


Please cite the Published Version

Mullen, Thomas , Twist, Craig and Highton, Jamie (2021) The Physiological and Perceptual Effects of Stochastic Simulated Rugby League Match Play. *International Journal of Sports Physiology and Performance*, 16 (1). pp. 73-79. ISSN 1555-0265

DOI: <https://doi.org/10.1123/ijsp.2018-0834>

Publisher: Human Kinetics

Version: Accepted Version

Downloaded from: <https://e-space.mmu.ac.uk/626822/>

Additional Information: This is an Author Accepted Manuscript of a paper accepted for publication in *International Journal of Sports Physiology and Performance*, published by and copyright Human Kinetics.

Enquiries:

If you have questions about this document, contact openresearch@mmu.ac.uk. Please include the URL of the record in e-space. If you believe that your, or a third party's rights have been compromised through this document please see our Take Down policy (available from <https://www.mmu.ac.uk/library/using-the-library/policies-and-guidelines>)

Abstract

Purpose: To examine responses to a simulated rugby league protocol designed to include more stochastic commands, and therefore require greater vigilance, than traditional team sport simulation protocols.

Methods: Eleven male university rugby players completed two trials (randomised and control) of a rugby league movement simulation protocol, separated by 7-10 days. The control trial (CON) consisted of 48 repeated ~115 s cycles of activity. The stochastic simulation (STOCH) was matched for the number and types of activity performed every 5.45 min in CON, but included no repeated cycles of activity. Movement using GPS, heart rate, RPE and Stroop test performance were assessed throughout. MVC peak torque, voluntary activation (%) and global task load were assessed after exercise.

Results: The mean mental demand of STOCH was higher than CON (Effect size (ES) = 0.56; ± 0.69). Mean sprint speed was higher in STOCH (22.5 ± 1.4 vs. 21.6 ± 1.6 km·h⁻¹; ES = 0.50; ± 0.55), which was accompanied by a higher RPE (14.3 ± 1.0 vs. 13.0 ± 1.4 ; ES = 0.87; ± 0.67) and a greater number of errors in the Stroop Test (10.3 ± 2.5 vs. 9.3 ± 1.4 errors; ES = 0.65; ± 0.83). MVC peak torque (CON = -48.4 ± 31.6 N·m, STOCH = -39.6 ± 36.6 N·m) and voluntary activation (CON = $-8.3 \pm 4.8\%$, STOCH = $-6.0 \pm 4.1\%$) was similarly reduced in both trials.

Conclusions: Providing more stochastic commands, which requires greater vigilance, might alter performance and associated physiological, perceptual and cognitive responses to team sport simulations.

Key Words: Team sports; vigilance; voluntary activation; attentional focus

27 Introduction

28 The use of team sport match simulation protocols in sports science research is
29 now common. These protocols seek to negate the large variation (~15%) in
30 running distance and intensity observed between matches,¹ which might
31 otherwise mask meaningful changes in performance owing to an intervention.
32 Furthermore, physiological and perceptual responses can be measured
33 regularly in a controlled environment, which would not be feasible in
34 competition. Accordingly, in rugby league, various iterations of the Rugby
35 League Movement Simulation Protocol (RLMSP) have successfully been used
36 to examine changes in performance.^{2,3,4}

37
38 One aspect of competitive rugby league match play, which has often been
39 excluded from simulation protocols, is the stochastic nature of performance.
40 For example, the current interchange rugby league simulation protocol
41 comprises repeated cycles of activity (115 s) lasting 46 min.⁵ The use of short
42 repeated cycles is common in team sport simulation protocols,^{6,7,8} with few
43 exceptions,⁹ which is likely an attempt to maintain the consistency of
44 performance in such activities.⁵ However, preserving high internal validity and
45 associated reliability might compromise the external validity of such
46 protocols.³

47
48 The predictable and repetitive nature of current protocols compared to the
49 stochastic nature of match play, which requires decisions to be made based on
50 information retrieved from a dynamic environment, might influence exercise
51 performance and associated physiological and perceptual responses in several
52 ways. For example, with sustained vigilance during a repetitive activity, a
53 'zoning out' might occur causing disengagement from the task.¹⁰ Task
54 disengagement and reduced vigilance negatively affects decision making,¹⁰
55 whilst maintaining vigilance is associated with a greater 'mental demand' (i.e.
56 the amount of mental and perceptual activity required to complete a task,
57 including thinking, deciding, calculating, and remembering).¹¹ Mentally
58 demanding tasks not only cause mental fatigue after a rugby match,¹² but can
59 also affect perceived exertion¹³ and running performance.¹⁴ Vigilance and
60 associated task engagement might also cause an altered attentional focus,¹⁰
61 which can alter perceived exertion¹³ and performance.¹⁵ Finally, the predictable
62 nature of existing simulation protocols might result in a different pacing
63 strategy to that observed in matches,^{2,16} where players must regulate their
64 exercise intensity whilst preserving the capacity to perform unpredictable
65 periods of exercise at an intensity greater than the match average.¹⁶

