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ABSTRACT

Purpose: This study aimed to evaluate the effect of multiple sets of repeated-sprint ability (RSA) induced fatigue on subsequent passing skill performance among field hockey. **Methods:** Ten elite U-21 male field hockey players performed five sets of a combination of RSA test (6 × 20 m – 20 s of passive recovery) followed by a 1-min passing skill test (passing reception with subsequent passes at a pre-designed target). Fastest sprint time and cumulated sprint time for RSA test; total number of balls played, targeted and passing accuracy (number of balls targeted / total number of balls played) for passing skill test; heart rate (HR), blood lactate concentration ([La-]) and rating of perceived exertion (RPE) were collected throughout the protocol. **Results:** RSA performance was significantly impaired from set 1 to set 5 (fastest sprint time: +4.1%, $P < 0.001$; cumulated sprint time: +2.3%, $P < 0.01$). For a similar averaged number of balls played (12.8 ± 1.4) during each set, number of balls targeted (-1.7%, $P < 0.05$) and passing accuracy (-3.1%, $P < 0.05$) decreased up to the third set before re-improving over the last two sets. Psychophysiological responses (HR, [La-] and RPE) progressively increased ($P < 0.05$) towards protocol cessation. The decrease in passing accuracy with increasing RSA cumulated sprint time was fitted to a 2nd order polynomial function ($r^2 = 0.94$, $P < 0.05$). **Conclusion:** Multiple set RSA-induced fatigue was accompanied by passing skill adjustment variation suggesting a complex interaction between physiological and psychological/cognitive function to preserve passing skill under fatigued condition.

Key words: Team sports; fatigue; repeated-sprint ability; technical skill; ecological validity.

INTRODUCTION

Field hockey is an invasive territorial game that involves semi-stochastic intermittent activities (*i.e.*, maximal or near-maximal anaerobic efforts interspersed with low- to moderate-intensity aerobic phases) with and without the ball over an extended period of time (4×15 min since the Fédération Internationale de Hockey’s rule changes).¹ The physical demands therefore require aerobic and anaerobic abilities combined with the aptitude to repeatedly execute technical skills (*e.g.*, passing, shooting) under pressure and while fatigued. Previous time-motion analysis studies have reported a decline in locomotor activities (*e.g.*, sprinting, acceleration and deceleration) between halves² or quarters.³ Although the proportion of match-play at high-intensity is small,^{4,5} the ability to repeat maximal short-duration sprints (the so-called repeated-sprint ability, RSA)⁶ is an integral fitness component of field hockey^{2,4} and is typically associated with the key moments of a match (*e.g.*, gaining advantage over an opponent or creating scoring opportunities).

Transient and sustained fatigue-related decline in physical performance (*i.e.*, high-intensity running and sprinting) have been reported in several studies,^{7,8} with conflicting findings in accompanying technical skill performances.⁹⁻¹⁴ Most⁹⁻¹² but not all^{13,14} of these studies have demonstrated impaired throwing/shooting accuracy or speed of the ball after sport-specific fatigue development. These contrasting findings might be attributed to methodological differences such as the fatiguing exercise mode, intensity and duration, the elapsed time between the fatiguing exercise and subsequent testing, and/or the fitness level of participants. Specifically to field hockey, no research has yet assessed the effects of fatigue-induced exercise on field hockey-specific technical skills. Trying to unravel the mechanisms underpinning the fatigue-performance interaction would be of practical relevance for performance optimization and/or injury prevention.

Assessing the impact of fatiguing exercise on technical skill performance requires the use of the most sport-specific protocols.^{13,14} In this view, RSA test appears relevant to replicate the high-intensity intermittent nature of field hockey performance.^{4,5,15,16} Further, to better reflect the physical demands of a field hockey match,⁴ the use of multiple RSA sets would allow a more precise investigation of field hockey fatigue-induced physical and technical skills performance.

The purpose of this study was to assess the effect of multiple RSA sets on immediate subsequent passing skill performance, *i.e.*, ball reception/control and passing ability, in U-21 male field hockey players. We hypothesized that the passing skill performance would decline with the onset of fatigue during the first RSA set, and would mimic the physical performance alteration towards multiple RSA sets.

