The Influence of Acute Sprint Interval Training on Cognitive Performance of Healthy Younger Adults

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Research Article

Keywords: sprint interval training, acute exercise, cognition, lactate, exercise-cognition

Posted Date: April 8th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-403341/v1

Version of Record: A version of this preprint was published at International Journal of Environmental Research and Public Health on January 5th, 2022. See the published version at https://doi.org/10.3390/ijerph19010613.

Abstract

Considerable evidence has been accumulated showing that an acute bout of physical exercise can improve cognitive performance but the optimal exercise characteristics (e.g., exercise type and intensity) remain elusive. In this regard, there is a gap in the literature to which extent Sprint Interval Training (SIT) can enhance cognitive performance. Thus, this study aimed to investigate the effect of SIT on cognitive performance.

We assessed in healthy younger adults (n = 19; 20.0 to 28.0 years old), the attentional performance (via d2 test), the working memory performance (via Digit Span Forward/ Backward) and the peripheral blood lactate concentration immediately before and 10 minutes after an exercise condition (SIT) and a control condition (i.e., reading).

We observed that SIT can enhance specific aspects of attentional performance as it improved F% ($t(19) = -2.249$, $p = 0.037$, $d = -0.516$) which constitutes a qualitative measure of precision and thoroughness. However, SIT did not change other measures of attentional or working memory performance. In addition, we observed that the exercise-induced increase in peripheral blood lactate levels correlated with changes in attentional performance (e.g., F% ($r_m = -0.54$, $p = 0.015$)).

The present study provides initial evidence that a time-efficient SIT can improve specific aspects of attentional performance and conforming evidence for a positive link between cognitive improvements and changes in peripheral blood lactate levels. Further research is warranted to substantiate our findings by investigating (i) the optimal exercise characteristics (e.g., number of sprints), (ii) further neurobiological mechanisms driving the cognitive improvements (e.g., changes in functional brain activation patterns), and (iii) the generalizability of the effects (e.g., older adults).

Introduction

There is growing evidence in the literature that a single bout of physical exercise can acutely enhance cognitive performance [1, 2]. However, the optimal exercise characteristics (e.g., type of physical exercise, exercise intensity, and exercise duration) to effectively improve cognitive performance are largely unknown [1, 2] but there is some evidence suggesting that the greatest effects can be expected after strenuous physical exercises when a time delay of approximately 11 to 20 minutes between exercise cessation and cognitive testing is considered [1]. In line with this observation, it has been noticed that sprint interval training (i.e., "all-out" exercise intensity) can increase the performance in an executive function task in a cohort of adolescents [3] and younger adults [4].

SIT is a special form of high-intensity training (HIT) which is typically characterized by short working bouts of "all-out" efforts (≤ 30 seconds) that alternate with longer recovery bouts (2–4 minutes) at relatively low intensity [5–7]. The commonly used protocol for SIT is the so-called Wingate protocol which consists of four bouts of 30 seconds "all-out" sprints intermitted by 4 minutes of recovery [8]. However, the Wingate protocol is considered as physically and mentally very demanding and thus is not well situated to be applied in psycho-physiologically impaired cohorts (e.g., sedentary individuals, older adults) [8, 9]. Hence, it has been proposed that future studies should focus on the investigation of protocols with fewer sprint repetitions and lesser sprint time duration [8, 9]. Accordingly, less demanding SIT protocols have been developed (e.g., 2x 20-second sprints in a 10-minute training session) and their effects on various health-related parameters (excluding cognitive performance such as changes in attentional performance) have been investigated [10–13].

Interestingly, the findings of a recent study suggest that a reduction of the sprint time from 20 seconds to 5 seconds is favorable when psychological parameters such as affect, effort, and enjoyment were considered [14]. Given that psychological parameters such as enjoyment are important factors predicting long-term adherence to physical exercise interventions [15], it seems reasonable to assume that the investigation of the effects of SIT protocols with a shorter sprint time duration (termed as "shortened-sprint reduced exertion high-intensity training" [SSREHIT]) can be considered as a promising field for future research [14, 16, 17].

