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Intermittent Maximal Exercise Improves Attentional Performance Only in Physically Active Students

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Background and Aims. Regular physical activity participation seems to be linked to brain metabolism and to be one factor responsible for different effects of high intensity exercise on cognition. Due to this, we investigated the effect of an intermittent maximal exercise intervention on a neuropsychological test requiring sustained and selective attention in a group of low and high physically active subjects.

Method. Forty six healthy students (age: M = 23.11, SD = 2.60 years) performed in a cross-over design an intermittent incremental exercise until they reached their maximal heart rate (HR Max; intervention condition) or rested for the same duration (control condition) followed by the administration of the d2-test.

Results. A significant interaction between physical activity participation level and exercise effect on cognitive performance emerged, with only the more physically active participants improving the performance in the cognitive test after the intervention.

Conclusion. These data extend the current knowledge base by showing that a higher participation rate in physical activity may lead to neurobiological adaptations that facilitate selected cognitive processes (i.e., attention) after high exercise intensities. © 2012 IMSS. Published by Elsevier Inc.

Key Words: Intermittent exercise, Cognitive processes, Attention, Physical activity.

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Introduction

Research on the effects of acute exercise on cognitive performance has shown that it can positively influence cognition in adults (1,2) and adolescents (3). Effects, however, differ according to the characteristics of the exercise intervention (i.e., intensity, duration, and type) and of the cognitive test utilized (e.g., its typology and the time of administration) (References 1 and 2 for review). Moreover, subjects' characteristics such as gender, age, fitness status and level of physical activity participation (4−8) play a fundamental role in the determination of the effects of exercise on cognitive performance.

The assumption that there is an increase in arousal (i.e., neurophysiological activation) with increasing exercise intensity led some authors (9) to propose that exercise can affect cognitive performance in an inverted-U shape with better performance corresponding to submaximal exercise intensity and poorer performance occurring during or after minimal and maximal exercise. Accordingly, when focusing on a particular class of electroencephalogram (EEG) activity

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known as event-related brain potentials (ERPs, e.g., the P3 amplitude), Kamijo and colleagues (10) reported higher P3 amplitudes after moderate exercise and lower P3 amplitudes following high-intensity exercise, resembling an inverted U-shaped curve. Considering that the P3 amplitude reflects basic aspects of cognitive processing such as attention allocation (11), the lower values induced by maximum intensity exercise may be associated with reduced cognitive processing in the central nervous system and consequently with an attenuated amount of attentional resources devoted to the cognitive test administered (10,12).

However, other studies that have analyzed the effect of acute exercise on cognition at the behavioral level (i.e., neuropsychological tasks) provide evidence that cognitive performance was not always negatively affected by maximal intensity exercise sessions (13). In some cases it was even improved (14,15), weakening the support for an inverted-U effect of exercise on cognition. Such discrepancies may be related to the fact that the characteristics of the subjects tested, such as their fitness status and their participation level in sports and physical activities, have rarely been taken into consideration when analyzing the effects of acute exercise on cognition (16).

In a cross-sectional study with young adults, Brisswalter and coworkers (7) investigated the influence of different exercise intensities on reaction time and demonstrated that well-trained athletes were more capable of maintaining their cognitive skills during fatiguing exercise (80% VO_{2max}) than their less-fit counterparts. Brisswalter and colleagues concluded that high-intensity exercise leads to maximum arousal in unfit subjects and may be attributable to their decreased cognitive performance, whereas in more fit subjects, due to a training effect, arousal remained moderate and allowed a better outcome in the mental task. In this regard, in a longitudinal study, Zervas and co-workers (6) observed that young subjects who participated in a 6-month physical activity program revealed similar cognitive performance after a high-intensity acute exercise session (20 min of treadmill running above individual anaerobic threshold) than those who did not participate in the training program. However, the percentage of the improvement pre/postexercise was greater for the trained group (11.42 vs. 5.52%), suggesting a possible interaction between physical activity participation and acute exercise. The missing significance in this interation reveals the need for additional research in this area.

