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Acute coordinative exercise improves attentional performance in adolescents

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ABSTRACT

Teachers complain about growing concentration deficits and reduced attention in adolescents. Exercise has been shown to positively affect cognitive performance. Due to the neuronal connection between the cerebellum and the frontal cortex, we hypothesized that cognitive performance might be influenced by bilateral coordinative exercise (CE) and that its effect on cognition might be already visible after short bouts of exercise. One hundred and fifteen healthy adolescents aged 13–16 years of an elite performance school were randomly assigned to an experimental and a control group and tested using the d2-test, a test of attention and concentration. Both groups performed the d2-test after a regular school lesson (pre-test), after 10 min of coordinative exercise and of a normal sport lesson (NSL, control group), respectively (post-test). Exercise was controlled for heart rate (HR). CE and NSL enhanced the d2-test performance from pre- to post-test significantly. ANOVA revealed a significant group (CE, NSL) by performance interaction in the d2-test indicating a higher improvement of CE as compared to NSL. HR was not significantly different between the groups. CE was more effective in completing the concentration and attention task. With the HR being the same in both groups we assume that the coordinative character of the exercise might be responsible for the significant differences. CE might lead to a pre-activation of parts of the brain which are also responsible for mediating functions like attention. Thus, our results support the request for more acute CE in schools, even in elite performance schools.

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Many teachers in the western countries complain about growing concentration deficits, increased unrest and reduced attention in children. Due to this development, new education models are asked for in which the ability to concentrate and therewith the cognitive competence will be promoted. In this context, the relation of physical activity and fitness to academic performance is of special interest because physical education programs in schools are required to contribute to the primary mission of schools, i.e. the promotion of academic performance [8]. Compelling support for the view that acute aerobic exercise can facilitate cognitive functioning is provided by empirical data on adults reviewed by Tomporowski [24]. He stated that submaximal aerobic exercise performed for periods up to 60 min facilitates specific aspects of information processing. Accordingly, findings by Hillman and co-workers [12] imply that acute bouts of cardiovascular exercise may enhance the allocation of attentional and memory resources, and hence, benefit executive control function in undergraduates. Unfortunately, very little is known about the impact of acute physical activity on children and youth or young student's class attention and academic performance [24] and the underlying mechanisms.

Current studies have focused on the relation between physical activity and the academic performance of school-age children. A meta-analysis with children [22] has demonstrated that physical activity participation is associated with better cognitive performance. The results of this review, however, indicate that the relationship between physical activity and cognition in children differs with regard to the age – 11–13-year-old students showed the largest effect – and type of cognitive assessment with perceptual skill tests showing the largest effect. They found no differences, however, among types of physical activity and between chronic and acute interventions. Hillman and co-workers [11] showed that the aerobic fitness level has a positive relation to academic achievement. Accordingly, Coe and co-workers [4] reported that pupils who engaged in vigorous physical activity outside school 3 or more days per week for 20 or more minutes per occasion performed better in school than those that did physical exercise at a moderate level. A study with adolescents tested the relationship between motor coordinative abilities and cognition and showed positive and significant

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associations between the latent motor and the cognitive variables. With both sexes, the motor dimensions with the strongest associations with the cognitive abilities are those of coordination and the speed of movement [17]. A first intervention study with grade 5 students showed that a 6-week bimanual coordination program improved the reading comprehension skills compared to controls [25].

Despite this relationship between coordinative abilities and cognition, until now, to the best of our knowledge, no study has assessed the influence of an acute bout of coordinative exercise (CE) on cognition. This might be, however, of high importance within the development of new education models to prevent concentration lapse. Coordinative exercise is known to involve an activation of the cerebellum which besides motor functions [9] influences a variety of neurobehavioral systems including attention [5], working memory [13], and verbal learning and memory [1]. In addition, experimental and clinical evidence points to the importance of the frontal lobes, especially the prefrontal areas, in the mediation of cognitive functions like executive control [15] on the one hand and motor coordination [10] on the other. Due to the neuronal structures responsible for coordination as well as cognition, we hypothesized that coordinative exercise would lead to a general pre-activation of cognitive-related neuronal networks and would be more effective in improving the speed and accuracy of a concentration and attention task in a sample of adolescents compared to control. Demonstrating that short bouts of coordinative exercise have salutary effects on information processing and cognition should have direct application to those involved in promoting educational performance.