To the best of our knowledge, there is no study available that has investigated the acute effect of SSREHIT on cognitive performance. Based on accumulating evidence showing that acute exercise can influence cognitive performance positively [1, 2], we hypothesized that SSREHIT can improve cognitive performance, too. Hence, the current study aimed to investigate to which extent an acute bout of SSREHIT changes measures of cognitive performance in a cohort of healthy younger adults.

Material And Methods

We recruited 20 healthy young adults (11 female/ 9 male; age: 22.7 ± 2.3 years; body height: 176.0 ± 12.7 cm; body mass: 68.1 ± 11.0 kg), with normal or corrected vision. The study was approved by the local ethics committee of the Medical Faculty of the Otto von Guericke University Magdeburg (97/20) and was prospectively registered in the German Clinical Trial Register (DRKS00022577).

The participants were asked to visit our laboratory three times. The visits were separated by at least five days.

At the first visit, the participants were informed about the study procedures and were asked to complete the German version of the Physical Activity Readiness Questionnaire (PARQ) which screens for individuals at increased health risk when performing physical exercises [18]. Furthermore, the interested individuals are asked to complete the Beck Depression Inventory (BDI-II) to screen for depressive symptoms (cut-off score to be included ≤ 13) [19]. Based on the PARQ, the BDI, and self-reports, interested individuals which suffer from musculoskeletal, cardiovascular, endocrinological, psychiatric, and/or neurological disorders were excluded. The eligible participants were asked to complete the following questionnaires: (i) a physical activity questionnaire (BSA; derived from the German Bewegungs- und Sportaktivitatsfragebogen) [20], (ii) the Pittsburgh Sleep Quality Index (PSQI) [21], and (iii) Edinburgh Handedness Inventory (EHI) [22]. In addition, the participants performed two familiarization 6-seconds "all-out" sprints trials on a Wattbike cycle ergometer (Wattbike Pro, Wattbike, UK) at the first visit.

At the second and third visit, the participants completed the cognitive tests immediately before and 10 min after the exercise or the control condition. A passive rest period of 10 minutes after the exercise cessation was used because a meta-analysis reported that the largest effects of vigorous physical exercises (e.g., “all-out” efforts as in sprint interval training) on cognitive performance can be observed when such a time delay after exercise cessation is considered [1]. This study was conducted in a within-subject crossover design with both pretest and posttest assessments (see Fig. 1) and we randomized the order of the exercise and the control condition using a software (RITA version 1.51, Evidat, Germany)

The SIT condition started with a standardized 3-minute-long warm-up on the Wattbike set at resistance level of 1 for both the magnetic- and air-braked resistance at ~ 60 to 80 revolutions per minute with two acceleration phases of ~ 3 seconds at 60 and 120 seconds. Afterward, all participants performed six 6-seconds “all-out” sprints on the Wattbike ergometer which were intermitted with passive rest periods of 1 minute [23–26]. The resistance of the Wattbike was set to 1 and 10 for the magnetic- and air-braked resistance, respectively. In the control condition, the participants were asked to sit quietly in a comfortable chair and read for the same period of time.

As shown in Fig. 1, the following psychological parameters were quantified: (i) affective responses via 11-point Feeling scale (FS) which ranges from − 5 (i.e., “very bad”) to + 5 (i.e., “very good”) [27, 28], (ii) relative perceived exertion (RPE) via a 15-points Borg scale which ranges from 6 (i.e., no exertion) to 20 (i.e., maximal exertion) [29], and (iii) changes in concentration, motivation, and mental fatigue via visual analogue scales which ranges from 0 mm (i.e., not at all) to 100 mm (i.e., extremely) [30].

