Gejl, A. K., Bugge, A., Ernst, M. T., Tarp, J., Hillman, C. H., Have, M.,
Froberg, K., Andersen, L. B. (2018). The acute effects of short bouts of
exercise on inhibitory control in adolescents. *Mental Health and
Physical Activity, 15*, 34-39.

The acute effects of short bouts of exercise on inhibitory control in adolescents

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Abstract

Purpose: The main objective of the study was to investigate the effect of short bouts of aerobic exercise with various exercise intensities on inhibitory control using a flanker task in adolescents. *Methods:* The study used a randomized controlled crossover design with 52 adolescents (mean age 17.7 years). On separate days, participants completed four exercise bouts consisting of three 5-minute bouts at 50%, 65% and 80% of maximal oxygen uptake reserve (VO_2R) and one 30-minute bout at 65% of VO_2R along with a control condition consisting of 30 minutes of seated rest. Conditions were counterbalanced between participants and completed at ~4-day intervals. A modified Eriksen flanker task was conducted ~8 minutes after each condition. *Results:* Five minutes of aerobic exercise induced significantly higher response accuracy across stimuli type (i.e., congruent and incongruent) regardless of exercise intensity, and shorter reaction time (RT) was also observed following 80% of VO_2R compared to the rest condition. No selective effects on inhibitory control were observed. *Conclusion:* The results demonstrated that short bouts of aerobic exercise may be a time efficient approach for generally enhancing cognitive processes required during performance of tasks that modulate inhibitory control demands.

Keywords: aerobic exercise, cognitive performance, executive function, flanker task

Introduction

In recent years, it has become generally recognized that physical activity (PA) including aerobic exercise has the potential to improve cognition and academic achievement as well as brain structure and function (1). It is also well established that cognitive performance is temporarily enhanced via a single bout of aerobic exercise, but the results are dependent on the characteristics of the exercise intervention (2, 3). In particular, executive function (EF) appears to be especially susceptible to the effects of aerobic exercise (1-3). EFs refer to top-down, goal-directed cognitive processes (4) that comprise inhibition, working memory and cognitive flexibility (5); aspects of cognition that are central to success in everyday life including academic performance (6, 7), vocation (8) and social behavior (6, 9). Consistent findings suggest that acute bouts of moderate-intensity aerobic exercise for 20-40 minutes elicit improvements in EF (see (2, 3) for review).

To our knowledge, no studies have included short bouts of exercise of duration ≤ 5-min and it remains unclear whether such short bouts elicit the same positive effects on EF as those observed following 20-40 minutes of moderate-intensity exercise. To date, a few studies have reported positive effects of relatively short bouts (~10 minutes) of continuous low-to-moderate intensity aerobic exercise (10, 11) and high-intensity interval training (HIIT) (12-14) on EF. Kao and colleagues recently suggested that short bouts of HIIT (9-minutes) induced improvements in inhibitory control that were similar to those observed following 20-minutes of moderate-intensity aerobic exercise in young adults (14). However, the included type of exercise in the two conditions varied (i.e., continuous vs. interval) and thus, knowledge about the role of exercise duration and intensity cannot directly be derived from that study. Further, no studies have

included more than one short bout of exercise, and as such, the influence of exercise intensity during short bouts of exercise remains unclear.

While extensive research on the acute effects of exercise on EF has been performed in adults (e.g. (15, 16)), the literature on children (e.g. (17)) and adolescents (e.g. (18, 19), see (20) for review) is still limited. During adolescence, changes in neuronal architecture and function occur (21). In particular, brain areas involved in EF (e.g., the prefrontal cortex) have consistently been shown to undergo protracted development that continues throughout the adolescent years (21). Accordingly, EFs continue to develop during adolescence and into young adulthood (21-23). Consequently, the adolescent brain may be especially susceptible to interventions affecting EF (21). The acute effects of short bouts of exercise are particularly important to investigate in children and adolescents since these age groups are known to exhibit intermittent and unsustained patterns of physical activity (24). Further, a high level of aerobic fitness is not a prerequisite for transient improvements in EF, as both low- and high-fit participants appear to benefit to the same extent (3), with shorter bouts of exercise potentially easier to endure for unfit participants. As such, short bouts of exercise might be an applicable means for teachers and other educational practitioners to incorporate aerobic exercise into the classroom setting and across the school day for all students.

