect a moderate change in

B[la] (TE = 1.0 mmol·L^{-1}; CV% = 19.7%) associated with changes during the RLMSP-i after manipulated pacing strategies (1.8 – 2.8 mmol·L^{-1} or 38 – 50%; Highton et al., 2017).

The reliability in the modified simulation compares favourably to the large match-to-match variation in high speed running (stochastic RLMSP-i CV% = 6.4% and 7.1% first and second bouts, respectively cf. match-play CV% = 20.4% and 23.1% first and second half, respectively; Kempton et al., 2014). Furthermore, the current protocol is adequately reliable to detect moderate changes in high speed running (TE = 1.9 m·min^{-1}) associated with different contacts causing reductions in high speed running during bout one (3.8 m·min^{-1}) and two (7.7 m·min^{-1}) of the RLMSP-i (Mullen et al., 2015).

For the first time, this study has explored the test-retest reliability of neuromuscular function after activity that simulates several movement and physiological characteristics of elite rugby league match play. This reliability allows determination of a 'real' change in such measures during the RLMSP-i, which is desirable given that reductions in muscle function of ~6.3-7.7% after simulated rugby league (Highton et al., 2017; Mullen et al., 2015), rugby union (Barber, John, Brown & Hill, 2018) and soccer (Greig, 2008) performance are commonly reported. The reliability for MVC (CV% = 4.6 and 3.8%) and VA% (CV% = 1.8 and 3.1%) before and after the RLMSP-i, respectively, are comparable to previous studies reporting the test-retest reliability after soccer match-play and repeated MVCs (MVC = 2.2 - 4.3%, VA% = 0.7 – 3.4%, respectively; Place, Maffiuletti, Martin & Lepers, 2007; Morton et al., 2005). Not only is the variability of neuromuscular function measures (MVC and VA%) lower than the calculated small and moderate changes, they are also adequately reliable to detect the decrements in MVC (~10 N·m) and VA% (~8%) associated with simulated rugby union match play performed with and without a tackle (Pointon & Duffield, 2012).

The number of Stroop task errors (CV% = 13.6%) and total subjective task load (CV% = 6.8%) were amongst the least reliable measured variables. Nonetheless, both measures were still able to detect calculated moderate changes. These data provide a baseline for detection of meaningful changes in future research when using the same modified App-based Stroop task after simulated rugby league match play, with TEs of 2.7 s and 1.3 errors. Furthermore, time taken to complete the Stroop task provides adequate reliability (CV%= 3.6%) to detect changes associated with caffeine supplementation (~6.3%; Soar, Chapman, Lavan, Jansari & Turner, 2016) and sleep deprivation (~30%; Jarraya, Jarraya, Chtourou, Souissi & Chamari, 2013). Future research that uses the NASA-TLX to determine changes in total subjective task load would require a minimum change of 4.6 AU to determine a 'real world' change.

While insufficiently reliable to detect calculated small changes, these data demonstrate that a randomised rugby simulation can detect at least calculated moderate changes in commonly used measures of movement, physiological and perceptual load. Furthermore, several of these load measures were able to detect previously observed changes during similar exercise protocols. For the first time these data provide a baseline for future research using the random rugby simulation to determine 'real world' changes in Stroop test performance, subjective task load (NASA-TLX) and neuromuscular function (MVC and VA%). Using random rather than cyclic movements during a simulation of intermittent activity has no detrimental effect on its reliability that enables future studies to confidently examine alterations in several perceptual, neuromuscular, physiological and movement load measures related to rugby league match play.

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Figures and Table legends

Figure 1. Schematic of the rugby league movement simulation protocol, including measurements. MVC, maximal voluntary contraction; VA%, voluntary activation determined by interpolated twitch technique; TLX; NASA-Task Load Index; Stroop test, iPad based Stroop test.

Table 1. Test-retest reliability of external load measures (running intensities, PlayerLoad™, metabolic energy and high metabolic power) during the first and second interchange bouts of the modified rugby league movement simulation protocol.

Table 2. Test-retest reliability of internal load, physiological, perceptual, cognitive function and neuromuscular function measures during the first and second interchange bouts of the modified rugby league movement simulation protocol.

Table 1. Test-retest reliability of external load measures (running intensities, player load, metabolic energy and high metabolic power) during the first and second interchange bouts of the modified rugby league movement simulation protocol.