66
67 To the best of our knowledge, the effects of a stochastic order of activity during
68 simulated match play, compared to a conventional simulation comprising
69 repeated cycles, are currently unknown. It is important to understand the extent
70 to which making the required activity less predictable, and therefore increasing
71 the requirement for vigilance, might alter an individual's response to such
72 protocols if they are to be used in practice. Therefore, the purpose of the study
73 was to investigate the effects of a stochastic order of activity on performance
74 in, and physiological and perceptual responses to, the Rugby League
75 Movement Simulation Protocol for Interchange Players (RLMSP-i).

76

77 **Methods**

78

79 *Participants*

80 Eleven male university rugby players (league and union; age = 21.2 ± 2.0 y,
81 body mass = 80.5 ± 6.4 kg, stature = 1.80 ± 0.10 m, predicted maximal oxygen
82 uptake [VO_{2max}] = 50.8 ± 3.8 ml·kg⁻¹·min⁻¹) completed the experiment. *A priori*
83 calculations showed that a sample of at least 10 participants was required,¹⁷
84 based on a smallest worthwhile change (Cohen's d = 0.2) of 0.23 km·h⁻¹ for
85 sprint performance and a typical error of 0.28 km·h⁻¹ taken from an in-house
86 reliability study. Participants provided written informed consent and completed
87 a pre-test health questionnaire. Ethics approval was granted by the Faculty of
88 Medicine, Dentistry and Life Sciences Research Ethics Committee, University
89 of Chester (1011-15-TM-SES).

90

91 *Design*

92 After an initial baseline visit to predict VO_{2max} (using a progressive shuttle run
93 test)¹⁸ and habituate participants with all of the experimental procedures, each
94 participant completed two trials of RLMSP-i,⁵ separated by 7-10 days, in a
95 randomised cross-over design. Trials were completed at the same time of day
96 (± 2 h) and differed in that either the standard protocol (CON), or a protocol
97 with a more stochastic series of commands (STOCH), was used. Participants
98 were instructed to refrain from strenuous activity and avoid caffeine and
99 alcohol in the 24 h before each trial. A self-reported food diary was recorded
100 for the 48 hours immediately before trial one and replicated in the 48 hours
101 before trial two. Participants began each trial in a similarly hydrated state (pre-
102 exercise urine osmolality for CON = 615 ± 292 mOsmol·kg⁻¹ and STOCH =
103 621 ± 303 mOsmol·kg⁻¹).

104

105 *Procedures*

106 In the two trials, participants performed a standardised 10 min warm-up before
107 performing the RLMSP-i on an artificial synthetic grass surface. Participants
108 ran alone, following the instruction of an audio signal that dictated the speed
109 and type of movement between various coloured cones. The RLMSP-i lasted
110 46 min, comprising two 23 min bouts separated by 20 min passive recovery.
111 The CON trial comprised 24 repeated ~115 s cycles of activity.⁵ In the STOCH
112 protocol, the order of events was re-ordered to be non-cyclical and less
113 predictable (but was the same for every participant), with no repeated 'cycles'.
114 In an attempt to guarantee high and low-intensity actions were not 'bunched'
115 in the STOCH protocol, we ensured that the number and type of each
116 movement were identical for both protocols within each quartile of each bout
117 (i.e. every 5.45 min; see Waldron et al.⁵). For example, this resulted in a range
118 of 36.6 to 136 s between 20.5 m sprints in CON and between 26.83 to 95.19 s
119 in STOCH. In both CON and STOCH, the required movements were dictated
120 via a pre-recorded audio signal played through a sound system.

121

122 Throughout the RLMSP-i, participants were fitted with a GPS unit positioned
123 between the scapulae (10 Hz MinimaxX S5, firmware 6.75, Catapult
124 Innovations, Melbourne, Australia). The satellites available and horizontal
125 dilution of precision (HDOP) for all testing visits ranged from 12 – 17 and 0.5
126 – 1.5 AU, respectively. Participants' heart rate (HR) was collected throughout

127 the RLMSP-i using a HR monitor (Polar Electro Oy, Kempele, Finland)
128 wirelessly connected to the GPS. GPS data were analysed for speed ($\text{m}\cdot\text{min}^{-1}$),
129 low ($<14 \text{ km}\cdot\text{h}^{-1}$) and high speed running ($> 14 \text{ km}\cdot\text{h}^{-1}$), peak speed, sprint to
130 contact speed, PlayerLoadTM (AU) and time at high metabolic power $>20 \text{ W}\cdot\text{kg}^{-1}$
131 (s). In a separate in-house investigation, using a sample of $n = 20$ university
132 rugby players, the inter-day coefficient of variation (CV %) was determined
133 for each movement variable and ranged from 1.4 – 6.5%.