Consequently, the present study investigated the effects of short bouts (i.e., 5-minutes) of aerobic exercise with varying intensities (50%, 65% and 80% of oxygen uptake reserve (VO_2R)) on flanker task performance, a task used to measure of inhibitory control. Further, the influence of exercise intensity on task performance following short bouts of aerobic exercise was evaluated. Finally, a 30-minute bout of moderate-intensity aerobic exercise (65% of VO_2R) was included to examine the influence of exercise duration on task performance following moderate-intensity

aerobic exercise. Based on the literature, it was hypothesized that task performance would be better following all exercise bouts regardless of intensity and duration compared to a control condition consisting of seated rest. If positive results are found after short bouts of aerobic exercise, this would suggest that even brief bouts of exercise are efficacious for improving cognitive performance and may be an applicable tool to enhance scholastic performance.

Method

Participants

Participants were recruited from a local high school in Odense, Denmark. All students attending 11th and 12th grade according to the Danish school system (aged 16-19 years) were invited to participate (n=186). Exclusion criteria were 1) diagnoses of any neurological disease affecting cognitive function and 2) physical disabilities hindering participation in aerobic exercise. A total of 118 students were interested and 55 students agreed to participate. Three participants discontinued their participation before the completion of the five conditions. All included participants, and their legal guardians for participants under the age of 18 years, provided written informed consent. Participants received a small gift card as compensation. The study was approved by The Regional Scientific Ethical Committee for Southern Denmark (S-20130121).

Procedure

The study was conducted using a randomized controlled crossover design and included four exercise and one rest condition (control) conducted on five occasions separated by approximately

four days each. Specifically, participants completed randomized and counterbalanced orders of 30 minutes of seated rest, 30 minutes of 65% of oxygen uptake reserve (VO_2R) aerobic exercise, and three 5-minutes conditions of varying exercise intensities (50%, 65% and 80% of VO_2R). Exercise was completed on a cycle ergometer at approximately the same time of day. No other stimuli were provided during the rest or exercise conditions. Heart rate (HR) and rate of perceived exhaustion (RPE) were registered at the end of each condition. Participants were asked not to engage in moderate-to-hard physical activity 24 hours prior to each visit and to refrain from any physical activity on the day of testing. They were further asked to refrain from drinking alcohol at least 24 hours prior to their visits. Participants were transported by car from the school to the laboratory. Information about breakfast (yes/no), hours of sleep, alcohol intake (yes/no), smoking (yes/no) and engagement in moderate-to-vigorous physical activity (yes/no) during the last 24 hours were registered before completion of each exercise or rest condition.

Measurements

Cardiorespiratory fitness

One week prior to their first experimental visit, a cardiorespiratory fitness test was completed. The test was conducted on an electronically braked cycle ergometer (Monark Ergomedic 839, Vansbro, Sweden) with VO_2 measured directly using an AMIS 2001 Cardiopulmonary Function Test System (Innovision, Odense, Denmark). The test consisted of a five minutes warm-up with a load of 70 Watts for women and 110 Watts for men, followed by an additional 40 Watts every two minutes until exhaustion. The highest mean VO_2 uptake over 30 seconds in the last three-four minutes of the test was used as the VO_{2max} value. Participants were encouraged to maintain a

cadence between 70-80 RPM. The protocol has previously been applied in this age group (25).

Heart rate was registered every two minutes throughout the test and at the time of exhaustion

(Polar RS800CX, Polar Electro, Kempele, Finland). Maximal performance was achieved if a

minimum of two of the following three criteria were reached: 1) respiratory exchange ratio>1.10,

2) heart rate above 185 bpm, and/or 3) subjective evaluation/approval by test administrator.