In addition, all participants were instructed (i) to avoid strenuous physical activities 48h before each experimental session, (ii) to abstain from excessive alcohol or caffeine consumption for 24 h before each experiment, (iii) to keep their normal sleep rhythm, and (iv) to consume their last meal at least 3 h before the start of the experimental conditions.

Cognitive Performance Tests

In this study, the paper-pencil version of the d2 test measuring selective attention and concentration performance was used [31]. The d2 test consists of 14 lines and each line entails a string of 47 randomly mixed letters (i.e., “d” and “p”). Each letter is flanked by dashes (i.e., individually or in pairs above and/or below the letters). The participants are instructed to mark within 20 seconds all “d’s” in a line that are flanked by two dashes, which may be arranged individually above and below or in pairs above or below the “d”. After 20 seconds the participant is advised by the experimenter to continue with the next line of letters (the whole test lasts 280 seconds). The performance in the d2 test was assessed by using: (i) the total number of responses (german: “*Gesamtzahl aller bearbeiteten Zeichen*”; GZ) including correct responses and mistakes in the d2 test - a quantitative measure of working speed, (ii) the standardized number of correct responses minus errors of commission (german: “*Standardwert der Konzentrationsleistung*”; SKL) - objective measure of concentration, and (iii) number of all errors (error of omission + error of commission) related to the total number of responses (german: “*Fehlerprozentwert*”; F%)- a qualitative measure of precision and thoroughness. Errors are defined as errors of omission (number of correct responses [“d” with two dashes] missed), and errors of commission (any distractor items such as a “p” or a “d” with one dash or more than two dashes incorrectly marked) [32–34].

To assess working memory performance, the Digit Span Forward (DSF) and Digit Span Backward (DSB) were used, and the participant has to listen to sets of ascending digit numbers read out loud at a pace of one digit per second. After listening, the participant was asked to recall the sequence of given numbers out loud (in DSF in the same order, in the DSB in the reverse order). Both, the DSF and the DSB start with a sequence of two numbers (e.g., 7 – 3). For each span, two trials are performed, and the span is gradually increased in the step of one item. Each time a different sequence of numbers is used. The test is stopped after two consecutive fails on the same set of items [35, 36]. Each correct answer is scored with one point, so the maximal score is 28 and 20 for the DSF and DSB, respectively.

Statistical analysis

The statistical analysis was performed with JASP (version 0.14.1.0, JASP Team, Amsterdam, Netherlands).

The delta scores (values of post-test *minus* values of pre-test) of the cognitive tests (d2, DSF, DSB) were normally distributed (verified by Shapiro-Wilk test) and thus a paired T-tests and Cohen’s d (with 95% Confidence Intervals [CI]) were calculated to compare the delta scores of the exercise and control condition. We rated Cohen’s d as follows: small effect < 0.2; medium effect ≥ 0.2 to ≤ 0.8, and large effect > 0.8 [37, 38].

The data of the RPE scale, FS scale, VAS, and peripheral blood lactate concentration were not normally distributed, and thus the non-parametric Friedman test and Concover posthoc tests were used to analyze a possible time effect. The adjustment of the alpha level of the posthoc test was conducted using the Holm correction (p_{holm}) [39]. To compare the difference between the exercise and control conditions, Wilcoxon tests were conducted, and effect size r (with 95% CI) has been computed (Fritz et al., 2012). We rated the effect size r as follows: no correlation < 0.19 ; low correlation ≥ 0.20 to ≤ 0.39 ; moderate correlation ≥ 0.40 to ≤ 0.59 ; moderately high correlation ≥ 0.60 to ≤ 0.79; high correlation ≥ 0.8 [37, 38].

In addition, as previous studies reporting a relationship between changes in peripheral blood lactate and cognitive performance [30, 40], we conducted a repeated-measures correlation analysis between cognitive performance measures and peripheral blood lactate concentrations using a freely available R-package [41].

The significance level of all statistical tests was set to $\alpha < 0.05$.