134
135 Blood was analysed for lactate concentration (B[La]; Lactate Pro, Arkray,
136 Japan) from a fingertip capillary sample 5 min before and immediately after
137 the first and second bout of the RLMSP-i (typical error = $1.15 \text{ mmol}\cdot\text{l}^{-1}$).
138 Participants' rating of perceived exertion (RPE, 6-20 scale; Borg, 1985) was
139 recorded every quartile (5.45 min) of the first and second bout during each trial.
140 A global RPE for the session (sRPE, 0-10 scale) was recorded within 20 min
141 of completing each trial. Cognitive function was assessed using a commercially
142 available Stroop Test application on a tablet computer (EncephalApp Stroop)¹⁹
143 5 min before and immediately after the first and second bouts of the RLMSP-
144 i, which required participants to react 80 times as quickly as possible by
145 touching the corresponding colour at the bottom of the screen to various
146 coloured words (red, blue and green). Typical error of measurement was
147 calculated as 5.56 s and 1.65 for Stroop test time and errors, respectively.

148
149 Isometric force and voluntary activation of the knee extensors in the dominant
150 leg were measured using a dynamometer before and 15 min after the RLMSP-
151 i (Biodex 3, Biodex Medical Systems, Shirley, NY, USA). Participants sat in an
152 upright position with 90° flexion in the hip and knee; straps were tightly
153 secured across the thorax and hip to minimise extraneous body movements
154 from the dynamometer. Participants performed four MVCs (each 4 s duration)
155 with 2 min rest between efforts. Force output was A/D converted at a sampling
156 frequency of 1,000 Hz (AcqKnowledge III, Biopac Systems, Massachusetts).
157 Transcutaneous electrical stimulation of the quadriceps muscle was delivered
158 using a constant-current stimulator (Digitimer DS7, Hertfordshire, UK) to
159 determine voluntary activation. Two rectangle self-adhesive surface electrodes
160 ($5 \times 13 \text{ cm}$; Axelgaard Manufacturing Co. Ltd., Lystrup, Denmark) were
161 applied distally and proximally across the knee extensors. The outline of both
162 electrodes was drawn on to the skin using a permanent marker to minimise
163 variability of electrode placement between sessions. Paired electrical stimuli
164 (100 Hz ; at 20% above the amperage required for pre-determined peak twitch
165 torque) were delivered to the relaxed muscle pre-contraction (control twitch),
166 and 3 s into the MVC (superimposed twitch). Voluntary activation (VA%) was
167 calculated as a ratio of the superimposed twitch relative to the twitch response
168 of the relaxed muscle ($1 - [\text{superimposed twitch}/\text{control twitch}] \times 100$). Peak
169 MVC from the 4 contractions was calculated as the mean torque 50 ms before
170 the superimposed stimulation delivery. In-house typical error of measurement
171 was $10.8 \text{ N}\cdot\text{m}$ and 1.64 % for MVC and VA%, respectively.

172
173 Subjective task load was measured ~20 min after each trial of the RLMSP-i
174 using the National Aeronautics and Space Administration Task Load Index
175 (NASA-TLX). Participants rated six subscales of task load (mental demand,
176 physical demand, temporal demand, frustration, effort, and performance). Each

177 subscale was presented as a 10 cm line with visual anchors at either end (e.g.
 178 low/high), corresponding to an unseen numerical scale from 0-100 AU. A
 179 weighted scoring of the six subscales was ascertained using 15 pairwise
 180 comparisons between each subscale (e.g. mental demand vs. effort).
 181 Participants were instructed to circle the descriptor that represents the most
 182 important contributor to task load during the RLMSP-i. The weighted score
 183 corresponded to the number of times each subscale is selected as being the most
 184 important contributor to global task load. A task load (weighted rating) score
 185 was then calculated by multiplying the weighted score by the rated score for
 186 each individual subscale.

187

188 *Statistical Analysis*

189 All data are reported as means \pm SD. Changes in dependent variables were
 190 analysed using effect sizes and 95% confidence intervals (ES; \pm confidence
 191 interval). In using this approach, the reader can interpret our results in terms of
 192 traditional statistical significance should they wish to (i.e. if our confidence
 193 interval crosses 0, then $P \geq 0.05$), or as a ‘compatibility interval’ (i.e. the range
 194 of values compatible with our data that would not be deemed different to our
 195 observed effect at the 0.05 level). We interpreted our data based on the
 196 magnitude of the observed change between trials, calculated as the mean
 197 difference between trials divided by the pooled SD of trials, and considered as:
 198 small ≥ 0.2 , moderate ≥ 0.6 and large ≥ 1.2 . We considered a substantial effect
 199 to be any ES ≥ 0.2 or ≤ -0.2 , with a confidence interval that did not cross *both*
 200 ES -0.2 and 0.2. Effects were considered to be unclear when the 95%
 201 confidence interval crossed both substantially positive and negative effects.
 202 The above calculations were completed using a predesigned spreadsheet.¹⁷