If participants did not reach these criteria (n=2), VO_{2max} was estimated by extrapolating data on

heart rate and VO_2 and VO_{2max} was derived from an estimated maximal heart rate (208-0.7*age).

Target VO_2 (VO_2R_{target}) for each condition (50%, 65% and 80% of VO_2R) were calculated as

(VO_{2max}-oxygen uptake at rest (VO_{2rest}))*x+VO_{2rest}, where x=target intensity and VO_{2rest}=0.25 L

O_2/min (26). An individual equation from measured oxygen uptake (VO_2) and corresponding

Watts was constructed (VO_2=a*watt+b) (n=52). Following target Watt ($Watt_{target}$) for each

condition was retrieved from the individual equation. However, in two cases (females) $Watt_{target}$

was estimated as (VO_2R_{target}/0.91)*69watt (25) due to an invalid equation. Excluding participants

with estimated VO_{2max} or $Watt_{target}$ from the analyses did not change the results.

Anthropometrics

Body weight was measured to the nearest 0.1 kg and stature was measured to the nearest 0.5 cm

using standard equipment. Body mass index (BMI) was calculated by dividing body weight (kg)

with stature (m) squared.

Cognitive function

Participants completed a modified Eriksen flanker task (17, 27) 7 -9 minutes (average: 7.97

minutes) following the cessation of each condition (exercise or rest). The flanker task consisted

of an array of five arrows in which participants were instructed to respond as quickly and

accurately as possible to the direction of the centrally presented arrow (i.e., target) amid an array of flanking arrows (i.e., non-targets). Congruent trials were classified as target and flanking arrows pointing in the same direction (>>>>> or<<<<<) and incongruent trials (>><>> or <<><<) as flanking arrows pointing in the opposite direction relative to the target arrow. The test consisted of a familiarization block including 20 trials, two blocks of 100 trials comprised of 50 congruent trials and 50 incongruent trials presented in a randomized order. Blocks were separated by a 45 seconds break. Each trial was presented for 100 milliseconds (ms) with a response window of 1000 ms and an inter-stimuli interval varying between 1250, 1350, 1450 and 1550 ms (randomized). The outcomes were mean reaction time (RT) and response accuracy (percent of correct trials) for congruent and incongruent trials. No instances in which overall (congruent and incongruent) accuracy was <50% were observed. As such, no exclusions were made based on this criterion. In one case a participant did not follow the test instruction and this observation was excluded. The test was administered using E-prime software (Psychology Software Tools, Inc., Sharpsburg, Pennsylvania, USA). Familiarization to the modified flanker task was completed on the same day as the cardiorespiratory fitness test and anthropometric measurements to minimize a potential learning effect (28).

Statistics

Differences between sexes in physiologic, demographic and cognitive characteristics were analyzed using unpaired t-tests for normal distributed variables and Wilcoxon rank test for not-normal distributed variables.

Differences between experimental and control conditions were analyzed separately for task performance measures (RT and response accuracy) using multilevel mixed model with

individual as random effect to account for the cluster structure in the data. The interaction term congruency x condition was included to test whether exposure (exercise) has general or selective effects across stimuli requiring variable amount of inhibitory control (congruent and incongruent stimuli). If a significant interaction term was observed, performances (RT or response accuracy) on congruent and incongruent trials were analyzed separately. If no interaction between congruency and condition was observed this was reported. If a main effect for condition was observed, the interaction term 'congruency x condition' was removed and the analyses were conducted with accuracy and RT collapsed across stimuli type (congruent and incongruent), including "condition" as independent variable and adjusting for "congruency". Post hoc pairwise comparisons were conducted to test for difference between all 5-minutes conditions (exercise intensity) and between five minutes of aerobic exercise at 65% of VO_2R and 30 minutes of aerobic exercise at 65% of VO_2R (exercise duration). The variables breakfast (yes/no), hours of sleep, alcohol intake (yes/no), smoking (yes/no) and engagement in moderate-to-vigorous physical activity (yes/no) were equally distributed across the conditions and therefore, they were not included as covariate in any of the analyses. Mixed model analysis has the ability to provide an unbiased estimate given missing data (assuming data is missing at random conditional on variables included in the model) (29) and thus, all participants were included in all analyses.