Results

Participant’s characteristics

An overview of the general characteristics of the participants is provided in Table 1.

Cognitive performance

We observed a difference between SIT condition and control condition concerning F% ($t(19) = -2.249$, $p = 0.037$, $d = -0.516$ [CI 95% -0.999 to -0.030]) but not regarding GZ ($t(19) = 1.495$, $p = 0.152$, $d = 0.343$ [CI 95% -0.125 to 0.802]), SKL ($t(19) = 1.899$, $p = 0.074$, $d = 0.436$ [CI 95% 0.041 to 0.901]), DSF ($t(19) = -1.707$, $p = 0.105$, $d = -0.392$ [CI 95% -0.854 to 0.081]), or DSB ($t(19) = -0.218$, $p = 0.830$, $d = -0.050$ [CI 95% -0.499 to 0.401]). A descriptive overview on the cognitive performance measures is shown in Table 2.

Psychological and physiological parameters

We noticed a significant effect of time in the RPE ratings in the SIT condition ($X^2 = 35.041$ ($n = 20$; $df = 2$), $p < 0.001$) but not in the control condition ($X^2 = 2.000$ ($n = 20$; $df = 2$), $p = 0.368$). The post-hoc tests indicate that in the SIT condition the RPE rating was higher after exercise ($T(36) = 5.883$, $p_{holm} < 0.001$) and post-test ($T(36) = 2.320$, $p_{holm} = 0.026$) compared to pre-test. Furthermore, the RPE rating in the SIT condition was lower at post-test compared to after exercise ($T(36) = 3.563$, $p_{holm} = 0.002$).

The comparisons between the both conditions revealed that the RPE ratings in the SIT condition were higher after exercise ($W(n = 20) = 190.000$, $p < 0.001$, $r = 1.000$ [CI 95% 1.000 to 1.000]) and post exercise ($W(n = 20) = 120.000$, $p < 0.001$, $r = 1.000$ [CI 95% 1.000 to 1.000]) but not at pre exercise ($W(n = 20) = 4.000$, $p = 0.789$, $r = 0.333$ [CI 95% -0.704 to 0.917]).

We did not observe a significant effect of time in the FS ratings whether in the SIT condition nor in the control condition ($p > 0.05$). However, at the following timepoints the ratings in the FS were lower in the SIT condition compared to the control condition: after exercise ($W(n = 20) = 28.500$, $p = 0.013$, $r = -0.667$ [CI 95% -0.870 to -0.271]), and at post-test ($W(n = 20) = 4.000$, $p = 0.004$, $r = -0.912$ [CI 95% -0.974 to -0.728]). No difference in FS ratings were observed at pre-test ($W(n = 20) = 19.500$, $p = 0.070$, $r = -0.571$ [CI 95% -0.853 to -0.033]).

There are no significant differences between pre-test and post-test values of motivation, concentration, and mental fatigue (asses via VAS) in the SSREHIT condition and control condition ($p > 0.05$). Furthermore, there is no difference in motivation, concentration, and mental fatigue between the REHIT condition and the control condition ($p > 0.05$).

Regarding, peripheral blood lactate concentration, we observed a significant time effect in the SIT condition ($X^2 = 38.000$ ($n = 20$; $df = 2$), $p < 0.001$) and in the control condition ($X^2 = 7.891$($n = 20$; $df = 2$), $p = 0.019$). The post-hoc tests indicate that in the SIT condition the peripheral lactate concentration was higher after exercise ($T(38) = 6.164$, $p_{holm} < 0.001$) and at post-test ($T(38) = 3.082$, p_{holm} $p = 0.008$) compared to pre-test. Furthermore, we noticed that the peripheral lactate concentration in the SIT condition was lower at post-test compared to after exercise ($T(38) = 3.082$, p_{holm} $p = 0.008$).

In the control condition, the peripheral lactate concentration values measured at the post-test were lower than the values measured at the pre-test ($T(38) = 2.795$, p_{holm} $p = 0.025$).