METHODS

Subjects

Ten U-21 elite male field hockey players (mean \pm SD: age 18.9 ± 1.1 yr, stature 179.5 ± 5.9 cm, body mass 71.5 ± 5.2 kg) from the French Institute of Sport (INSEP) competing in the French or Belgium first division participated in the study. All participants had at least 12 years of competitive field hockey experience, trained regularly (6 field hockey sessions and 3 strength and conditioning sessions per week) and were familiar to the specific drills (*i.e.*, both RSA and passing skill test) used in the present study. Before providing written informed consent, all participants were informed of the nature of the study, of all associated risks, and of their right to withdraw at any time. The study protocol complied with the Declaration of Helsinki guidelines and was approved by the local research ethics committee.

Experimental design

After a 20-min standardized warm-up (*i.e.*, 5 min of jogging at 10 km.h⁻¹ and dynamic stretching; 10 min of sprint-specific drills including athletic movements using cones and ladders, short burst of acceleration and deceleration and progressive sprints; and 5 min of technical drills including dribbling and passing and change of direction), the experimental protocol took approximately 22 min. It required participants to complete 5 sets of a combination of RSA test followed by 30 s of passive recovery and then a 1-min technical skill test with 30 s of passive recovery before reinitiating the subsequent RSA set. Participants were instructed and verbally encouraged to provide maximal effort in each repetition throughout the five RSA sets. A schematic representation of the experimental protocol is presented in Figure 1. All data were collected in-season on a wet artificial hockey pitch (AstroTurf, Dalton, Georgia, USA).

Repeated-sprint ability test

The RSA test consisted of 6 × 20 m straight-line maximal sprints departing every 20 s. The sprints were performed in a back and forth format to allow for passive recovery during the short rest period. Standing start position was set to 30 cm before the first set of photocells (*i.e.*, 30 cm from the front of the player’s left foot to the first set of photocells). Participants were requested to decelerate as fast as possible (with a deceleration area fixed between 10 and 15 m), to walk back to the starting line and to assume a standing ready position for 3 s before the next sprint announced by a countdown. Timing was measured to the nearest 0.01 s using wireless single beam photocells connected to an electronic timer (Witty system; Microgate, Bolzano, Italy), whose height was adjusted according to the height of the participant’s hip and placed at 0, 10 and 20 m. During the first sprint, participants were required to achieve at least 95% of their criterion score (*i.e.*, defined as the best of three single 20-m sprints interspersed with 2 min of recovery performed after the

warm-up; data not presented) as a check on pacing. All of the subjects satisfied this criterion score ($98.5 \pm 1.7\%$) during the first RSA set.

Three scores were determined during the RSA test: the fastest (*i.e.*, initial in all cases) sprint time, the cumulated sprint time (*i.e.*, sum of the six sprints) and the sprint decrement score [$S_{\text{dec}} (\%) = ((\text{cumulated sprint time}) / (\text{fastest sprint time} \times 6) - 1) \times 100$].⁶

Although using slightly different testing mode (*i.e.*, grass surface vs. non-slip wooden floor vs. AstroTurf ground), the reliability (typical error and coefficient of variation) for one RSA set (0.06 s and 1.8%, respectively), for the fastest sprint time (0.11-0.19 s and 1.1-2.5%) and for cumulated time (0.59 s and 2.1%) was previously reported using a resembling multiple RSA set (*i.e.*, 3 and 5 sets of 6×20 m – 25 s recovery between sprints and 4 min between sets).^{17,18}

Passing skill test

The passing skill test required participants to perform a specific field hockey task during a 1-min period. It consisted to play the maximal number of balls received in movement, controlled during turning and subsequently passed as fast and as accurately as possible at a pre-designed target (1.20×0.25 m) located at ground level in the middle of a standard field hockey goal. Participants were instructed to perform the test in an inverse clockwise direction, to play on the right side of their stick. For each ball played, participants were positioned at 10 m from the target, ran from the starting position to the action zone, received a ball, controlled it, turn and passed it roughly toward the target. The total number of balls played and targeted were recorded through the passing skill test. Passing score was graded as one point for a ball correctly received, controlled with clean pass on the target (*i.e.*, ball targeted) and zero point if the ball touched the feet (field hockey regulation) or failed to go through the target. A passing accuracy was calculated as the number of balls targeted / total number of balls played (expressed in %). The intraclass correlation

coefficient (ICC = 0.70, 0.89 and 0.88 for number of balls played, targeted and passing accuracy, respectively) from two separate passing skill tests (interspersed by 10 min of passive rest) of seven elite U21 male field hockey players indicate acceptable reliability.