The above-mentioned findings seem to indicate that when a high-intensity acute exercise session is performed for the same duration and at the same relative individual intensity (e.g., % of VO_{2max}), better-fit participants or participants with a higher physical activity level will show better cognitive outcome than their less-fit counterparts. Physical activity level seems to be an important variable that may affect cognitive performance following intense acute exercise. Yet, there appear to be inconsistencies in the literature to utilize an exercise intensity that is properly controlled according to individual fitness level and exercise session duration (1). As a result, the design of this study will focus on the achievement of the maximal heart rate (HR max; ± 10 beats per minute; bpm) after the intermittent maximal exercise (IME) during a fixed amount of time for all the subjects. With the IME we chose a properly controlled exercise intensity to provide an exercise intervention with a similar physiological outcome regardless of the individuals' physical fitness level.

This study explored to better understand the influence of IME on the attentional performance of students in regard to physical activity status. The aim of our study was, therefore, to analyze the effect of IME (vs. resting controls) on a cognitive task requiring sustained and selective attention. Additionally, we focused on how such effect could be moderated by the physical activity participation level of the participants. Based on the literature, we hypothesized that only the participants with a higher physical activity level would improve their cognitive output even after IME. Their neurobiological status derived from regular physical activity would allow them to reach an optimal arousal level, which may be related to more efficient brain functionality.

By confirming our hypothesis that short bouts of IME have differential effects on attention with regard to the physical activity participation levels, we would further clarify on the task-specificity of the exercise-induced modification and how it is also influenced by the interactive effects between acute and chronic exercise (characterized by the physical activity status). Moreover, such a finding would provide additional information how to tailor acute exercise interventions as nonpharmacological cognitive enhancers (17).

Subjects and Methods

Participants

Fifty one healthy university students between 19 and 29 years of age participated in this study. Participants signed an informed consent form approved by the local board of the Humboldt Universität zu Berlin, Germany. Written informed consent was obtained before inclusion from all participants. Exclusion criteria for study participation were dyslexia, body mass index (BMI) >25 because excess body fat has been linked to cognitive deficits in young students (18), diagnosed mental or physical impairments, and a history of psychoactive substances use (screened by a previous anamnesis). Two participants were excluded from data analysis due to a performance incongruent to the instructions of the d2-test. In order to assure that the subjects reach the same relative workload during exercise, another exclusion criterion was the achievement of a minimum heart rate (HR) of 220 bpm minus age (±10 bpm) when conducting the exercise intervention (cf. Reference19). Two subjects from the high-activity group (n = 23, 10 males, 13 females, age: M = 23.22, SD = 2.58)

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and one subject from the low-activity group ($n = 23$, 16 males, 7 females, age: M = 23.00, SD = 2.68) did not reach their HR max (±10 bpm) at the end of the exercise intervention and therefore were excluded from further analysis.

The remaining sample (26 males and 20 females) had a mean age of M = 23.11 (SD = 2.60) (male: M = 23.08, SD = 2.70; female: M = 23.15, SD = 2.54). The subjects were asked to refrain from alcohol and caffeine consumption and exercise participation the night before and on the testing day.

Cognitive Testing

Neuropsychological performance was assessed in the areas of sustained and selective attention using the d2-test (20) in the paper and pencil version. The d2-test is a letter-cancellation test consisting of 14 lines of 47 randomly mixed letters each (either d or p). Subjects were instructed to mark, within 20 sec for each line and within a string of letters (“d” and “p”), only the letter “d” with two dashes that can be either both above, both below, or above and below the letter. After 20 sec there was an acoustic signal that instructed the subjects to continue with the next line. The test has a total duration of 4.67 min. The internal test-retest reliability of the d2-test has been proven to be extraordinarily high (0.95−0.98) for all parameters (20). Its criterion, construct, and predictive validity have been documented, and test values have been shown to be stable over an extended period of up to 23 months after initial testing (20). Its duration and difficulty allow analysis of the participants’ ability to achieve, shift, and maintain attention (elements of sustained attention) and to focus on and select target stimuli (elements of selective attention) (21). According to Miller and Cohen (22), the selective attention mechanism is a special case of behavioral inhibition, a component of the executive functioning.