In comparison to the control condition the peripheral lactate concentration in the SIT group was higher after exercise (W (n = 20) = 190.000, $p < 0.001$, r = 1.000 [CI 95% 1.000 to 1.000]) and at post-test (W (n = 20) = 190.000, $p < 0.001$, r = 1.000 [CI 95% 1.000 to 1.000]) but not at pre-test (W (n = 20) = 53.000, p = 0.453, r = -0.221 [CI 95% -0.654 to 0.321]). A detailed overview about the psychological and physiological measures is provided in Table 3.

In addition, in the exercise condition we observed the following correlations between changes in peripheral blood lactate levels and measures of attentional performance: GZ (r_m = 0.70 [CI 95% 0.342–0.878], $p < 0.001$), SKL (r_m = 0.73 [CI 95% 0.391–0.891], $p < 0.001$), and F% (r_m = -0.54 [CI 95% -0.802-0.093], p = 0.015). In the control condition, we did not find significant correlations between changes in peripheral blood lactate levels and attentional performance ($p > 0.05$).

Discussion

In this study, we tested whether SSREHIT as a time-efficient exercise modality can improve cognitive performance (i.e., attentional performance) in younger adults. We observed that SSREHIT compared to the control condition improved F% (a qualitative measure of precision and thoroughness) but did not lead to an increase in GZ (a quantitative measure of working speed), SKL (an objective measure of concentration) or the number of correctly remembered items in DSF and DSB (a quantitative measure of working memory performance).

The observed increase in attentional performance is consistent with the evidence provided in the literature [1, 2] whereas the unaltered working memory performance does not fully match with the findings of two previous meta-analyses that reported exercise-related improvements in this cognitive domain [1, 44]. However, in the literature, it has also been reported that acute physical exercises influence different cognitive domains differentially [1]. Our observation that the magnitude of the effect of acute physical exercises varies among different cognitive domains might be driven by specific mediators (e.g., study-design related factors such as the time of cognitive testing after exercise cessation) influencing the (positive) relationship between acute physical exercises and cognitive performance [2]. In this context, it can be hypothesized that SSREHIT might trigger neurobiological processes which lead to an improvement of attentional performance, but which do not directly benefit working memory performance. Given that the neurobiological mechanisms causing the exercise-induced improvement of cognitive performance are yet not fully understood [2], this explanation remains speculative and needs to be empirically proven (or rebutted) by future studies. However, even though the exact neurobiological mechanisms driving the exercise-related improvements of cognitive performance are yet not fully understood, it is undoubted that the cognitive enhancement relies on changes on different levels of analysis [2, 45]. For instance, there is evidence in the literature showing that changes on a functional level (e.g., changes in cognition-related brain activity patterns) [46, 47] or even on a molecular and cellular level (e.g., changes in the blood concentration of peripheral lactate or brain-derived neurotrophic factor) [30, 40, 48] are associated with the acute exercise-induced improvements in cognitive performance.

In line with previous studies [30, 40], our repeated-measure correlation analysis indicated that changes of peripheral blood lactate levels were linked to cognitive performance improvements in the exercise condition. Thus, our findings buttress the idea that peripherally muscle expressed lactate, which is able to cross the blood brain barrier via monocarboxylate transporters, is utilized as “fuel” for cognitive processes [30, 40, 49–57]. However, such a finding is not universal since negative associations between peripheral blood lactate levels and attentional performance [58], and executive functions [59] have been reported, too. The divergent findings between our study and the study of Coco and colleagues [58] could be, at least, partly explained by difference in study methodology (e.g., exercise regime [SIT protocol vs. maximal multistage discontinuous incremental cycling test, used cognitive test [d2 test vs. Attention and Concentration Task], and statistical analysis [repeated measures correlation vs. Pearson correlation]). Given the mixed evidence in the literature, unarguably more critical examinations of the complex relationships between exercise prescription (e.g., exercise intensity), blood lactate levels, and cognitive performance are needed to broaden our understanding of the exercise-cognition interaction [60].