Physiological measures and rating of perceived exertion

Heart rate (HR) was continuously monitored using a heart-rate monitor (RS800sd, Polar Electro Oy, Kempele, Finland) and was collected prior to, immediately after both RSA and technical skill efforts in each set, as well as 4 min after completion of the protocol. HR was expressed as percentage of maximal HR (197 ± 8 bpm) determined beforehand using a multistage 20 m shuttle run test. Ratings of perceived exertion was recorded at the same time points using a 6–20 point scale.¹⁹ Participants were given detailed instructions on how to use the scale (*i.e.*, they were requested to rate “*how heavy and strenuous the exercise was overall felt?*”).

Finger-tip capillary blood samples were collected at rest in a standing position, immediately after each technical skill effort in each set, and 4 min after protocol cessation, and were analysed for blood lactate concentration ([La⁻]) (Lactate Pro Analyser, Arkray Inc, Kyoto, Japan).

Statistical analyses

Statistics were carried out using Sigmaplot 11.0 software (Systat Software, Inc., San Jose, CA, USA). All data were expressed as mean \pm standard deviation (SD) and statistical significance was set at $P < 0.05$. Before using parametric statistical test procedures, the assumptions of normality and sphericity were verified using the Shapiro-Wilk test. A one-way ANOVA for repeated measures (set number) was used to compare changes in RSA performance, passing skill, physiological and RPE parameters with time. Multiple comparisons were made with the Holm-Sidak HSD post-hoc test. Partial eta-squared (η^2) was calculated as measures of effect size. Values

of 0.01, 0.06, and above 0.14 were considered as small, medium, and large, respectively. Due to the non-linear behaviour of the passing skill performance outcome, a 2nd order polynomial (quadratic) regression analysis was performed to determine the relationship between passing accuracy and RSA fatigue-induced (*i.e.*, cumulated sprint time) values from each set.

RESULTS

Repeated-sprint ability

Table 1 and Figure 2 displayed the RSA performance changes for each distance interval from set 1 to set 5. Sprint time significantly increased over the six sprints in set 1 (0-10 m distance interval: from 1.86 ± 0.08 s for the first sprint to 1.95 ± 0.09 s for the last sprint, +4.7 %, $P < 0.001$; 10-20 m distance interval: from 1.29 ± 0.04 s to 1.33 ± 0.04 s, +3.2 %, $P < 0.001$; 0-20 m distance interval: from 3.15 ± 0.11 s to 3.28 ± 0.11 s, +4.1%, $P < 0.001$) and further increased as sets progressed (Fig. 2). Compared to set 1, fastest sprint time increased in subsequent sets for 0-10 m (pooled values: +3.6%, $P = 0.05$, $\eta^2 = 0.06$), 10-20 m (+4.0%, $P < 0.001$, $\eta^2 = 0.11$) and 0-20 m (+4.1%, $P < 0.001$, $\eta^2 = 0.09$) distance intervals (Table 1). Cumulated sprint time increased in sets 2, 3, 4 and 5 compared to set 1 for 10-20 m (pooled values: +2.8%, $P < 0.001$, $\eta^2 = 0.07$) and 0-20 m (+1.9%, $P = 0.002$, $\eta^2 = 0.05$) distance intervals, but not for 0-10 m (+1.3%, $P = 0.178$, $\eta^2 = 0.02$) distance interval (Table 1). Corresponding S_{dec} was $2.4 \pm 1.3\%$ for set 1 and significantly ($P = 0.039$) increased ($4.8 \pm 2.5\%$ for set 5) until protocol cessation.