Determination of Physical Activity Level

Physical activity level was assessed using a German one-item questionnaire (23) (“How many times a week do you engage in moderate or vigorous physical activity long enough to work up a sweat?”). The outcome of the questionnaire has been shown to correlate with the physical fitness level of the subjects interviewed (24). This type of questionnaire is well accepted for fast physical activity assessment (24) and is used in large panel studies (25). Physical activity level can also be used as an indirect marker for physical fitness because regular participation in (moderate) physical activity at least three times each week has been shown to result in an increase in cardiovascular fitness (26).

Due to the assumption that acute exercise helps to improve cognitive performance of participants with a higher level of physical activity participation, we divided the participants into low- and high-physically active subjects (low-activity group: physical activity participation <3 times per week; high-activity group: physical activity participation 3x per week or more often according to the recommendations of the American College of Sports Medicine (26).

Treatment

Intermittent Maximal Exercise (IME). To assess maximum exercise levels (220 bpm minus age) during exercise intervention, heart rate was measured using a heart rate monitor (HRM RS400, Polar, Kempele, Finland). Subjects performed 20-m sprints for 3 min. Participants were asked to continuously increase their HR and to reach the individual HR max (±10 bpm) after 3 min. Such condition was repeated twice separated by a 2-min break maintained in standing position. During running the remaining time was communicated to the subjects every 15 sec, whereas in the last 30 sec of the sprint time was called every 5 sec and the subject was verbally encouraged to run at individual maximal speed. During the week before the testing day, students were introduced to sprinting and instructed how to reach their HR max gradually and precisely after 3 min. This form of exercise has been shown to create an anaerobic condition with lactate levels >10 mmol/l (15).

Control condition. During the control condition, the subjects remained sedentary in a seated position for the duration of the exercise intervention (8 min).

Procedure. Using a cross-over design, every subject participated in the two conditions (IME and the control condition) on different days, spaced 1 week apart at the same time of the day. To further control for learning effects, the sequence of the two conditions was randomized across subjects; 25 students performed the exercise intervention at t1 (group 1) and 21 at t2 (group 2). The measurements of the d2-tests took place shortly after the exercise intervention or the control condition, respectively, and were performed in a quiet room. In the week before the first testing day, students were introduced to the test procedure and were asked to complete one full data sheet of the d2-test to minimize the learning effects within in the study, which may occur because of test familiarization.

Data Analysis

D2-test. The total number of worked symbols within the d2-test (GZ), the standardized number of correct responses minus errors of confusion (SKL), and the number of all errors (F%; errors of confusion and errors of elimination) related to GZ were calculated and used as parameters for sustained and selective attention. The GZ value is a quantitative measure of the working speed, and the F% value is a measure of precision and thoroughness. Both values can be affected by the strategy of execution chosen by the subjects. The SKL value instead is interpreted as independent from adulteration, and thus an objective measure to reflect attention span (20). Raw data of GZ, SKL and F% were transformed into age-adjusted standardized scores to provide a better comparison with studies using other age groups. A value of 100 represents the age-adjusted mean performance regarding this parameter. Standardized values <100 represent poor performance, and values >100 represent better performance as the normative sample. Standardized scores between 70 and 130 are possible.

Statistical Analysis

First, to control for the cross-over design, a 2 (condition: control condition, exercise intervention) x 2 (group: exercise intervention at t1, exercise intervention at t2) mixed factor analysis of variance (ANOVA) was used to test for differences between control condition and exercise intervention (within) and differences between groups (group 1: exercise intervention at t1, group 2: exercise intervention at t2) (between). Analyses were conducted separately for the outcome variables GZ, F%, and SKL and controlled for gender. Greenhouse Geyser adjustment was reported when the sphericity assumption was violated. Post hoc contrasts were used to determine effects within the two groups.

Second, to account for the effect of physical activity level, we further conducted 2 (condition: control condition, exercise intervention) x 2 (activity level: low activity, high activity) analysis of variance with condition (control condition, exercise intervention) as within subject factor, and physical activity level (low, high physically active) as between factor. Analyses were controlled for group (exercise intervention at t1, exercise intervention at t2) and gender. Again, analyses were conducted separately for the outcome variables GZ, F%, and SKL.