One hundred and fifteen healthy adolescents aged 13–16 years of an elite performance school participated in this study and were randomly assigned to an experimental and a control group. Participants signed an informed consent approved by the local board of the Humboldt University, Berlin, Germany. Written informed consent was obtained before inclusion from all participants. Other inclusion criteria for study participation were no dyslexia (teachers statement) and a BMI not higher than 25. No participant had to be excluded due to these criteria. Sixteen participants were excluded from data analysis due to a performance incongruent to the instruction, i.e. a *F*% (number of all errors related to the total number of responses) higher than 20. The remaining sample (80 male and 19 female) had a mean age of 14.98 years (S.D. = 0.78, n = 52) in the control (44 male, 8 female) and of 15.04 years (S.D. = 0.87, n = 47) in the experimental group (36 male, 11 female). According to Brickenkamp [3], gender has no effect on the results in the d2, so we randomly recruited and assigned the students in the participating classes to the groups regardless of gender.

Neuropsychological performance of the students was assessed in the areas of attention and concentration using the d2-test [3]. The d2-test is a paper and pencil letter-cancellation test that consists of 14 lines of 47 randomly mixed letters each (either d or p). Subjects are instructed to mark, within 20 s for each line, only the letter “d” within a string of letters (“d” and “p”), only when 2 dashes are arranged either individually or in pairs above and below “d”. After 20 s there is an acoustic signal, which shows the subjects to continue with the next line. The test lasts 4.67 min.

The d2-test determines the capacity to focus on one stimulus/fact, while suppressing awareness to competing distractors [3]. Processes of selective attention are also required for successful completion, since not only the letter “d” is orthographically similar to the letter “p”, but there are many distractor letters “d” with more than 2 dashes [3]. According to Miller and Cohen [15], the selective attention mechanism measured with the d2-test is in fact just a special case of cognitive control – one in which the biasing occurs in the sensory domain or a measure of response inhibition and executive functions [14].

The performance on this test does not correlate with IQ, but reflects visual perceptual speed and concentrative capacities. The internal test–retest reliability of the d2-test of attention has been proven to be extraordinarily high (0.95–0.98) for all parameters [3]. 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 [3].

The heart rate was measured during exercise sessions in both groups using a heart rate monitor (HRM RS400, Polar, Kempele, Finland). The heart rate data (every 5 s) were downloaded to a computer.

Coordinative exercises were selected from special coordinative training forms for soccer [19] and exercises from the Munich Fitness Test [18]. Within these exercises different bilateral coordinative abilities were stressed within short periods of time, for example, the ability to balance, to react, to adjust and to differentiate [19]. Exercises were organized in stations with a maximum of four students at each station per time. Altogether, the pupils completed five different CE for 1.75 min each.

At station 1 the participants were asked to bounce a volleyball alternating with the left or right hand while standing on a turned sport bench. At the second station the task was to bounce a basketball and a volleyball respectively with the left and the right hand at the same time. Task 3 was to throw a handball alternating with the left and right hand into a gymnastic hoop at a distance of 10 m. In the fourth exercise two pupils faced each other in a distance of 5 m, one with a handball and the other with a football. They were asked to pass the balls alternating with the right and left hand and/or with the foot at the same time. In the fifth exercise pupils bounced a volleyball with the hand and were asked to control a soccerball with the foot at the same time altogether on one half of the volleyball court.

In the 10 min of the normal sport lesson the physical education teachers instructed the students to exercise at a moderate intensity without any specific coordinative request. The teachers who accomplished this intervention had a special qualification to advise the students to exercise at the same intensity as the CE group but without any specification on motor coordination.

In the week before the first testing the students were introduced to the test procedure and instructed how to complete it. The measurements of the d2-tests took place immediately after a normal school lesson (pre-test, week 2) and after 10 min of coordinative exercise or after 10 min of a normal sport lesson (post-test, week 3), and were accomplished in a quiet room. The interval between the test sessions was 1 week in each case. The adolescents participating in the normal sport lesson served as controls. On the test days the students refrained from any exercise prior to the investigation.