Passing skill test

Results of the passing skill test are presented in Table 2. For a similar averaged number of balls played (12.8 ± 1.4 , $P = 0.855$, $\eta^2 = 0.01$) during each set, number of balls targeted (-1.7% from set 1 to 3, $P = 0.024$, $\eta^2 = 0.11$) and accuracy (-3.1% from set 1 to 3, $P = 0.044$, $\eta^2 = 0.09$) were significantly altered up to the third set. Over the last two sets, a subsequent re-improvement

(+28.6% and +25.5%, respectively for number of balls targeted and accuracy) was observed (Table 2).

Physiological measures and rating of perceived exertion

HR reached 88.0% and 92.0% of maximal HR after the first RSA and technical phases (set 1) and significantly ($P < 0.001$, $\eta^2 = 0.05$) increased (92.8% and 94.6% of maximal HR, respectively) until protocol cessation (Fig. 3). Similarly, RPE progressively increased from set 1 to set 5 for both RSA and technical skill phases and reached near exhaustion level (18.7 ± 0.8 , $P < 0.001$, $\eta^2 = 0.48$). $[La^-]$ rapidly increased ($P < 0.001$, $\eta^2 = 0.07$) from warm-up to set 1 (9.4 ± 1.7 mmol · L⁻¹), reached maximal value after third set (11.5 ± 1.7 mmol · L⁻¹) and remained stable thereafter (11.2 ± 2.1 mmol · L⁻¹ and 11.1 ± 2.2 mmol · L⁻¹ at set 4 and 5, respectively) (Fig. 3).

Polynomial regression analysis

The decrease in passing accuracy with increasing RSA cumulated sprint time was fit to a 2nd order polynomial function ($r^2 = 0.94$, $P < 0.043$) (Figure 4). To further investigate this finding, an individual quadratic regression model was performed for each subject and revealed that 80.0% of them fit the quadratic model (demonstrated a decrease in passing ability with RSA fatigue-induced up to the third set, followed by a re-improvement in passing skill performance despite continuing fatigue development).

DISCUSSION

To the best of our knowledge, this is the first study to investigate the effect of multiple RSA sets on subsequent passing skill performance in team-sport athletes. Contrarily to our primary hypothesis, the main results indicate that, despite an expected progressive increase in fatigue development (*i.e.*, RSA performance decrement and concomitant increase in physiological

responses), passing skill performance varied throughout the protocol (*i.e.*, reduction up to the third set followed by re-improvement towards the last set).

RSA performance variables (*i.e.*, fastest sprint time, cumulated sprint time, S_{dec}) were altered (especially in the 10-20 m sprint interval) over repetitions and sets throughout the protocol. This was further accompanied by an increase in psychophysiological responses (*i.e.*, HR and RPE). Thus, the multiple RSA-induced fatigue observed here appears consistent with previous work examining single^{15,20} and multiple RSA test.^{17,18,21} Although the aetiology of RSA-induced fatigue is far from clear, such exercise imply a complex interaction between peripheral (*i.e.*, limitation in energy supply and metabolic by-products intramuscular accumulation) and central (*i.e.*, neural drive and muscle recruitment strategies) mechanisms.^{6,22} Recent evidences using manipulations of pre-existing fatigue levels²³ and hypoxia severity²⁴ support the view that mechanical performance and muscular electromyography signals are characterized by a biphasic profile during RSA test in order to limit the attainment of a critical peripheral fatigue threshold. Further, the comparison of fatigue responses in a RSA sprint-matching paradigm [*i.e.*, matched for initial output in a “non-fatigued” (first RSA set) *vs.* “fatigued” state (second RSA set)]²⁵ indicated that muscle activation was lower (~12 %) in the initial sprint of the second *vs.* first set despite similar output. This was accompanied by a greater fatigability in the second *vs.* first set.²⁵ In the present study, despite progressive fatigue development throughout the protocol, initial sprint of each set remained within the 95% target of best single sprint. Although muscular activity has not been recorded here, this may indicate that the short-term muscular activation history alters muscular recruitment pattern and fatigability during subsequent RSA sets.²² Further researches investigating neuromuscular functions during multiple RSA sets may contribute to the understanding of fatigue-causing mechanisms during repeated sprinting.