Results

For the standardized d2 performance value (SKL), results revealed a condition (control condition, intervention) effect [$F(1,43) = 13.38$, $p = .001$, $\eta^2 = .24$], no group effect $F(1,43) = 0.01$, $p = 0.915$], but a significant group x condition interaction [$F(1,43) = 4.90$, $p = .032$, $\eta^2 = .102$], indicating a different performance change from t1 to t2 for both groups (group 1: exercise intervention at t1, group 2: exercise intervention at t2). Further, we found a significant condition x gender interaction [$F(1,43) = 5.36$, $p = .025$, $\eta^2 = .111$] indicating a higher intervention effect for males. Whereas group 1 (exercise intervention at t1) did not significantly improve performance due to the exercise intervention [$F(1,43) = 0.23$, $p = .635$], group 2 (exercise intervention at t2) revealed a significant performance change with higher values after the exercise intervention [$F(1,43) = 7.09$, $p = .011$, $\eta^2 = .141$] (cf. Table 1 for descriptives). These results were confirmed for the total number of responses (GZ) and the percentage of errors (F%).

When data were analyzed with regard to the physical activity level (and controlled for group and gender), intervention effects became clear: we found a significant physical activity effect [$F(1,42) = 10.27$, $p = .003$, $\eta^2 = .197$], a significant condition x physical activity interaction [$F(1,42) = 6.70$, $p = .013$, $\eta^2 = .138$], and a significant condition x group (group 1: exercise intervention at t1, group 2: exercise intervention at t2) interaction [$F(1,42) = 5.07$, $p = .030$, $\eta^2 = .108$], but no condition by gender interaction (cf. Table 1and 2). Follow-up tests revealed a significant condition effect for high-active participants [$F(1,42) = 8.86$, $p = .005$, $\eta^2 = .174$], but not for low-active participants [$F(1,43) = 0.46$, $p = .013$] (cf. Figure 1). When controlled for group (exercise intervention at t1 or t2, respectively), high-active participants profited from the intervention, whereas low-active participants revealed a test repetition effect rather than an interventional effect. These results were also shown for GZ (cf. Table 2). For F%, results were somewhat different, showing no significant results. Follow-up tests, however, revealed (as shown for GZ and SKL) a significant condition effect for physically high-active participants ($p < 0.05$) but not for low-active participants (cf. Table 2).

Table 1. Standardized mean and SD for control condition (control) and intermittent maximal exercise intervention (intervention) (SKL, GZ, and F%)[a]

	Control		Intervention		Group 1 Control		Group 1 Intervention		Group 2 Control		Group 2 Intervention	
Measure	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
SKL	109.15	9.87	111.04	11.53	111.68	10.10	109.80	11.45	106.14	8.89	112.52	11.73
GZ	106.54	7.99	108.09	9.87	107.84	8.23	106.12	10.41	105.00	7.62	110.43	8.85
F%	101.35	10.33	102.48	10.96	103.20	10.94	102.12	11.34	99.14	9.34	102.91	10.75
Active												
GZ	107.48	8.22	112.48	8.29	109.18	9.21	112.73	8.11	105.92	7.24	112.25	8.80
F%	101.87	9.31	105.65	9.23	100.46	11.20	104.36	10.40	103.17	7.45	106.83	8.29
Non Active												
SKL	107.65	9.73	105.39	9.68	110.93	9.27	104.29	8.21	102.56	8.53	107.11	11.94
GZ	105.61	7.83	103.70	9.49	106.79	7.56	100.93	9.14	103.78	8.36	108.00	8.82
F%	100.83	11.45	99.30	11.81	105.36	10.62	100.36	12.11	93.78	9.23	97.67	11.84

[a]For the whole sample and divided by group (group 1: intervention at t1; group 2: intervention at t2) and physical activity level (active, nonactive).