The total number of responses (GZ) within the d2-test, the standardized number of correct responses minus errors of confusion (SKL), and the number of all errors related to the total number of responses (*F*%) are calculated and used as a parameter for sustained attention and concentration. The GZ value is a quantitative measure of the working speed, and the *F*% value is a qualitative measure of precision and thoroughness. Both values are subject to learning effects. The *SKL* value is interpreted as independent from adulteration and, thus, an objective measure of concentration. It reflects individual attention span and concentration ability [3]. It is calculated by the total number of correctly marked items minus errors of confusion. Raw values were expressed in percentiles (derived from age-matched norm samples [3]), in order to achieve age-independent test scores. Additionally, changes across test trials were computed as difference scores between pre- and post-test (improvement = $(M_{t1} - M_{t2})/(M_{t1}) \times 100$).

Table 1
Results of the 2 (pre-test, post-test) × 2 (CE, NSL) repeated measure ANOVA with the main effects time and group for the total number of responses (GZ), the standardized value of the number of correct responses minus errors of confusion (SKL), and the number of errors related to the total number of responses (*F*%)

Measure	Time				Group				Group × time			
	F	d.f.	*p*	η^2	*F*	d.f.	*p*	η^2	*F*	d.f.	*p*	η^2
GZ	68.18	1	<.01	.41	.03	1	.87		15.46	1	<.01	.14
SKL	99.92	1	<.01	.51	.35	1	.56		20.93	1	<.01	.18
F%	52.62	1	<.01	.35	.81	1	.37		12.14	1	<.01	.11

A 2 × 2 mixed factor analysis of variance (ANOVA) was used to test for differences between pre- and post-test (within) and differences between the experimental (CE) and the control group (NSL) (between). Analysis was conducted separately for the outcome variables GZ, *F*%, and SKL. Greenhouse Geyser adjustment was reported when the sphericity assumption was violated. Post hoc contrasts (Bonferroni adjustment) were used to determine effects within the two groups (CE, NSL). Since gender showed no significant effect on pre- to post-test changes (always $p > .05$), we did not include gender in the analysis. Group specific differences in learning efficiency were analyzed using *t*-tests for independent samples. To analyze intertrial correlations for the experimental and control groups, Pearson's bivariate correlations were computed.

A 2 (pre-test, post-test) × 2 (CE, NSL) ANOVA revealed a significant effect of time (pre-test, post-test), no significant effect of group and a significant group × time interaction for the outcome variables GZ, SKL, and *F*% (cf. Table 1 for statistics). All participants improved their d2 performance from pre- to post-test throughout practice and decreased the number of errors across time (cf. Fig. 1 and Table 2). The interaction, however, indicated a different pre- to post-test development for experimental and control group. Fig. 1 displays the pre- and post-test performance and indicates that the CE group improved performances from pre- to post-test to a higher degree as compared to the NSL group. Post hoc contrasts revealed an improvement in d2 performance for both groups across test sessions for SKL, GZ, and *F*% (always $p < .01$). Additionally, post hoc tests revealed no significant group differences in pre-test ($p > .05$), but in post-test for SKL and *F*% ($p < .05$).

Improvement across test sessions was analyzed using difference scores. The *t*-tests for independent samples revealed group differences for performance improvement as significant for GZ ($t(97) = 3.67$, $p < .01$, $\omega^2 = .11$), SKL ($t(97) = 4.44$, $p < .01$, $\omega^2 = .16$), and for *F*% ($t(96) = -3.85$, $p < .01$, $\omega^2 = .12$) (cf. Fig. 2 and Table 2). These results indicated that CE led to a higher improvement of d2 performance.

The heart rate revealed no significant difference between the control ($M = 121.96$, S.D. = 27.06) and the experimental ($M = 122.30$, S.D. = 21.91) group ($t(44) = 0.05$, $p = .96$).

Table 2
Means (*M*) and Standard Deviations (S.D.) for d2 performance (GZ, SKL, *F*%) at pre- and post-test and for the performance improvement (difference scores, I_GZ, I_SKL, I_*F*%) for the experimental (CE) and control group (NSL)

Measure	CE		NSL	
	M	S.D.	*M*	S.D.
GZ				
Pre-GZ	413.64	70.49	430.42	77.73
Post-GZ	473.06	64.94	452.10	63.15
SKL				
Pre-SKL	97.38	8.86	99.48	10.09
Post-SKL	107.32	7.66	103.27	8.65
F%				
Pre-*F*%	7.98	4.22	7.27	4.22
Post-*F*%	3.99	2.96	5.83	2.83
Improvement				
I_GZ	−15.67	12.70	−6.39	12.45
I_SKL	−10.64	7.61	−4.20	6.83
I_*F*%	43.17	47.06	10.48	36.71

Note: Negative values for the difference scores for I_GZ and I_SKL, and positive values for I_*F*% indicate performance improvements.