Because RSA circumvents pacing regulation (in comparison to endurance-based tests such as time trials or time to exhaustion), a faster build-up of fatigue may affect subsequent exercise. Accordingly, using a short post-RSA delay (*i.e.*, 30 s) to limit any fatigue recovery, the ensuing passing skill exercise led to further increase in HR and RPE. [La-] also rapidly increased up to the third set and remained stable upon protocol cessation. These (psycho)physiological responses align with multiple RSA sets studies.^{17,21} While Serpiello et al.²¹ reported an increase in [La-] up to the third set, Carr et al.¹⁷ observed that [La-] remained stable from set 3 to 5. These findings support the activation of feedback pathways from the metabo- and mechano-sensitive muscle afferents (*i.e.*, thinly myelinated group III and unmyelinated group IV nerve fibres) to limit the development of peripheral muscle fatigue, thereby avoiding severe disturbance of locomotor muscle homeostasis.²⁶ Besides, it is also conceivable that [La-] stabilization observed after the third set resulted from conscious (*i.e.*, based on the “anticipatory-RPE” model)²⁷ or subconscious²⁸ micro-pacing adjustments during the passing skill test. However, with a similar number of balls played, this seems unlikely. Similarly, the link between oxygen uptake kinetics and RSA performance²⁹ could have contributed to smaller [La-] accumulation (*i.e.*, lower production and higher removal). Another potential explanation may relate with the cell-to-cell lactate shuttle hypothesis³⁰ where [La-] is exchanged throughout the body – including the brain – to be emphasize as an energy intermediate substrate for oxidation, gluconeogenesis or glycogenesis.³¹

Contrary to our hypothesis, passing skill performance did not mirror RSA performance decrement. While the average number of balls played was not affected, our participants’ responses in passing ability reflect a parabolic effect. The first phase of this effect could be explained by the above mentioned impaired contractile process induced by [La-] accumulation and acidosis³² as previously observed during fatigue-induced tennis skill performance.¹⁴ Therefore, this may

support previous research findings⁹⁻¹¹ that have shown an influence of sport-specific fatigue on technical skills performance. However, the second phase of the parabolic effect observed here may support other research findings that have reported no influence of fatiguing exercise on subsequent technical skill performance.^{13,14} Possible justification could be related to synergistic muscles recruitment compensation³³ of the afferents' inhibition feedback from the working muscles and its corollary discharges (*i.e.*, neural signals from premotor/motor areas to sensory areas of the brain).³⁴ Further, our participants – considered as highly-skilled athletes – may have been able to cope with RSA-induced physiological stress and overcome its negative effects, concomitantly with an improved cognitive behaviour.³⁵ Accordingly, it has been proposed that the negative physiological effects induced by high-intensity exercise may be offset by positive cognitive arousal, resulting in near-baseline performance rather than worsening outcome.³⁶ Altogether, this suggests a complex interaction between physiological and psychological/cognitive function to preserve technical skills such as passing or shooting under fatigued condition. More studies measuring cerebral blood flow, electroencephalography and psychological/cognitive tasks in response to fatigue-induced sport-specific skills are required to bring insight in its underlying mechanisms and to ascertain any definitive statement regarding the impact of fatigue-induced exercise on technical skill performance.

A potential limitation of this study may relate to the passing skill test used. While we focused on an ecologically sounded passing skill performance to better reflect in-match field hockey technical activity, the multiple motor phases (*i.e.*, ball reception in movement, control during turning and passing) may have altered our participants' passing accuracy. Thus, rather than a target focus, some alterations could have been observed during the motor phase preceding the pass. Another point to mention is related to the small sample size of this study. The inclusion of

additional participants may have contributed to a clearer interpretation of the results and its potential underlying mechanisms. The addition of a control condition (*i.e.*, 5 sets of passing skill test interspersed by ~3 min of rest) may also permit to better delineate the contribution of the RSA-induced fatigue on technical skill performance.