In addition, we observed that the participants provided higher ratings on the FS (indicating more pleasure) in the control condition than in the SIT condition (i.e., after exercise and at post-test) while our ratings in the SSREHIT condition are comparable to other SSREHIT studies [14, 16, 17]. In this context, it should be noted that the mean rating on the FS immediately after exercise and before post-test remained positive (1.40 and 1.55 - correspond to “fairly good”) suggesting that SSREHIT does not induce strong displeasure. In addition, we did not observe time or condition effects regarding the motivation, ability to concentrate, and mental fatigue implying that these psychological variables did not have a strong influence on changes in our cognitive performance measures.

Conclusion

Our findings suggest that an acute bout of SSREHIT can improve specific aspects of attentional performance in younger adults and that these performance improvements are linked to an exercise-induced increase in peripheral blood lactate levels. Thus, our study adds initial evidence to the literature that time-efficient exercise modalities such as SSREHIT can provide a sufficient stimulus to increase the performance in specific cognitive domains (e.g., attention) and provides conforming evidence for a link between cognitive performance improvements and exercise-induced changes in peripheral blood lactate levels.

Further research which investigates the generalizability of our findings by studying the effect of SIT on cognitive performance in other cohorts (e.g., older adults) and by considering further neurobiological mechanisms underlying cognitive performance improvements (e.g., changes in functional brain activity patterns) is necessary to substantiate our observations.

Declarations

Acknowledgments

The authors thank all participants who devoted their free time to participate in this study.

Author Contributions Statement

Conceptualization: F.H. and T.B.; methodology: F.H. and T. B; software: F.H. and T.B.; validation: F.H.; formal analysis: F.H. and T.B.; investigation: F.H., T.B., and C.M.; resources: L.S.; data curation; F.H. and T.B.; writing—original draft: F.H.; writing—review and editing: F.H., T.B., N.G.M. and L.S.; visualization: F.H.; supervision: N.G.M, and L.S.; project administration: F.H. and T.B.; All authors have read and approved the final version. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest Statement

The authors declare no conflict of interest.

Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Tables

Table 1 *Overview of the general characteristics of the participants. BDI-II: Becks Depression Inventory-II (a score > 13 indicates depression [19]); BSA: Bewegungs- und Sportaktivitätsfragebogen (physical activity questionnaire); EHI: Edinburgh Handedness Inventory (a score of ≥ 50 indicates right-handedness [42]); kg: kilogram; PSQI: Pittsburgh Sleep Quality Index (a score of ≥ 6 indicates insomnia [43]); PA: physical activity; PE: physical exercise; PC: peak cadence; rpm: revolutions per minute; RPP: relative peak power (peak power divided by body mass); W: watt; [a]: please note that only data of 19 participants was analyzed as one participant did not complete the full questionnaire.*

General characteristics of the participants	*Mean ± Standard deviation*	*Exercise characteristics*	*Mean ± Standard deviation*
Education level [in years]	15.21 ± 1.69	1. Sprint RPP [in W/kg] / PC [rpm]	12.89 ± 3.12 / 115.37 ± 14.37
BDI-II [total score]	3.63 ± 2.52	2. Sprint RPP [in W/kg] / PC [rpm]	12.87 ± 2.91 / 115.11 ± 13.98
EHI [score]	89.21 ± 15.34	3. Sprint RPP [in W/kg] / PC [rpm]	12.69 ± 2.63 / 114.39 ± 12.92
BSA PA [in minutes per week]	371.91 ± 218.18	4. Sprint RPP [in W/kg] / PC [rpm]	12.34 ± 2.48 / 113.39 ± 12.41
BSA PE [in minutes per week]	292.30 ± 232.46	5. Sprint RPP [in W/kg] / PC [rpm]	11.95 ± 2.34 / 112.37 ± 12.00
PSQI [global score]	5.11 ± 2.61 [a]	6. Sprint RPP [in W/kg] / PC [rpm]	11.88 ± 2.21 / 112.00 ± 11.14