203

204

204 **Results**

205 The mean speed was higher during the STOCH trial over the entire simulation.
 206 Differences between trials were unclear for low intensity distance, high
 207 intensity distance, sprint to contact speed, PlayerLoadTM and high metabolic
 208 power (see Table 1). Similarly, differences between trials across bout quartiles
 209 for speed, high speed running and sprint to contact speed across the protocol
 210 were generally unclear (Figure 1A, B and C). However, for mean sprint speed
 211 (that is, the mean of the peak speed attained in each sprint), there was a mean
 212 increase in the STOCH trial compared to the CON across all quartiles of the
 213 protocol (Figure 1D).

214

215 *****Insert Table 1 about here*****

216

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

218

219 Physiological and perceptual responses to the trials are shown in Table 2.
 220 Unclear differences were observed between trials in %HR_{max} across the entire
 221 protocol (ES = 0.15; ± 0.38). After the first and second bout, blood lactate
 222 concentration increased less after the STOCH compared to the CON trial.
 223 Participants reported higher average RPE (ES = 0.87; ± 0.67) and sRPE (ES =
 224 0.52; ± 0.60) after the STOCH protocol.

225

226 *****Insert Table 2 about here*****

227
 228
 229
 230
 231
 232
 233
 234
 235
 236
 237
 238
 239
 240
 241
 242
 243
 244
 245
 246
 247
 248
 249
 250
 251
 252
 253
 254
 255
 256
 257
 258
 259
 260
 261
 262
 263
 264
 265
 266
 267
 268
 269
 270
 271
 272
 273
 274
 275
 276

The reduction in isometric knee-extensor torque after exercise was small for the CON (-48.4 ± 31.6 N·m, ES = 0.56; ± 0.25) and STOCH (-39.6 ± 36.6 N·m, ES = 0.48; ± 0.30). Accordingly, the difference in post-exercise knee extensor peak torque between trials was unclear (CON = 282.7 ± 80.7 N·m, STOCH = 279.0 ± 66.7 N·m; ES = 0.04; ± 0.19). Voluntary activation (VA%) decreased after exercise in both the CON ($-8.3 \pm 4.8\%$; ES = 0.95; ± 0.68) and STOCH ($-6.0 \pm 4.1\%$; ES = 1.23; ± 1.04) protocols (Table 2).

The time taken to complete the Stroop test after STOCH (75.0 ± 4.3 s) was higher than CON (72.2 ± 4.3 s) (ES = 0.59; ± 0.62). The total number of attempts required to complete the task was higher (ES = 0.65; ± 0.83) after the STOCH (10.3 ± 2.5) compared to the CON trial (9.3 ± 1.4 ; Table 3).

*****Insert Table 3 about here*****

Total task load score was higher (ES = 0.25; ± 0.38) in the STOCH (67.1 ± 9.8 AU) compared to the CON trial (61.9 ± 19.2 AU). Differences in task load subscales were unclear between trials, with the exception of mental demand, where a small increase in the STOCH trial was observed (ES = 0.56; ± 0.69 ; Figure 2).

*****Insert Figure 2 about here*****

Discussion

This is the first study to seek to manipulate and quantify the mental demands associated with simulated rugby activity. Our data shows that having more unpredictable movement commands than those traditionally used in team sport simulations might result in a small increase in how mentally demanding the exercise is perceived to be. This would be consistent with observations that repetitive²⁰ and learnable actions²¹ necessitating less vigilance require fewer attentional resources and result in lower mental fatigue.²² As such, the unpredictable order of events employed in the STOCH trial might have increased vigilance requirements for participants to respond correctly to the upcoming audio command. Greater mental demands also occur when uncertainty of a signal's origin (in this case the nature of the command) is increased,²² which results in a greater 'vigilance decrement' (i.e. a decrement in information processing and resulting cognitive performance). The observation here that elements of Stroop test performance were worse in the STOCH trial would support such a notion. Given that we observed a small effect with confidence intervals that incorporate zero, we encourage other researchers to examine the vigilance requirements of team sport simulations to determine whether mental demands are indeed affected. Future studies might also explore whether cognitive function that more closely replicates match-like actions (e.g. decision making for skill execution) is influenced by the degree of mental demand associated with simulated match activity.