All analyses were performed using Stata 14.0 (StataCorp, College Station, Texas, USA). The level of statistical significance was set to $p < 0.05$, except in regard to interaction terms; here the level of statistical significance was set to $p < 0.1$, as suggested by Twisk et al. (30).

Results

Participant Characteristics

Participant characteristics are shown in table 1. Compared to girls, boys had higher body weight, height and VO_{2max} (all p<0.001). No differences were found for age or BMI (all p>0.05). Furthermore, no differences between boys and girls were observed for flanker task outcomes after the rest condition (all p>0.05, data not shown).

Table 1 here

Participation rate, HR and RPE

Participation rate for each condition varied from 88.5% to 96.2%. Participants with data obtained from all experimental conditions (n=35), four experimental conditions (n=13) or three conditions (n=4) were included in the analyses. Means and standard deviations (SD) for Watts as well as HR and RPE registered at the end of each condition are presented in table 2.

Table 2 here

Flanker task performance

No interaction between congruency and condition was found for response accuracy or RT (p=.45 and p=.97, respectively). Despite a lack of interaction between congruency and condition, main effects were observed for both factors in the analysis of accuracy (congruency: p<.0001, condition: p=.0366) as well as RT (congruency: p<.0001, condition: p=.0073). As such, lower response accuracy (congruent as reference, β=-8.49 (95% CI -9.23, -7.75), p<.001) and longer

RT (congruent as reference, β=48.81 (95% CI 45.44, 52.17), p<.001) were observed for incongruent stimuli compared to congruent stimuli regardless of condition.

Comparison of all exercise conditions and the rest condition

To decompose the condition effect, we collapsed congruent and incongruent trials to examine differences among the various conditions. Compared to the rest condition, higher response accuracy was observed following five minutes of aerobic exercise at 50% of VO_2R (rest as reference, β=1.18 (95% CI .008, 2.34), p=.049), 65% of VO_2R (rest as reference, β=1.85 (95% CI .68, 3.02), p=.002) and at 80% of VO_2R (rest as reference, β=1.24 (95% CI .052, 2.43), p=.041) (figure 1a). No difference was observed for response accuracy between 30 minutes of aerobic exercise at 65% of VO_2R and the rest condition (β=.95 (95% CI -.230, 2.13), p=.114).

Five minutes of aerobic exercise at 80% of VO_2R demonstrated shorter RT compared to the rest condition (rest as reference, β= -7.17 (95% CI -12.54, -1.80), p=.009) (figure 1b). No differences were found for RT between the rest condition and remaining exercise conditions; five minutes at 50% of VO_2R (rest as reference, β=.002 (95% CI -5.28, 5.28), p=.999), five minutes at 65% of VO_2R (rest as reference, β=1.55 (95% CI -3.74, 6.85), p=.566) or 30 minutes at 65% of VO_2R (rest as reference, β=-4.59 (95% CI -9.93, .74), p=.092) .

Figure 1 here

Post hoc comparisons revealed no difference in accuracy across stimuli type between five minutes at 50% and 65% of VO_2R (5 min 50% as reference, β=.673 (95% CI -.513, 1.86), p=.266), 50% and 80% of VO_2R (5 min 50% as reference, β=.064 (95% CI -1.14, 1.27), p=.917) or 65% and 80% of VO_2R (5 min 65% as reference, β=-.609 (95% CI -1.81, .593), p=.320). However, five minutes of aerobic exercise at 80% of VO_2R elicited significantly shorter RT

across stimuli type compared to 50% of VO$_2$R (5 min 50% as reference, β=-7.17 (95% CI -12.61, -1.73), p=.010) and 65% (5 min 65% as reference, β=-8.72 (95% CI -14.16, -3.28), p=.002). No difference in RT across stimuli type was observed between five minutes of aerobic exercise at 50% and 65% of VO$_2$R (5 min 50% as reference, β=1.55 (95% CI -3.82, 6.91), p=.571). Finally, no difference in accuracy across stimuli type was observed between five minutes and 30 minutes of aerobic exercise at 65% of VO$_2$R (5 min 65% as reference, β=-.899 (95% CI -2.09, .292), p=.139) . However, shorter RT across stimuli type was found following 30 minutes compared to five minutes (5 min 65% as reference, β=-6.14 (95% CI -11.53, -.76), p=.025).