Table 2 *Means (standard deviation) of the cognitive performance. DSB: Digit Span Backward (higher score indicates better performance); DSF: Digit Span Forward (higher score indicates better performance); F%: number of all errors related to the total number of responses (lower score indicates better performance); GZ: total number of responses in the d2 test (higher score represents better performance); pts: points; SIT: Sprint Interval Training condition; SKL: standardized number of correct responses minus errors of commission (higher score indicates better performance); *: indicates a significant difference between conditions (p < 0.05).*

	SIT condition			*Control condition*		
	Pre-test	*Post-test*	*Delta score*	*Pre-test*	*Post-test*	*Delta score*
GZ [score]	558.05 (91.46)	608.63 (77.22)	49.74 (31.70)	563.58 (87.96)	596.12 (75.03)	32.58 (29.78)
SKL [score]	234.90 (48.27)	267.68 (41.55)	32.79 (21.92)	241.47 (48.62)	260.16 (39.52)	18.68 (16.60)
F% [score]	2.29 (2.34)	0.96 (1.05)	-1.33 (1.74) *	1.21 (1.16)	0.88 (0.99)	-0.33 (0.63) *
DSF [pts]	10.37 (1.64)	10.37 (1.89)	0.00 (1.89)	10.11 (1.66)	10.90 (1.80)	0.79 (1.36)
DSB [pts]	7.47 (2.09)	7.74 (2.02)	0.26 (1.52)	7.47 (2.17)	7.84 (2.12)	0.37 (1.46)

***Table 3** Means (standard deviation) of the RPE scale and Feeling scale. n.a.: not applicable; RPE: rating of perceived exertion; SIT: Sprint Interval Training; VAS: Visual Analogue Scale; significant differences between both conditions are marked in Control condition, *: indicates a significant difference between conditions at the same timepoint ($p < 0.05$); #: indicates a significant effect of time compared to Pre-test ($p < 0.05$), †: indicates a significant effect of time compared to After exercise ($p < 0.05$).*

	SIT condition			***Control condition***		
	Pre-test	*After exercise*	*Post-test*	*Pre-test*	*After exercise*	*Post-test*
RPE (Borg scale)	6.47 (1.31)	15.47 (1.98) #	9.79 (2.35) #,†	6.26 (0.65)	6.21 (0.63) *	6.21 (0.63) *
Feeling scale	2.21 (1.65)	1.42 (1.39)	1.56 (1.50)	2.90 (1.56)	2.79 (1.62) *	2.84 (1.34) *
VAS (Motivation) [in mm]	*72.21 (19.67)*	*n.a.*	*73.11 (16.16)*	*78.68 (11.53)*	*n.a.*	*79.58 (10.96)*
VAS (Concentration) [in mm]	*65.47 (23.21)*	*n.a.*	*65.68 (22.76)*	*70.53 (17.42)*	*n.a.*	*72.58 (16.71)*
VAS (Mental fatigue) [in mm]	*34.47 (22.85)*	*n.a.*	*35.58 (21.03)*	*30.53 (19.23)*	*n.a.*	*31.58 (19.51)*
Peripheral blood lactate concentration [in mmol/l]	1.04 (0.47)	8.08 (3.82) #	6.32 (3.60) #,†	1.13 (0.71)	0.83 (0.41)*	0.82 (0.41) *,#