RPE is a key determinant of performance and fatigue in team sports such as rugby.³ The potentially higher mental demand associated with the modified RLMSP-i might explain the observed increase in state and session RPE in the

277 STOCH trial. RPE is informed by numerous afferent and efferent factors,¹⁶
278 including the cognitive demands of a task.²³ Indeed, McLaren et al.²⁴ recently
279 demonstrated that cognitive RPE explained a significant proportion of variance
280 in session RPE reported during rugby conditioning sessions. However, others
281 have reported no difference in RPE when performing a mentally demanding
282 task during exercise;²⁵ additional explanations for the observed increase in RPE
283 are therefore needed.

284
285 The greater vigilance required to correctly respond to the commands in the
286 STOCH trial potentially resulted in participants adopting a greater associative
287 attentional focus (i.e. participants' attention was directed toward pertinent
288 information associated with completing the RLMSP-i, such as sprinting to the
289 correct cone).¹⁰ If true, this could explain the higher RPE *and* increased sprint
290 performance in the STOCH trial. Task association can increase RPE relative to
291 task dissociation,²⁶ due to a greater internal focal awareness of physiological
292 sensations. Furthermore, task association, particularly when it is external
293 (where attention is focussed on completing the outcome of the task rather than
294 the bodily movements required and associated physiological responses), can
295 enhance performance across a variety of exercise tasks, such as maximal force
296 production, vertical jumping, sprinting and endurance exercise.¹⁵ An
297 alternative explanation for our observations of altered performance is that the
298 CON trial induced more boredom, which has can negatively affect exercise
299 intensity²⁷. However, a limitation of our research is that we did not assess
300 attentional focus or boredom, and therefore such a mechanism for our
301 observations is speculative. Further research should explore the influence of
302 attentional focus on simulated team sport performance with differing mental
303 demands.

304
305 Afferent feedback from multiple physiological systems is thought to influence
306 RPE,¹⁶ and both heart rate and B[La] are related to athletes' RPE during small-
307 sided games.²⁸ In the present study, %HRmax was not different between trials,
308 and is therefore unlikely to have resulted in a higher RPE. The lower B[La] in
309 the STOCH trial might be expected to be associated with a lower RPE.
310 However, the reliability of B[La] measured during the RLMSP-i is poorer than
311 other measures (CV% = 13.4 – 19.7%; interchange bout 1 and 2, respectively).
312 It is also well established that work performed immediately before sampling
313 influences blood lactate concentrations.²⁹ After the final maximal intensity
314 effort (20 m maximal sprint and 8 m sprint to contact), there was 1.11 min and
315 0.26 min until the end of the protocol for CON and STOCH, respectively.
316 Given that participants seemingly have an increased external load during
317 STOCH (i.e. sprinting faster and covering more distance), the higher blood
318 lactate concentration during CON is likely to reflect the movement activity
319 before sampling rather than an overall increase in exercise intensity (which
320 might increase in RPE).

321
322 For the first time, this study assessed changes in MVC and VA% after a
323 simulated rugby league match. The proportional decrease in MVC and VA%
324 response was similar after the STOCH (12 and 7%, respectively) and CON (14
325 and 9%, respectively) trials. The MVC response is comparable to the mean
326 values reported for rugby league players immediately ($8 \pm 11\%$) and two hours

327 after competitive match play ($12 \pm 13\%$).³⁰ However, Duffield et al.³⁰ reported
328 no difference in VA% when comparing baseline ($90.1 \pm 6.7\%$) to immediately
329 (-0.4%) and two hours (-0.8%) after match play. These disparities in VA%
330 reported after actual and simulated rugby league match play might be due to
331 procedural differences, such as stimulation site, stimulation frequency, the
332 exercise intensity of the RLMSP-i and participant training status.³¹ It is also
333 possible that the greater amount of high intensity running in the current
334 protocol (~ 1230 m) compared to that reported by Duffield et al.³⁰ (~ 877 m),
335 induced a greater degree of central fatigue. Nonetheless, the observed
336 decrement in VA% in STOCH (-6.5%) and CON (-9.1%) trials of the RLMSP-
337 i when compared to baseline ($92.9 \pm 4.5\%$ and $91.3 \pm 8.1\%$, respectively),
338 suggest reductions in force generating capacity of the knee extensors after
339 movements replicating rugby league match play are due to both central and
340 peripheral mechanisms.¹⁶

341

342 The similar neuromuscular response to both conditions is consistent with
343 research reporting no difference in both MVC and VA% after periods of mental
344 exertion.³² Unlike the negative effects of mental fatigue on endurance
345 performance,³³ mental fatigue seemingly does not impair maximal force
346 production over a short duration.³² This might explain why greater maximal
347 sprints occurred in the stochastic protocol, despite the small potential increase
348 in mental demand.