Discussion

Our results indicate greater response accuracy following all 5-minute conditions (50%, 65% and 80% of VO$_2$R) compared to the 30-minute rest condition when collapsing accuracy across stimuli type (i.e., congruent and incongruent). Further, a faster response speed (i.e., shorter RT) was observed following five minutes of aerobic exercise at 80% of VO$_2$R compared to the rest condition when collapsing RT across stimuli type. No selective effects of congruency (i.e., congruent or incongruent) were observed across the rest and exercise conditions, indicating no specific effects on inhibitory control. As such, our findings suggest that short bouts of aerobic exercise benefit cognitive tasks requiring variable amounts of inhibitory control.

To date, few studies have examined the acute effect of aerobic exercise on cognition in adolescents (18, 19, 31-33). In agreement with our results, most studies report a facilitative effect of single bouts of aerobic exercise on cognitive performance in adolescents (18, 19, 31, 33). The present study is the first to suggest that five minutes of aerobic exercise is sufficient to enhance

cognitive performance in adolescents. However, unlike other studies, including relatively short bouts of aerobic exercise (~10 minutes) in other age groups (10-14), we did not observe a specific effect for task conditions that increased inhibitory control demands. These discrepancies may be due to differences in exercise durations, cognitive tests, and the age of the study participants. Existing studies in adolescent have mainly investigated the effect of bouts lasting 20-30 minutes, and to our knowledge, no studies in this age group have included shorter or longer bouts. Browne and colleagues observed improved Stroop performance, a different task that modulates executive control demands, after 30 minutes of aerobic exercise at 65-75% of heart rate reserve (HRR) relative to a control condition of 30 minutes of rest in adolescents (n=20, mean age= 13.0±1.8 years) (33). Unlike the present study, Browne and colleagues reported that a 30-minute aerobic exercise bout induced specific, beneficial effects on inhibitory control. Contrary to those findings, Stroth and colleagues reported no effect of 20 minutes of aerobic exercise at 60% of HR_{max} on flanker task performance in adolescents (n=55, mean age=14.2±0.5 years) (32). It may be argued, that the design of the flanker task applied in the Stroth et al. study greatly enhanced task complexity compared to more traditional versions of the flanker task, and thus, the lack of observed results may be attributable to the test being too complicated for the young participants. However, the results by Stroth et al. are in agreement with our findings, showing no significant effect of 30 minutes of aerobic exercise at 65% of VO_2R on flanker task performance in adolescents. Supporting these findings, a recent meta-analysis reported no overall effect of moderate intensity aerobic exercise (i.e., 55-70% of HR_{max} or 40-60% of HRR) on executive function in adolescents (3). The inconsistent findings in adolescents may, at least partly be explained by methodological discrepancies (e.g. differences in exercise intensities).

Exercise intensity

Our results suggest that an exercise intensity of 80% of VO_2R may induce the largest effects on flanker task performance after short bouts of aerobic exercise. Contrary, most studies in other age groups including multiple bouts of aerobic exercise with longer durations (20-40 min) and varying exercise intensities (16, 34, 35) demonstrate that bouts of continuous moderate-intensity exercise elicit the largest improvements in task performance compared to lower and higher intensities. Consonant with these findings, a recent meta-analysis by McMorris and Hale proposed that continuous moderate-intensity exercise (40-79% of maximum power output) was related to greater task performance (i.e., RT), particularly for EF tasks, compared to both light and high intensities (36). This inverted U-shaped relationship between exercise intensity and cognitive performance may be explained by increased arousal during moderate intensity exercise, possibly due to increased concentrations of dopamine and norepinephrine in the brain, resulting in a faster speed of processing (37-39). However, results from a large number of studies do not support this inverted U-shaped relationship, and accordingly also high intensity exercise has been shown to elicit beneficial effects on cognitive performance (12, 14, 40, 41). As such, In line with our results, several more recent studies have reported significant effect of intermittent high-intensity exercise (e.g. HIIT) (12, 14, 40, 41). Findings from these studies further suggest, that not only the intensity, but also how the exercise intervention is delivered (i.e., continuous vs. interval) may interact to exert their influence on cognitive outcomes. Finally, discrepancies between studies investigating the influence of exercise intensity may be caused by differences in the duration of the included exercise bouts and inconsistencies in the age groups studied.