PRACTICAL APPLICATIONS

Based on the present findings, practitioners should be aware that, even if sport-specific performance is susceptible to fatigue, maintenance of technical skills (*e.g.*, passing or shooting) could be expected through potential regulatory mechanisms/strategies that remain to be determined. From a practical perspective, proposing technical skills at the end of a fatiguing exercise would be beneficial to develop sport-specific fatigue resistance strategies in elite athletes.

CONCLUSION

In summary, the fatigue induced by the performance of multiple set of RSA exercise was not mirrored in the subsequent passing skill performance in elite U-21 field hockey players. Moreover, passing skill improvement observed at protocol cessation indicates that players seem to cope with the increasing psychophysiological responses. This suggests a complex interaction between physiological and psychological/cognitive function to preserve technical skills under fatigued condition. Further multidisciplinary (*e.g.*, exercise physiology, neuroscience, (cognitive) psychology) approaches should shed light on the potential mechanisms underpinning technical skill performance regulation.

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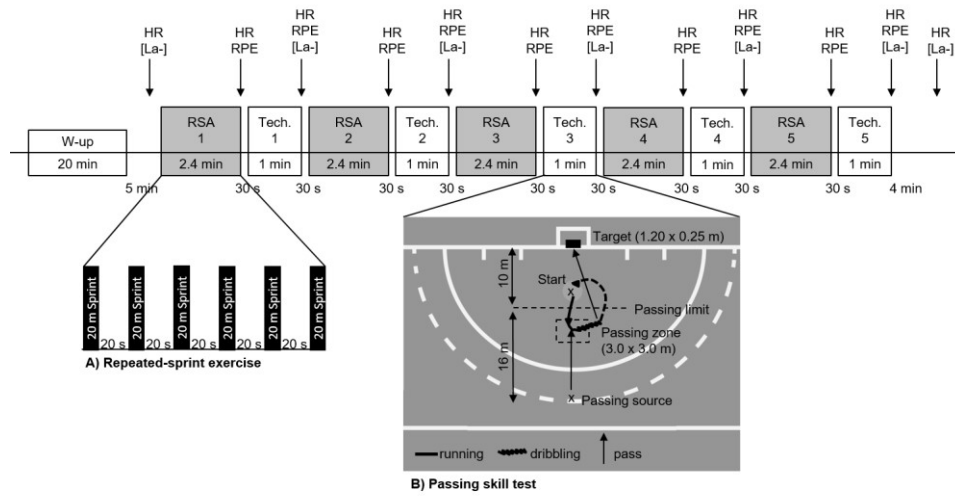


Figure 1. Schematic illustration of the experimental protocol. RSA, repeated-sprint ability test; Tech., passing skill test; HR, heart rate; [La-], blood lactate concentration; RPE, rating of perceived exertion.