349

350 The present study has several limitations that should be acknowledged. As we
351 previously stated, the proposed mechanism of the STOCH trial being affected
352 by task association is speculative and would have benefited from a direct
353 attempt to assess attentional focus. However, these methods are associated with
354 numerous threats to validity.³⁴ Secondly, whilst we endeavoured to ensure that
355 the number, type and relative spacing of demanding activities – such as
356 sprinting - were as well-matched between protocols as feasible, it cannot be
357 discounted that the activity performed immediately before and after demanding
358 activities influenced their outcome. Whilst this, in itself, is a notable outcome
359 of this research, future studies might wish to explore the extent to which this,
360 rather than altered mental demands for example, affects simulated team sport
361 performance. Thirdly, we acknowledge that the new STOCH protocol, which
362 does not have short (~ 115 s) repeated cycles of activity, cannot be used to
363 compare performance between distinct small time periods (for example,
364 changes across 2 min periods), given that no two short periods will be the same.
365 However, given that we have matched the number and frequency of commands
366 for each ~ 5.45 min, we feel that changes over approximately 5 min can be
367 explored with the STOCH protocol. **Finally, we acknowledge that some of**
368 **our observed effects have confidence intervals that contain zero or the**
369 **interval demarcating a ‘trivial’ effect (i.e. ES = -0.2 to 0.2). As such, we**
370 **encourage researchers to replicate and/or extend our investigation to**
371 **clarify if more stochastic simulation protocols do indeed change perceived**
372 **mental demands and elements of running performance.**

373

374 **Practical Implications**

- 375 • Those designing team sport simulation protocols should note that
376 physiological, perceptual and performance responses can be influenced by the

377 order of events that are performed. Such differences might have important
378 implications for the validity of team sports protocols.

- 379 • More repetitive movement patterns, which require less vigilance, might reduce
380 repeated sprint performance in team sports protocols. We propose that less
381 predictable movements be used when seeking to maximise external work in
382 players.
- 383 • These findings also have implications for those seeking to replicate the
384 movement and mental demands of match play in training situations and
385 promote the use of practices that employ stochastic rather than repetitive
386 movements, e.g. small-sided games.

387

388 **Conclusions**

389 Manipulating the order of events to be more stochastic during a simulation of
390 rugby league match-play potentially increases the mental demand of this
391 activity, which appeared to be associated with increased self-paced sprint
392 performance, impaired decision making capacity and increased perceived
393 exertion. Accordingly, when simulating match play, the cognitive demand and
394 vigilance requirement associated with the task should be considered.
395 Investigations into the mental demands of competitive rugby league match play
396 are needed, such that valid training and research replications of match demands
397 can be made.

398

399

400 **Acknowledgements**

401 None.

402

403 **References**

- 404 1. Kempton T, Sirotic AC, Coutts, AJ . Between match variation in professional
405 rugby league competition. *J Sci Med Sport* 2014; 17(4):404-407.
- 406 2. Highton J, Mullen T, Twist C. Influence of knowledge of task endpoint on
407 pacing and performance during simulated rugby league match play. *Int J Sports*
408 *Physiol Perf* 2017; 12(9):1192-1198.
- 409 3. Norris JP, Highton J, Hughes SF et al. The effects of physical contact type on
410 the internal and external demands during a rugby league match simulation
411 protocol. *J Sports Sci* 2016; 34(19):1859-1866.
- 412 4. Clarke JS, Highton J, Close et al. (2016). Carbohydrate and caffeine improves
413 high intensity running of elite interchange players during simulated match play.
414 *J Strength Cond Res*, <https://doi.org/10.1519/JSC.0000000000001742>
- 415 5. Waldron M, Highton J, Twist C. The reliability of a rugby league movement-
416 simulation protocol designed to replicate the performance of interchanged
417 players. *Int J Sports Physiol Perf* 2013; 8(5):483-9.
- 418 6. Roberts SP, Stokes KA., Weston, L et al. The Bath University Rugby Shuttle
419 Test (BURST): A Pilot Study. *Int J Sports Physiol Perf* 2010; 5(1):64-74.
- 420 7. Williams JD, Abt G, Kilding AE. Ball-sport endurance and sprint test
421 (BEAST90): Validity and reliability of a 90-minute soccer performance test. *J*
422 *Strength Cond Res* 2010; 24(12):3209-3218.
- 423 8. Nicholas CW, Nuttall FE, Williams C. The Loughborough Intermittent Shuttle
424 Test: a field test that simulates the activity pattern of soccer. *J Sports Sci* 2000;
425 18(2):97-104.