	Distance ($m \cdot min^{-1}$)	HSR ($m \cdot min^{-1}$)	LSR ($m \cdot min^{-1}$)	Peak Speed ($km \cdot h^{-1}$)	Peak Speed to Contact ($km \cdot h^{-1}$)	Player Load (AU)	High Metabolic Power (s)
Interchange bout 1							
Trial 1 (± SD)	106.4 ± 3.9	30.1 ± 4.9	76.0 ± 4.7	25.2 ± 1.2	13.6 ± 1.1	236.6 ± 29.5	192.7 ± 21.3
Trial 2 (± SD)	105.8 ± 3.8	29.9 ± 5.5	75.6 ± 4.4	23.7 ± 1.4	12.9 ± 1.1	231.9 ± 29.7	186.8 ± 21.4
CV (%)	1.5	6.4	2.6	2.9	2.7	2.3	3.9
TE	1.6	1.9	1.9	0.7	0.3	5.3	7.6
SWC	0.8	1.0	0.9	0.3	0.2	5.8	4.3
MC	2.3	3.1	2.7	0.9	0.7	17.5	12.8
LC	4.6	6.2	5.4	1.8	1.4	35.1	25.5
VLC	7.6	10.3	9.0	3.1	2.3	58.5	42.6
Interchange bout 2							
Trial 1 (± SD)	106.1 ± 3.7	27.5 ± 4.0	78.3 ± 4.3	24.7 ± 1.4	13.4 ± 1.1	235.9 ± 28.1	200.8 ± 23.7
Trial 2 (± SD)	105.5 ± 4.3	27.9 ± 4.4	77.2 ± 4.2	23.4 ± 1.7	12.6 ± 1.1	231.2 ± 28.8	193.5 ± 25.1
CV (%)	1.4	7.1	3.1	3.0	2.4	2.3	4.0
TE	1.5	1.9	2.4	0.7	0.3	5.3	7.8
SWC	0.8	0.8	0.8	0.3	0.2	5.6	4.9
MC	2.4	2.5	2.5	1.0	0.7	16.9	14.6
LC	4.8	4.9	5.1	2.0	1.3	33.8	29.2
VLC	7.9	8.3	8.4	3.3	2.2	56.3	48.6

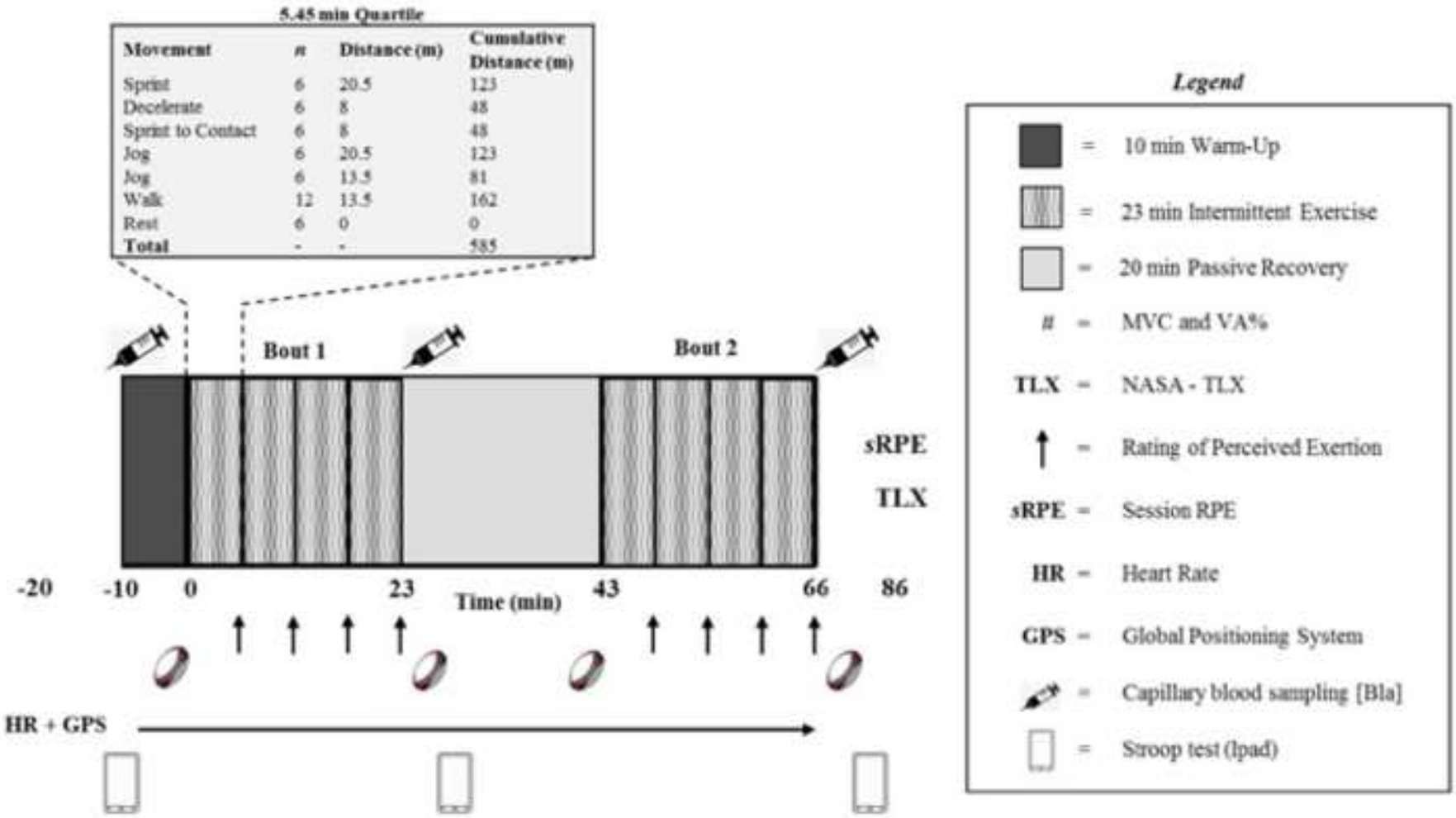
*HSR = high speed running (> 14 $km \cdot h^{-1}$), LSR = low speed running (< 14 $km \cdot h^{-1}$), TE = typical error, CV% = coefficient of variation (%), SWC = smallest worthwhile change, MC = moderate change, LC = large change, VLC = very large change.