The correlation between pre- and post-test performance was higher for the control group (GZ: $r(52) = .78$, $F\%(52) = .71$; SKL: $r(52) = .77$) than for the experimental group (GZ: $r(52) = .77$, $F\%(52) = .35$; SKL: $r(52) = .67$), particularly regarding the number of errors.

The aim of this study was to investigate the effect of 10 min of physical exercise on concentration and attention performance in a school setting. Adolescent students participated in 10 min of coordinative exercise or a non-specific physical education lesson, respectively, and afterwards performed the d2-test [3]. Results revealed an enhanced attention and concentration performance in both groups with a significantly higher progression in the CE group. This was true for all measures of the d2; the SKL value as well as for the quantity (GZ) and the quality of working which comes along with a decline in value of incorrect marked items (*F*%). Since the heart rate was the same in both groups, this supports that the coordinative character of the exercise is responsible for the significant difference between the two groups.

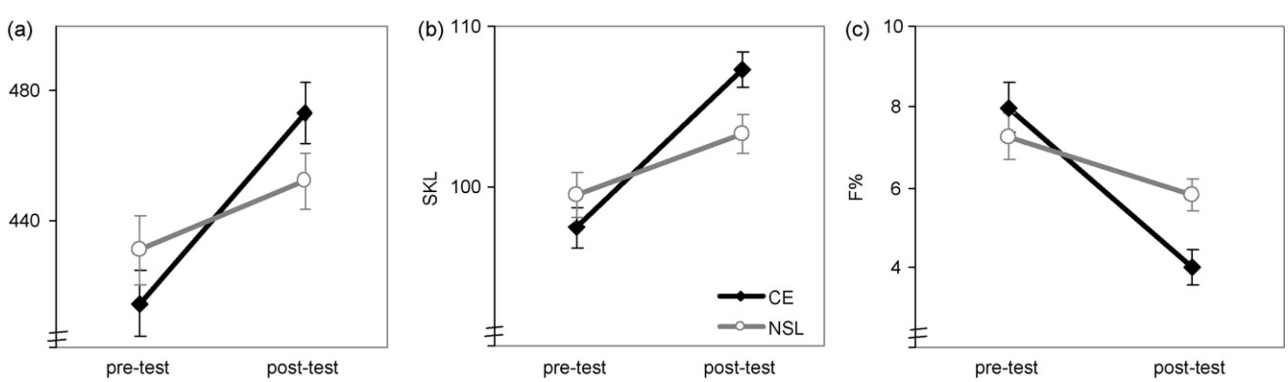

Fig. 1. (a) Results of the GZ for the experimental group (CE) and the control group (NSL). (b) Results of SKL for the experimental group (CE) and the control group (NSL). (c) Results of *F*% for the experimental group (CE) and the control group (NSL).