Exercise duration

Only studies in adults have previously compared exercise bouts of various exercise durations (16, 42). For examples, Chang and colleagues investigated the acute effects of aerobic exercise on Stroop performance including warm-up, cool-down, and cycling at moderate intensity (approximately 65% of HRR) for 10, 20, or 45 minutes (n=26, mean age= 20.77 ± 0.91) (42). Chang and colleagues reported that 20 minutes of aerobic exercise at 65% of HRR induced shorter RT and higher accuracy for both congruent and incongruent conditions of a Stroop task compared to seated rest. In agreement with the present study, no selective effects across stimuli type (i.e., congruent and incongruent) were reported, indicating that 20 minutes of moderate-intensity exercise benefits cognitive tasks requiring variable amounts of inhibitory control in young adults. Only negligible benefits were achieved from 10 minutes or 40 minutes of aerobic exercise, suggesting a curvilinear relation between exercise duration and task performance. In agreement, we observed significantly shorter RT across stimuli type following 30 minutes compared to five minutes of aerobic exercise at 65% of VO$_2$R. It should be noted, however, that no difference between the 30-minute condition and the rest condition was demonstrated in the present study (only a trend). Moreover, we observed significantly better accuracy across stimuli type following all 5-minute conditions, which was not found following 30 minutes of aerobic exercise at 65% of VO$_2$R. As such, it may be speculated that short and long bouts of aerobic exercise have differential effects on measures of task performance (i.e., accuracy and RT) in adolescents, but not in young adults. In addition, exercise volume may also be an important factor moderating the effect of aerobic exercise on RT, since a shorter RT was observed following five minutes of aerobic exercise at 80% of VO$_2$R.

Strength and limitations

The current study was conducted using a randomized crossover design, which is optimal for investigating this topic. A major strength of the crossover design is that the influence of genetic, hormonal and a number of behavioral factors are strongly minimized because individuals act as their own control. The study was designed to examine the influence of exercise intensity and duration in a standardized setting and the exercise conditions therefore do not resemble the normal intermittent and unsustained patterns of physical activity observed in young people (24). Despite a strong design, it is important to be aware of the limitations of the present study. First, a modified flanker task was used as a measure of cognitive performance, and thus only one specific aspect of executive function was investigated. As such, the effects of shorts bouts of aerobic exercise on other aspects of executive function and cognition more broadly in adolescents are still unknown. Further, only one post-measurement sample was included and therefore, we are not able to determine whether the observed effects are due to an enhancement following exercise or a decrement following 30 minutes of seated rest, and further whether the observed effects were sustained over time. A second limitation of the study is the relatively small sample size, but with this number of participants we were able to detect an effect size of 0.16 SD with a power of 80%.

Conclusion

Collectively, short bouts of aerobic exercise may be a time efficient approach for enhancing cognitive performance in adolescent and an applicable tool to transiently enhance students' academic performance during the school day. However, no selective effects on inhibitory control

were observed for any of the included conditions, suggesting that short bouts of aerobic exercise more broadly benefit cognitive processes requiring variable amounts of inhibitory control. As such, our results do not suggest that short bouts of aerobic exercise induce improvements in EF comparable to the improvements previously observed following moderate-intensity exercise of longer durations (20-40 min) in various age groups.