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Table 2. Results of the mixed factor ANOVA with the main effects test (control condition, intervention) and physical activity (active, nonactive)[a]

	Condition				Physical activity				Condition x physical activity				Condition x group			
Measure	F	df	P	η^2	F	df	p	η^2	F	df	p	η^2	F	df	P	η^2
SKL	0.13	1	0.72		10.27	1	0.01*	0.20	6.70	1	0.01*	0.14	5.07	1	0.03*	0.11
GZ	0.04	1	0.84		7.69	1	.01*	.16	5.37	1	.03*	.11	4.63	1	.04*	.10
F%	0.34	1	.57		2.81	1	.10		3.75	1	.06		2.73	1	.11	

	Condition x Gender			
Measure	F	df	p	η^2
SKL	3.21	1	.08	
GZ	2.46	1	.13	
F%	0.00	1	1.00	

[a]Controlled for group (Group 1: intervention at t1, Group 2: intervention at t2) and gender for the standardized total number of worked symbols within the d2-test (GZ); the standardized number of correct responses minus errors of confusion (SKL), and the number of all errors related GZ (F%).
*Statistically significant ($p < 0.05$).

Discussion

The aim of this study was to investigate the effects of an IME intervention on a task assessing sustained and selective attention performance. Using a cross-over design, university students participated in an IME session or rested for the same duration and afterwards performed the d2-test. Overall, results did not identify a significant effect of IME on cognitive performance; however, there was an interaction between chronic (physical activity participation levels) and acute exercise, with only the high-activity group profiting from IME.

This beneficial effect of the IME intervention is not consistent with some previous investigations pointing to lower attentional resources following high-intensity exercise (10,12). Based upon these studies, there should have been a negative influence of the exercise session utilized in this study on cognitive performance of the subjects. There are, however, also hints supporting our finding that cognitive performance was not always negatively affected following maximal intensity exercise sessions but in some cases even improved (14,15). Although differences in the type and duration of exercise and in the features of the cognitive tests administered are well-known factors that may have contributed to the different results (1,2), another explanation is that these earlier studies have not taken into account individual differences in physical activity participation (16). Our results did not show an effect of the physical activity status on cognitive performance at the resting conditions. However, when the participant sample was divided into low and high physically active participants, findings revealed that only participants with high physical activity levels profited from the intervention and were able to significantly increase their attention after the IME. These data align with the finding that well-trained athletes were more capable of maintaining their cognitive skills during fatiguing exercise than their less fit counterparts (7). Gender did not influence the interaction between physical activity level and condition. Thus, a slightly different distribution of males and females across the high- and low-activity groups did not seem to influence the results.

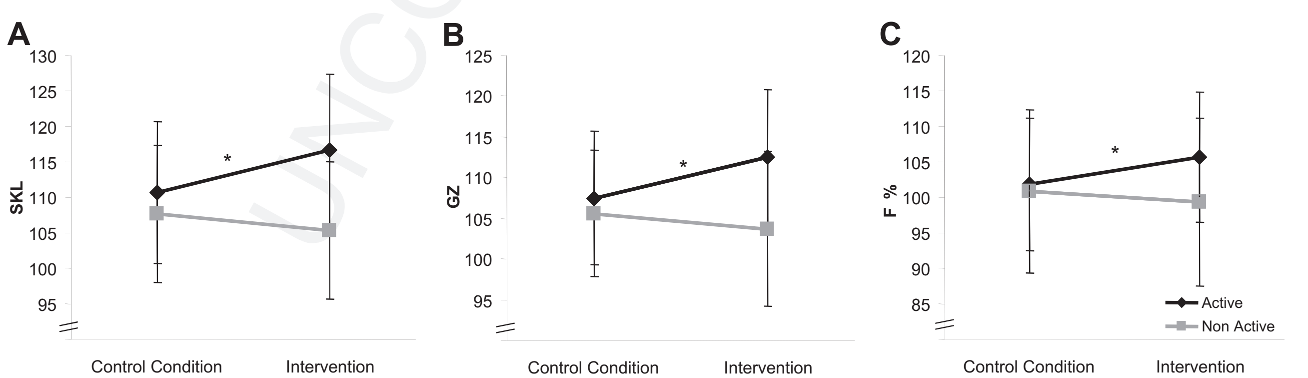

Figure 1. Results of the d2 performance (mean and standard deviation) after control condition and intermittent maximal exercise (intervention) for physically high active (active) and less active (nonactive) participants; (A) standardized results of the SKL, (B) standardized results of the GZ, (C) standardized results of the F%. Data were collapsed across the two groups (exercise intervention at t1, exercise intervention at t2). Asterisk marks significant differences between the control and intervention condition (*$p < 0.05$).