Figures

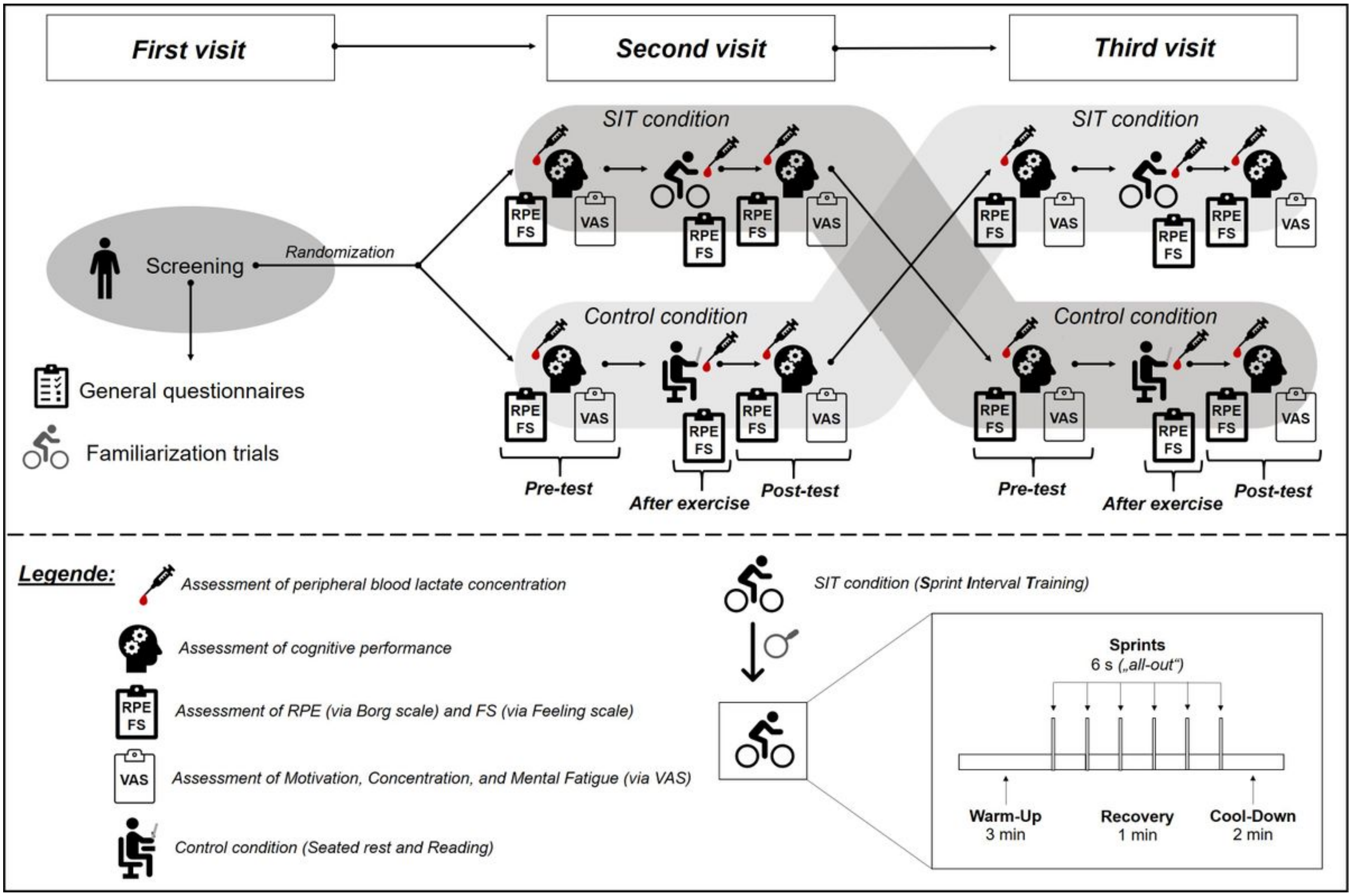

Figure 1

Schematic illustration of the study procedures. FS: Feeling scale; min.: minute(s); s: seconds; SIT: Sprint Interval Training; RPE: Rating of Perceived Exertion (via Borg scale); VAS: Visual Analogue Scale