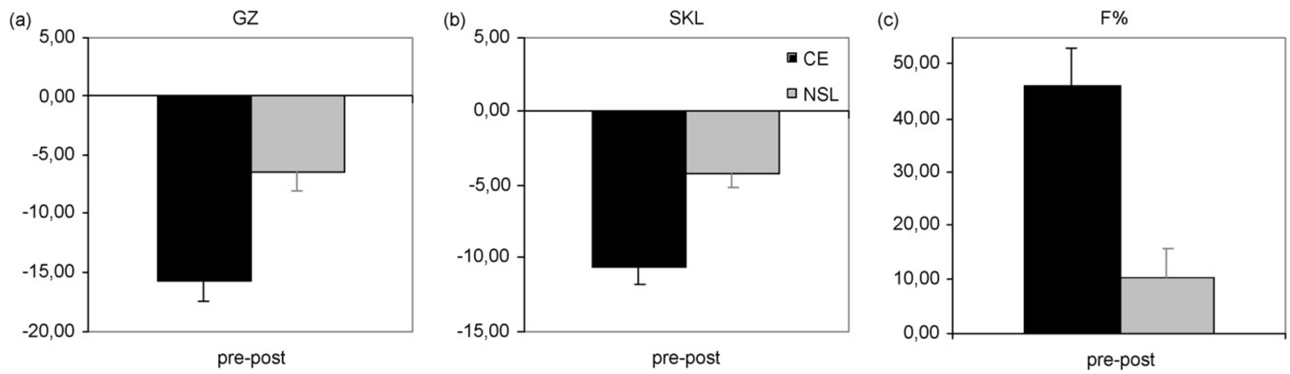

Fig. 2. (a) Performance improvements in GZ from pre- to post-test for the experimental group (CE) and the control group (NSL). (b) Performance improvements in SKL from pre- to post-test for the experimental group (CE) and the control group (NSL). (c) Performance improvements in *F*% from pre- to post-test for the experimental group (CE) and the control group (NSL).

On the basis of human brain imaging and animal studies showing that neuronal structures like the cerebellum and the frontal lobe are responsible for coordination as well as cognition [20] it was hypothesized that coordinative exercise would be more effective than the control condition in improving the speed and accuracy of the following concentration and attention task. Picard and Strick [16] specified that motor complexity co-varies with the pattern of brain activation, and thus the degree of information processing. It has been suggested that automatic motor behaviors, like they were requested during the 10 min of exercise without an emphasis on motor coordination (NSL), are controlled by the basal ganglia [7]. The higher the motor demand, the more prefrontal cortex activity is required during the execution of motor tasks [20]. Thus, the type of exercise stressed in the CE group is believed to require a higher variety of frontal-dependent cognitive processes as compared to completing basic moves at a moderate intensity [21].

In addition to an activation of neural parts of the brain like the frontal lobes [10], CE is supposed to lead to an excitation of the cerebellum [6] which is also responsible for mediating cognitive functions [23]. Our results suggest that CE leads to a facilitation of neuronal networks resulting in a general pre-activation of consequent cortical activities responsible for cognitive functions like attention. In contrast, the normal sport lesson might require the participants to perform more automated movements and in turn prefrontal structures might not be directly required to the same extent than in the coordinative tasks. The result is a less efficient neurophysiological profile which could be responsible for the poorer outcome in the d2-test.

A likelihood of a specific effect of CE, regardless of pre-test performance, could also be confirmed by analyzing the individual differences from pre- to post-test. The correlation between pre- and post-test performance was higher for the control than for the experimental group, particularly regarding the number of errors. While in the control group individual participants maintained their performance levels relative to one another from pre- to post-test, the individuals of the experimental group reduced the amount of errors regardless of their initial performance. This might indicate that the performance increase of the control group was caused by learning effects while the performance of the experimental group (particularly the reduced number of errors) was more strongly influenced by the intervention program.

Our study was designed as a “proof of principle” experiment, probing the effects of a single bout of bimanual coordinative exercise on concentration and attention. Because of its pilot character, the study lacks a group being inactive for the two time points. This explains why the reported effects could only compare CE and NSL and do not provide information about the effect of acute exercise in general. The SKL value, which is considered as the most stable value, increased in both groups when the test was applied a second time. As stated by Brickenkamp [3], the internal test–retest reliability of the d2-test of attention has been proven to be high. Due to the improvement in SKL over the time in both groups, however, we cannot separate a general effect of acute exercise from a learning effect which might interfere with the impact of the compounds on attention.

The missing assessment of further neuropsychological functions beyond performance on the d2-test makes it difficult to issue a generalized statement of changed cognitive functions. The d2-test performance, however, as used in the current study is known to be a measure of response inhibition and executive functions [14] and to be related to school performance [3]. Additionally, it is well known that concentration deficits are associated with poorer academic performance [2]. Hillman and co-workers [12] argued in a study with undergraduate students that the allocation of attentional resources benefits executive control function. Thus, a faultless function of attention can be seen as a predictor for efficient cognitive control and academic performance.

Taken together, our results support the request for more short bouts of exercise in schools with a focus on coordinative skills, for example, via instructed exercise in school breaks. The fact that our results were achieved with students of an elite performance school, where the students practice sport every day (25–30 h per week) supports our demand for more acute coordinative exercise.

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