Psychology of Sport & Exercise 64 (2023) 102300

Contents lists available at ScienceDirect

Psychology of Sport & Exercise

journal homepage: www.elsevier.com/locate/psychsport

Effects of acute endurance, strength, and coordination exercise interventions on attention in adolescents: A randomized controlled study

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ARTICLE INFO

Keywords:
Physical activity
School
Attention
Cognition
d2 test

ABSTRACT

Objectives: The aim of this study was to compare three different modes of an acute bout of exercise – endurance, strength, and coordination – in their effects on adolescents' attention.
Design: This was a preregistered, prospective, randomized intervention study with four groups and two distinct measurement occasions.
Method: Eighty adolescent students aged 15–18 years were randomized to one of three exercise intervention groups (endurance, strength, coordination) or to a non-exercise, control group. The exercise interventions lasted for 25 min. The random assignment to the study groups was stratified according to participants' age and gender. Before and after the exercise intervention, all participants completed the revised d2-test of attention. A 4 × 2 repeated measures ANOVA with contrast-coded test was used as the main analysis method.
Results: Attentional test performance increased from before to after the exercise intervention for all exercise groups, as compared with the control group. The three exercise groups improved equally and did not differ in their attentional scores after the intervention.
Conclusions: An acute bout of exercise was in general beneficial for adolescent students' attention, while the mode of the provided exercise training was not decisive. School directors and teachers are encouraged to incorporate exercise-related breaks into their school plan.

Acute physical exercise has been found beneficial for people's attention, but the effect varies across age groups and types of exercise (see de Sousa et al., 2018, for a review). Whereas positive results are consistently (and frequently) documented for children and adult samples, studies with adolescents are rare and the effects less consistent. Of the few studies with adolescents, Budde et al. (2008) and Hogan et al. (2013) observed better attention performance after an acute bout of exercise, while Hogan et al. (2015) and Stroth et al. (2009) reported null effects. Moreover, there seems to be a variation in attentional benefits depending on the type of exercise. A higher increase in attention test performance was found after an exercise with coordinative tasks than after a regular aerobic exercise (Budde et al., 2008; Janssen et al., 2014). Yet the vast majority of prior studies tested aerobic exercise only, which limits the comparison as well as potential implications for educational praxis (de Sousa et al., 2018). Physical educational teachers working with adolescents are thus still left in the dark about what type of exercise to use to best stimulate their students' attention. Given that adolescents experience frequent external distractions (Stawarczyk et al., 2014), we need more profound knowledge of how to best promote their ability to concentrate (Budde et al., 2008).

The aim of this study therefore was to compare three different modes of acute exercise training – endurance, strength, and coordination – in their effect on adolescents' attention. *Endurance* training typically consists of continuous aerobic exercise (e.g., running, cycling) of moderate intensity and is known to enhance aerobic capacity and improve cardiac performance (Spalding et al., 2004). An alternative is a high-intensity interval training (HIIT), consisting of repeated bouts of short high intensity efforts (e.g., sprinting, cycling) followed by short recovery periods, which shows similar or even higher benefits for cardiorespiratory fitness (Maturana et al., 2021). *Strength* (resistance) training involves exercises that causes the muscles to contract against a weight or force (e.g., weight lifting, push-ups). Similar to endurance training, strength training produces beneficial adaptations in the cardiovascular system, even though aerobic capacity does not increase as much (Spalding et al., 2004). Finally, *coordination* training involves exercises that challenge people's balance and motor control (e.g., walking on a balance bench).

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https://doi.org/10.1016/j.psychsport.2022.102300
Received 14 February 2022; Received in revised form 1 September 2022; Accepted 24 September 2022
Available online 29 September 2022

This type of training requires a great deal of cognitive involvement and facilitates cortical activities responsible for cognitive functions (Budde et al., 2008).

The advantages of an acute bout of exercise for attention have been mostly reported on endurance exercise training (e.g., Hillman et al., 2009; Kujach et al., 2018; Popovich & Staines, 2015; Sanabria et al., 2011), with fewer studies looking at effects of strength exercise training (Chang et al., 2014; Chang & Etnier, 2009; Engeroff et al., 2019, 2021) and coordination exercise training (Budde et al., 2008; Janssen et al., 2014; Palmer et al., 2013). We are not aware of any study that would directly compare acute bouts of endurance and strength exercises in their effects on attention (see also de Sousa et al., 2018) and there are only two studies that compared endurance exercise with coordinative skills exercise, both showing stronger effects for the coordination training (Budde et al., 2008; Janssen et al., 2014). A comprehensive meta-regression that compared different types of exercise in relation to overall cognitive (or executive) function also showed a greater effectiveness of coordinative exercise types than endurance and strength exercises across all age groups, while the effectiveness of the latter two types of exercise was comparable (Ludyga et al., 2020). Similarly, exercise trainings enriched with coordinative demands elicited the greatest benefits for response inhibition in children and adolescent samples (Álvarez-Bueno et al., 2017).