Brisswalter and colleagues (7) hypothesized that high exercise leads to only moderate arousal in fit subjects, which is beneficial for enhancing their cognitive ability, whereas it leads to high (i.e., detrimental) arousal in less-fit subjects. Also, in our study it is likely that the more active subjects could reach and maintain, in the immediate postexercise period, an optimal arousal level, which allowed them to perform better on the d2- test. Yet, it is still debated how this optimal arousal state induced by exercise is reflected at a neurobiological level.

Accordingly, Kemppainen and coworkers (27) found in a PET study that the physical training status was related to adaptive metabolic changes locally in the frontal cortical regions during high-intensity exercise (75% VO_{2max}). Trained men revealed a more pronounced decrease in glucose uptake compared to less-trained men. It is likely that substrates other than glucose, most likely lactate, are utilized by the brain of trained subjects to a higher extent in order to compensate for the increased energy needed to maintain neuronal activity during high-intensity exercise (27) and, therefore, the trained participants performed better in the cognitive testing. Interestingly, regional analysis indicated that this more efficient use of energy substrates was restricted to the anterior cingulate cortex (ACC), an area of the brain that is widely believed to be involved in the regulation of attention (28). These indications on brain metabolism during intense exercise are consistent with our findings that the physical activity participation level of the subjects (and the associated fitness status) may play a fundamental role in moderating the effects of high-intensity exercise on selected cognitive tasks (i.e., attention), which are controlled by brain regions like the ACC.

Because we measures physical activity level and not physical fitness, one may speculate that, besides a higher physical fitness level, more experience in motor coordination skills and cognitive experience derived from higher physical activity may have also accounted for the improvement in cognitive performance of high-active participants because both have been shown to play a role in resource allocation during acute exercise and may have an impact on the immediately following cognitive performance (16). The questionnaire used in this study was previously correlated with the physical fitness level of the responders (23). In addition, according to Westerterp (29), questionnaires show a lower reliability and validity than physiological markers but can be adequately applied as an activity-ranking instrument and are found to be an accessible and fast application in an educational setting.

By using a cross-over design with the sequence of the two conditions randomized across subjects, we controlled for pure learning effects. Repeated measure analysis of variance with the two test conditions and groups (exercise intervention at t1, exercise intervention at t2) revealed that overall effects are influenced by the order of the tests (test repetition effect) rather than by the exercise intervention itself. Thus, due to the improvement in SKL and GZ over time, we cannot separate a general effect of exertion from a learning effect. Nevertheless, when splitting the groups into participants with a high and low physical activity level we found a significant improvement in cognitive performance for high-active participants after exercise.

A limitation of the study may be the missing assessment of further neuropsychological functions (in addition to the d2-test) and neural correlates that make it difficult to issue a generalized statement of changed cognitive functions. Future studies should aim to verify how other neuropsychological tasks measuring different cognitive abilities are affected by short sessions of high-intensity exercise in differently active groups.

In conclusion, our study shows that only more active individuals improved sustained and selective attention after short intermittent bouts of maximal intensity exercise, supporting the belief that exercise-induced modification on cognitive performances are determined by the interactive effects between acute and chronic exercise (16). Therefore, it is only speculative, yet reasonable, to think that a high physical activity status can boost learning in educational settings. We proposed that changed neural activation patterns of selected brain regions (for example, in the ACC) (28) in highly active participants may result in a more efficient neurophysiological profile, which may be responsible for the improved outcome in the d2-test.

If similar findings were confirmed in populations with chronic difficulties in maintaining attention [e.g., children with attention-deficit hyperactivity disorder (ADHD) and aging populations], it would become reasonable to use adjusted acute exercise interventions as cognitive enhancers (17).

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