- 426 9. Tofari PJ, McLean BD, Kemp JG, Cormack SJ. A self-paced intermittent
427 protocol on a non-motorised treadmill: a reliable alternative to assessing team-
428 sport running performance. *J Sports Sci Med* 2015;14(1):62-68.
- 429 10. Smallwood J, Davies JB, Heim D et al. Subjective experience and the
430 attentional lapse: Task engagement and disengagement during sustained
431 attention. *Conscious Cogn* 2004; 13(4):657-690.
- 432 11. Warm JS, Parasuraman R, Matthews G. Vigilance requires hard mental work
433 and is stressful. *Hum Factors* 2008; 50(3):433-441.
- 434 12. Mashiko T, Umeda T, Nakaji S et al. Position related analysis of the appearance
435 of and relationship between post-match physical and mental fatigue in
436 university rugby football players. *Br J Sports Med* 2004; 38(5): 617-621.
- 437 13. Greig M, Marchant D, Lovell R et al. A continuous mental task decreases the
438 physiological response to soccer-specific intermittent exercise. *Br J Sports
439 Med* 2007; 41(12):908-913.
- 440 14. Smith MR, Marcora SM, Coutts, AJ. Mental fatigue impairs intermittent
441 running performance. *Med Sci Sports Exerc* 2015; 47(8):1682-1690.
- 442 15. Wulf G. Attentional focus and motor learning: a review of 15 years. *Int Rev
443 Sport Exerc Psychol* 2013; 6(1):77-104.
- 444 16. Waldron M, Highton J. Fatigue and pacing in high-intensity intermittent team
445 sport: an update. *Sports Med* 2014; 44(12):1645-1658.
- 446 17. Hopkins W. Spreadsheets for analysis of controlled trials, with adjustment for
447 a subject characteristic. *Sports Sci* 2006; 10:46–50.
- 448 18. Ramsbottom R, Brewer J, Williams C. A progressive shuttle run test to estimate
449 maximal oxygen uptake. *Br J Sports Med* 1988; 22:141-144.
- 450 19. Bajaj JS, Heuman, DM, Sterling RK et al. The Stroop smartphone application
451 is a short and valid method to screen for minimal hepatic encephalopathy.
452 *Hepatology* 2013; 58(3):1122-1132.
- 453 20. Manly T, Robertson IH, Galloway M, et al. (1999). The absent mind: further
454 investigations of sustained attention to response. *Neuropsychologia*
455 1999; 37(6):661-670.
- 456 21. Van der Linden D, Frese M, Meijman TF. Mental fatigue and the control of
457 cognitive processes: effects on perseveration and planning. *Acta Psychologica*
458 2003; 113(1):45-65.
- 459 22. Warm JS., Dember WN, Hancock PA. Vigilance and workload in automated
460 systems, chapter 9, in *Automation and Human Performance: Theory and
461 Applications* . Mahwah, NJ: Erlbaum, 1996.
- 462 23. Bray SR, Graham JD, Ginis KAM et al. Cognitive task performance causes
463 impaired maximum force production in human hand flexor muscles. *Biol
464 Psychol* 2012; 89(1):195-200.
- 465 24. McLaren SJ, Smith A, Spears IR et al. A detailed quantification of differential
466 ratings of perceived exertion during team-sport training. *J Sci Med Sport* 2017;
467 20(3):290-295.
- 468 25. Mehta RK, Agnew MJ. Influence of mental workload on muscle endurance,
469 fatigue, and recovery during intermittent static work. *Eur J Appl Physiol* 2012;
470 112(8):2891-2902.
- 471 26. Hutchinson JC, Tenenbaum G. Attention focus during physical effort: The
472 mediating role of task intensity. *Psych Sport Exerc* 2007; 8:233-245.
- 473 27. Barwood MJ, Weston NJV, Thelwell R, Page J. A motivational music and
474 video intervention improves high-intensity exercise performance. *J Sports Sci
475 Med* 2009; 8(3): 435-442.

- 476 28. Coutts AJ, Rampinini E, Marcora SM et al. Heart rate and blood lactate
477 correlates of perceived exertion during small-sided soccer games. *J Sci Med*
478 *Sport*; 12(1):79-84.
- 479 29. Bangsbo J, Nørregaard L, Thorsoe F. Activity profile of competition soccer.
480 *Can J Sport Sci 1991*; 16(2):110-116.
- 481 30. Duffield R, Murphy A, Snape A et al. Post-match changes in neuromuscular
482 function and the relationship to match demands in amateur rugby league
483 matches. *J Sci Med Sport 2012*; 15(3):238-243.
- 484 31. Shield A, Zhou S. Assessing voluntary muscle activation with the twitch
485 interpolation technique. *Sports Med 2004*; 34 (4):253-267.
- 486 32. Rozand V, Pageaux B, Marcora SM et al. Does mental exertion alter maximal
487 muscle activation?. *Front Hum Neurosci 2014*; 8:755.
- 488 33. Marcora SM, Staiano W, Manning V. Mental fatigue impairs physical
489 performance in humans. *J Appl Physiol 2009*; 106(3):857-864.
- 490 34. Brick N, MacIntyre T, Campbell M. Attentional focus in endurance activity:
491 new paradigms and future directions. *Int Rev Sport Exerc Psychol 2014*;
492 7(1):106-34.