Table 2. Test-retest reliability of internal load, physiological, perceptual, cognitive function and neuromuscular function measures during the first and second interchange bouts of the modified rugby league movement simulation protocol.

	Physiological		Neuromuscular Function		Perceptual			Cognitive Function	
	%HR_{max}	B[la] ($mmol \cdot L^{-1}$)	MVC (N·m)	VA%	RPE	*s*RPE	NASA-TLX Total	Stroop (s)	Stroop Errors (*n*)
Interchange bout 1									
Trial 1 (± SD)	82.3 ± 4.1	4.9 ± 2.3	318.6 ± 76.3	92.8 ± 4.4	14.9 ± 1.4	-	-	73.2 ± 6.5	9.3 ± 1.4
Trial 2 (± SD)	81.5 ± 5.0	4.2 ± 1.8	319.3 ± 84.9	93.7 ± 4.3	14.1 ± 1.2	-	-	73.6 ± 7.1	9.2 ± 1.6
CV (%)	2.1	13.4	4.6	1.8	5.5	-	-	3.6	5.9
TE	1.7	0.6	14.8	1.6	0.8	-	-	2.6	0.6
SWC	0.9	0.4	15.7	0.9	0.3	-	-	1.3	0.3
MC	2.7	1.2	47.2	2.6	0.8	-	-	4.0	0.9
LC	5.5	2.5	94.5	5.2	1.6	-	-	8.0	1.7
VLC	9.1	4.1	157.6	8.6	2.6	-	-	13.3	2.9
Interchange bout 2									
Trial 1 (± SD)	82.2 ± 3.9	5.2 ± 2.8	279.0 ± 66.8	86.9 ± 7.4	14.6 ± 1.4	6.5 ± 1.4	68.3 ± 6.5	74.9 ± 4.3	10.3 ± 2.5
Trial 2 (± SD)	81.2 ± 4.8	4.4 ± 2.3	289.4 ± 78.1	87.6 ± 8.1	14.1 ± 1.3	5.7 ± 1.5	69.5 ± 15.7	74.1 ± 8.4	9.6 ± 1.8
CV (%)	1.8	19.7	3.8	3.1	3.6	11.4	6.8	3.6	13.6
TE	1.4	1.0	10.8	2.7	0.5	0.7	4.6	2.7	1.3
SWC	0.9	0.5	15.1	1.5	0.3	0.3	2.6	1.3	0.4
MC	2.6	1.5	45.2	4.5	0.8	0.9	7.7	3.9	1.3
LC	5.2	3.0	90.3	9.1	1.6	1.7	15.5	7.8	5.6
VLC	8.7	5.0	150.5	15.1	2.6	2.9	25.8	13.0	4.3

*%HR_{max} = percentage heart rate maximum, RPE = momentary rating of perceived exertion, *s*RPE = session rating of perceived exertion, B[la] = blood lactate concentration, NASA-TLX = subjective task load, MD = mental demand, MVC = maximal voluntary contraction, VA% = voluntary activation, TE = typical error, CV% = coefficient of variation (%), SWC = smallest worthwhile change, MC = moderate change, LC = large change, VLC = very large change.

Figure


5.45 min Quartile
Movement | n | Distance (m) | Cumulative Distance (m)
Sprint | 6 | 20.5 | 123
Decelerate | 6 | 8 | 48
Sprint to Contact | 6 | 8 | 48
Jog | 6 | 20.5 | 123
Jog | 6 | 13.5 | 81
Walk | 12 | 13.5 | 162
Rest | 6 | 0 | 0
Total | - | - | 585
Bout 1
Bout 2
sRPE
TLX
-20
-10
0
23
43
66
86
Time (min)
HR + GPS
Legend
= 10 min Warm-Up
= 23 min Intermittent Exercise
= 20 min Passive Recovery
# = MVC and VA%
TLX = NASA - TLX
= Rating of Perceived Exertion
sRPE = Session RPE
HR = Heart Rate
GPS = Global Positioning System
= Capillary blood sampling [Bla]
= Stroop test (Ipad)