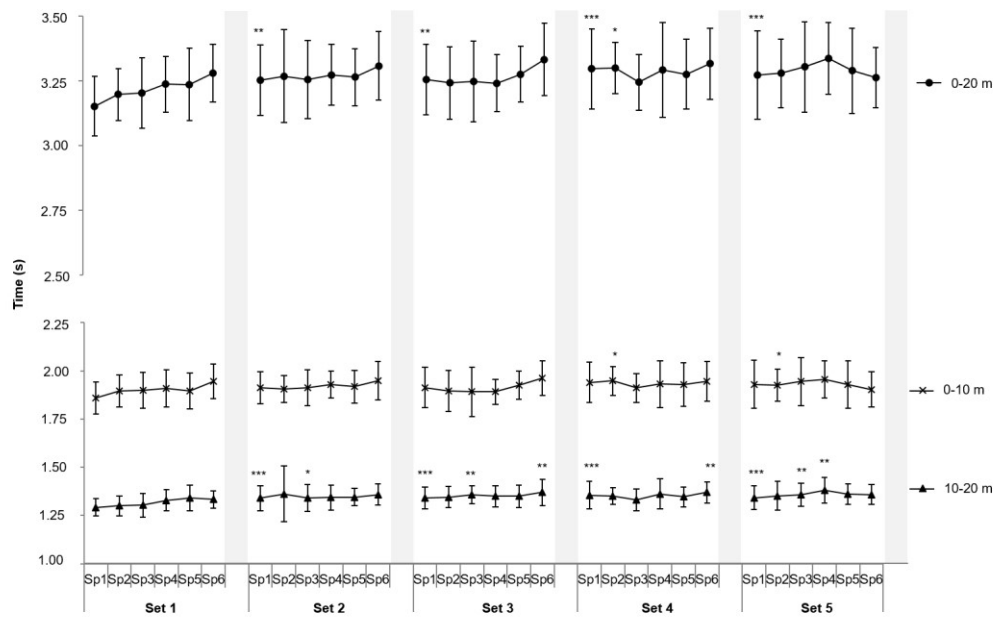


Figure 2. Sprint performance recorded for each distance intervals (0-10 m, 10-20 m and 0-20 m) during each repeated-sprint ability (RSA) set. Grey areas represent interspersed periods dedicated to the 1-min passing skill test (including 2×30 -s recovery/transition period allowed before and after). * Significantly different from the relative sprint performance of set 1, $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$. Values are mean \pm SD.

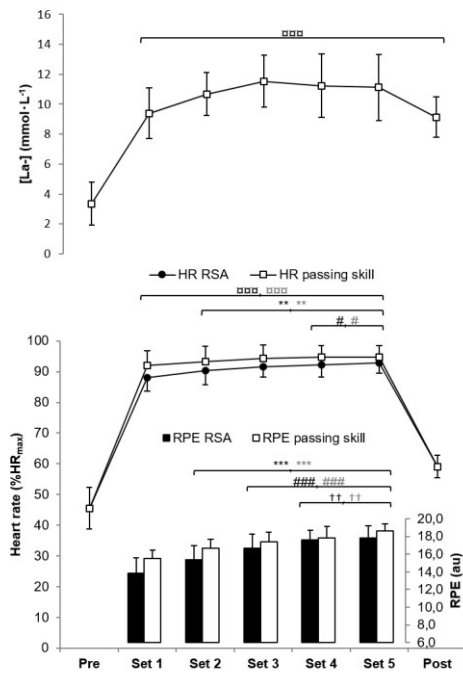


Figure 3. Heart rate (expressed in % of maximal HR), rating of perceived exertion (RPE) and blood lactate concentration ([La-]) collected after each repeated-sprint ability (RSA) and passing skill set. ** Significantly different from set 1, $P < 0.01$; *** $P < 0.001$. # Significantly different from set 2, $P < 0.05$; #### $P < 0.001$. † Significantly different from set 3, $P < 0.05$. □□□ Significantly different from Pre, $P < 0.001$. Values are mean \pm SD. Black and grey symbols represents significance for RSA and passing skill, respectively. Maximal HR was determined on a multistage 20 m shuttle run test (data not presented).