493
494

495

496

497

498

499

500

501

502

503

504

505

506

507

508

509 **Tables**

510 **Table 1.** Speed, low intensity activity (<14 km·h⁻¹), high intensity running
 511 (≥14 km·h⁻¹), mean sprint speed, player load and time at high metabolic power for control
 512 and random trials during the whole simulation. Mean ± SD, Effect Size (± 95% CI)

	Trial		ES (95% CI)
	CON	STOCH	
Speed (m·min ⁻¹)	104.0 ± 5.1	105.5 ± 4.0	0.26 (0.44)
Low (m·min ⁻¹)	77.0 ± 3.9	77.8 ± 3.8	0.19 (0.80)
High (m·min ⁻¹)	26.7 ± 4.9	27.7 ± 4.3	0.19 (0.68)
Sprint to Contact (km·h ⁻¹)	13.2 ± 1.4	13.5 ± 1.1	0.17 (0.48)
Sprint Speed (km·h ⁻¹)	21.6 ± 1.6	22.5 ± 1.4	0.50 (0.55)
PlayerLoad TM (AU)	459 ± 52	450 ± 47	0.17 (0.53)
Metabolic Power >20 W·kg ⁻¹ (s)	246 ± 40.2	252 ± 48	0.11 (0.63)

527 Low = low intensity activity, <14 km·h⁻¹; High = distance covered high speed running, ≥
 528 14km·h⁻¹ per minute; Sprint to Contact = maximum speed achieved during the 8 m sprint to
 529 contact; Sprint Speed = an average of the maximum speed during each 20 m sprint.

530
531
532
533

534 **Table 2.** Physiological, perceptual and neuromuscular responses to the RLMSP-i. Mean ± SD,
 535 effect size (± 95% CI).

	Trial		ES (95% CI)
	CON	STOCH	
%HR _{max}	83.1 ± 7.2	81.9 ± 3.9	0.15 (0.38)
B[La] (mmol·l ⁻¹)			
- Pre	2.5 ± 1.1	2.6 ± 0.7	0.10 (0.64)
- Mid	6.0 ± 2.5	4.9 ± 1.9	0.40 (0.39)
- Post	5.9 ± 2.7	5.1 ± 5.9	0.28 (0.39)
RPE	13.0 ± 1.4	14.3 ± 1.0	0.87 (0.67)
sRPE	5.5 ± 1.8	6.5 ± 1.3	0.52 (0.60)
Peak torque (N·m)			
- Pre	331.1 ± 79.9	318.6 ± 76.3	0.56 (0.30) &
- Post	282.7 ± 80.7	279.0 ± 66.8	0.48 (0.25)*
VA (%)			
- Pre	91.3 ± 8.1	92.9 ± 4.5	0.95 (0.68) &
- Post	83.0 ± 8.0	86.9 ± 7.4	1.23 (1.04)*

536 %HR_{max} = percentage of heart rate maximum; RPE = rating of perceived exertion; sRPE =
 537 session rating of perceived exertion. VA = voluntary activation. * Refers to the pre-post change
 538 for CON and STOCH, respectively.

539
540

541 **Table 3.** Reaction time and accuracy during the Stroop test for control and random trials,
 542 Mean ± SD, Effect Size (± 95% CI).

	Trial		ES (95% CI)
	CON	STOCH	
ST - Time (s)			
Pre	75.6 ± 5.3	76.9 ± 5.8	0.21 (0.71)
Mid	73.6 ± 7.3	73.2 ± 6.5	0.06 (0.49)
Post	72.2 ± 4.3	75.0 ± 4.3	0.59 (0.62)
Total	221.5 ± 15.1	225.1 ± 14.5	0.22 (0.49)
ST - Attempts (n)			
Pre	9.5 ± 1.6	10.4 ± 3.2	0.51 (0.77)
Mid	9.7 ± 2.0	9.3 ± 1.3	0.21 (0.56)
Post	9.3 ± 1.4	10.3 ± 2.5	0.65 (0.83)
Total	28.5 ± 4.4	29.9 ± 6.5	0.30 (0.54)

543 ST-time = Stroop test reaction time; ST-attempts = Stroop test number of attempts.

544

545 **Figure Captions**

546 **Figure 1.** A) speed, B) high speed running, C) sprint to contact speed and D) sprint speed
 547 during the RLMSP-i trials. Mean ± SD, with ES; ±95% CI.

548 **Figure 2.** NASA-Task Load Index weighted rating of the six subscales. MD = mental demand;
 549 PD = physical demand; TD = temporal demand; P = performance; E = effort; F = frustration.
 550 Mean (dark line) with individual plots (circles), ES; ±95% CI.

551

552

553

554

555