Perspectives

The present study adds to the current knowledge regarding the acute effects of aerobic exercise on cognitive performance in adolescents, with important information about potential differences in the influence of exercise intensity and duration. However, to gain a better understanding of the characteristics (e.g. exercise intensity, duration, type, timing etc.) of exercise interventions necessary for improvements in cognitive outcomes, additional high-quality studies in this age-group are needed (20). In particular, future research should focus on the effects of exercise duration and intensity across different age-groups, and future studies must clarify the duration in which acute effects are sustained. Such information will enable age-specific recommendations in regard to the implementation of aerobic exercise to transiently improve cognition in the school setting. An increasing focus has recently been on the development of physical activity interventions for improving academic performance in young people (see (1) for review). However, it remains to be elucidated to what extend the acute effects of aerobic exercise will translate into improved academic performance over time in an ecological setting.

Conflict of interest: All authors report no potential conflict of interest. We declare that the

results of the study are presented clearly, honestly, and without fabrication, falsification, or

inappropriate data manipulation.

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Table 1. Characteristics of participants. Mean (SD)

	All subjects	Male	Female	p-
	(n=52)	*(n=23)*	*(n=29)*	values
Age (years)	17.7 (1.0)	17.7 (1.0)	17.8 (1.0)	>.05
Body weight (kg)	63.4 (9.8)	71.0 (8.2)	57.5 (6.1)	<.001
Height (cm)	172.6 (11.5)	182.6 (7.1)	164.7 (7.4)	<.001
BMI (kg/m^2)	21.3 (2.1)	21.3 (2.1)	21.2 (2.2)	>.05
HR$_{max}$ (bpm)	190.8 (6.9)	190.1 (7.9)	191.4 (6.2)	>.05
VO$_{2max}$ (L/min)	2.9 (.8)	3.7 (.4)	2.3 (.3)	<.001

BMI=body mass index, HR$_{max}$=maximal heart rate, VO$_{2max}$=maximal oxygen uptake

Table 2. Target Watt, heart rate (HR) and rate of perceived exhaustion (RPE) for each condition. Mean (SD)

	Rest	5 min 50% VO₂R	5 min 65% VO₂R	5 min 80% VO₂R	30 min 65% VO₂R
	(n=50)	*(n=49)*	*(n=48)*	*(n=46)*	*(n=47)*
HR (bpm)	71.5 (11.0)	137.9 (14.6)	161.8 (12.3)	176.2 (9.1)	175.9 (11.5)
RPE (Borg scale)	6.1 (.34)	9.5 (2.2)	12.3 (2.2)	14.5 (1.2)	14.3 (1.6)
Watt	-	114.1 (28.0)	153.9 (38.1)	197.4 (44.7)	155.5 (37.5)

HR=heart rate, RPE=rate of perceived exhaustion, Borg Scale
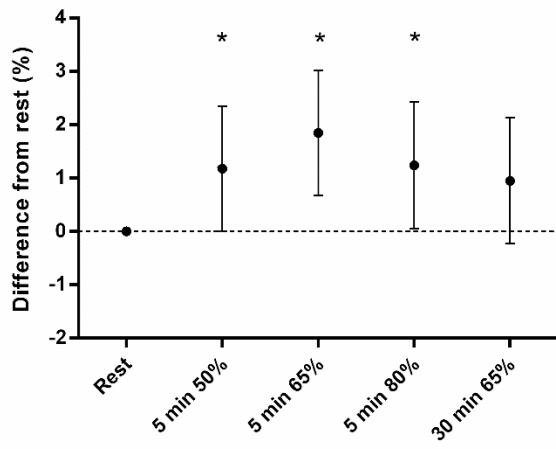
Figure 1 Difference in response accuracy (A) and reaction time (B) from rest (rest as reference).

Figure 1 legend: For accuracy a higher value is preferable and for reaction time a smaller value is preferable. *p≤0.05, compared to 30 minutes of seated rest.

Figure 2 Difference in accuracy interference score (A) and reaction time interference score (B) from rest (rest as reference).

Figure 2 legend: A lower value is preferable in both cases. *p≤0.05 compared to 30 minutes of seated rest.