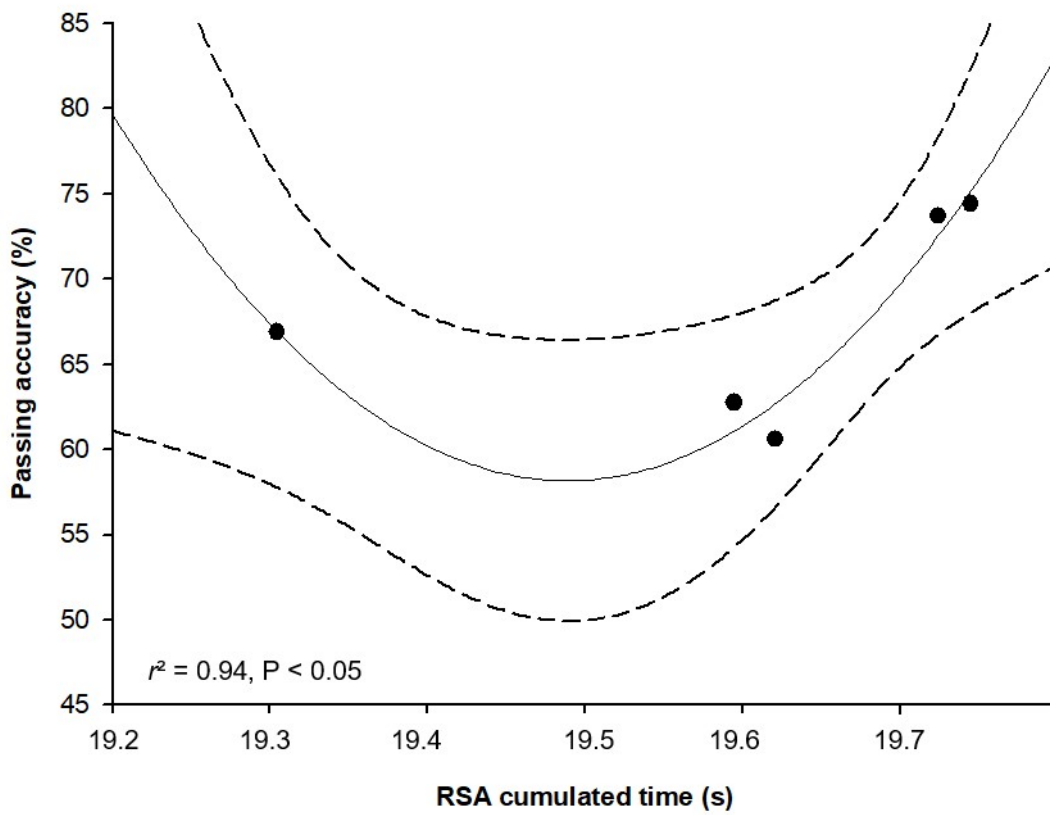


Figure 4. Polynomial regression for passing accuracy and RSA fatigue-induced (*i.e.*, cumulated sprint time) from each set. The 95% confidence interval is represented between the dashed lines.

Table 1: RSA performance from set 1 to set 5.

	Set 1	Set 2	Set 3	Set 4	Set 5
Fastest sprint time (s)					
0-10 m	1.86 ± 0.08	1.91 ± 0.08	1.91 ± 0.10	1.94 ± 0.10	1.93 ± 0.08
10-20 m	1.29 ± 0.04	1.34 ± 0.07***	1.34 ± 0.06***	1.36 ± 0.07***	1.34 ± 0.04
0-20 m	3.14 ± 0.12	3.25 ± 0.14***	3.26 ± 0.14***	3.30 ± 0.16***	3.27 ± 0.12
Cumulated sprint time (s)					
0-10 m	11.40 ± 0.39	11.53 ± 0.40	11.48 ± 0.47	11.61 ± 0.53	11.59 ± 0.39
10-20 m	7.90 ± 0.28	8.09 ± 0.40***	8.11 ± 0.30***	8.12 ± 0.27***	8.15 ± 0.28
0-20 m	19.30 ± 0.60	19.62 ± 0.72**	19.60 ± 0.69*	19.72 ± 0.74***	19.75 ± 0.60
S_{dec} (%)					
0-20 m	2.4 ± 1.3	4.1 ± 1.8*	4.0 ± 1.9*	4.7 ± 2.5**	4.8 ± 2.5

Values are mean ± SD.

* Significantly different from set 1, P < 0.05; ** P < 0.01; *** P < 0.001. η², partial eta-square.

Table 2: Passing skill performance from set 1 to set 5.

	Set 1	Set 2	Set 3	Set 4	Set 5
Number of ball played (n)	12.6 ± 1.6	13.0 ± 1.3	12.7 ± 1.4	12.9 ± 1.2	13.0 ± 1.3
Number of ball targeted (n)	8.4 ± 2.5	7.8 ± 1.7	7.9 ± 1.8	9.5 ± 1.8#, †	9.6 ± 1.7
Accuracy (%)	66.9 ± 19.1	60.6 ± 14.6	62.7 ± 14.5	73.7 ± 12.6#, †	74.4 ± 14.5

Values are mean ± SD.

Significantly different from set 2, P < 0.05; † Significantly different from set 3, P < 0.05. η², partial eta-square.