There are several mechanisms that could explain the positive effect of acute exercise on attentional performance, such as increased blood and oxygen flow to the brain (Chang et al., 2012; Hillman et al., 2003; Pereira et al., 2007), elevated levels of peripheral catecholamines and brain-derived neurotrophic factor (Ferris et al, 2007; McMorris et al., 2016; Moreau & Conway, 2013), and functional adaptations in the brain (Fernandes et al., 2017; Kao et al., 2020). However, the pattern of brain activation co-varies with motor complexity, with more complex motor tasks requiring more prefrontal cortex activity, and in turn a higher variety of frontal-dependent cognitive processes, than basic moves and automatic motor behaviors which are more controlled by the basal ganglia (Budde et al., 2008; Leisman et al., 2016; Netz, 2019; Serrien et al., 2006). Moreover, there is a closely coupled activation of the prefrontal cortex and the cerebellum, which are both related to motor and cognitive skills (Stoodley et al., 2012). Consequently, coordinative exercise may especially facilitate cortical activities responsible for cognitive functions including attention, whereas the less complex endurance and strength exercises might require people to perform more automated movements and thus prefrontal structures might not be required to the same extent than in the coordinative tasks (Koutsandréou et al., 2016).

We sampled adolescent students aged 15–18 years and randomized them to one of three exercise intervention groups (endurance, strength, coordination) or to a non-exercise, control group. The intervention groups performed the respective exercise intervention for 25 min. We chose the 25-min period because it had been found that exercise bouts of 20 to 30-min duration most consistently affected attention test performance (de Sousa et al., 2018; Sipavičienė, Dumčienė, Ramanauskienė, & Skurvydas, 2012). The perceived intensity of each exercise intervention was controlled with an adapted Borg scale (Foster et al., 2001). Before and after the exercise intervention, all participants completed the revised d2-test of attention (Brickenkamp et al., 2010) which is a reliable and commonly used measure of visual-perceptual speed and concentrative capacities (Steinborn, Langner, Flehmig, & Huestegge, 2018). This test is easily applicable to school settings and has been widely used in work with child and adolescent samples (Bölte et al., 2000). Based on the above evidence that acute exercise improves attention, we hypothesized that the three exercise intervention groups would increase their attention test performance more that the control group. Based on the evidence that coordinative tasks require more cognitive involvement than endurance and strength tasks, we further hypothesized that the coordination exercise group would show a higher increase in attention that the endurance and strength exercise groups.

1. Method

Data are available on figshare (https://doi.org/10.6084/m9.figshare.19165883), and preregistrations of sample size and primary analyses are available on AsPredicted (https://aspredicted.org/zs2pp.pdf).

1.1. Participants and design

This was a preregistered, randomized intervention study with four groups and two distinct measurement occasions. An a priori calculation with G*Power (Faul et al., 2007) for a 4 × 2 (Group × Phase) analysis of variance (ANOVA) with repeated measures revealed that a sample size of at least 76 (19 per group) would give sufficient power (0.95) to detect significant differences at the alpha level of 0.05 with a middle effect size ($f = 0.25$). The middle effect size was based on previous research investigating the effect of acute exercise on performance in the d2-test of attention (Budde et al., 2008; Budde et al., 2012). Participants were students recruited from an academic secondary school in Vienna, Austria. Inclusion criteria were the target age (15–18 years), no physical limitations, and proficiency in German. For each age category (15, 16, 17, and 18 years), we stopped recruiting when the sub-sample reached 20 persons. The total sample thus included 80 students (41 women and 39 men). The participants attended between 2 and 5 h of physical education per week and about half of them (55%) also reported being active outside the school for at least 3 h per week. The majority of participants (90%) self-reported as right-hand dominant, with only eight participants identifying as left-hand dominant. Participants and their parents signed an informed consent before taking part in the study. The study was approved by the ethics committee of the first author's institution (#00595) and ran from March to June 2021.

1.2. Measures

Participants indicated their age, gender, handedness, whether they wear glasses, and how frequently they engage in exercise and sports inside and outside of school. They also reported whether they were members of a sport club or participated in any organized sports. In addition, to control for participants' academic achievements, participants indicated their most recent semester grades for graduation subjects (Mathematics, German, and English). The grades ranged from 1 to 5, with lower value representing better achievement, and were averaged into an academic achievement score.

Attention was measured with the revised d2-test of attention (Brickenkamp et al., 2010). It is a cancellation test which consists of a single paper sheet with 14 rows of letters (*d*'s and *p*'s) which each are surrounded with up to four short dashes. Participants' task was to search each row of letters for *d*'s with two dashes either above it or below it and cross them out, while also refraining from responding to seductively similar stimuli (e.g., a *d* with three dashes, or a *p* with two dashes). Each row consisted of 57 items and participants had a time limit of 20 s per row. They were instructed to work as fast and accurately as possible. Three main scores were derived from the test: the concentration performance score, the error score, and the speed score. The concentration performance score reflects the absolute number of detected targets minus the number of omission and commission errors, thus reflecting both speed and accuracy. The error score indicates the percentage of processed items that were processed incorrectly (either due to omission or commission errors). The speed score indicates the absolute number of detected targets.

Rate of perceived exertion was measured using an adapted version of the Borg CR-10 scale (Foster et al., 2001). The CR-10 scale is a 11-point Likert scale, ranging from 0 (*"nothing at all"*) to 5 (*"heavy"*) to 10 (*"very, very heavy"*), with nominal descriptors attached to specific intensities.

1.3. Study groups

Using a computer-generated list of random numbers (Microsoft Excel; Microsoft, Redmond, WA), we randomized participants to one of three intervention groups (endurance, strength, coordination) or to a control group (Figure 1). The random assignment to the study groups was stratified according to participants' age and gender. Participants in the *endurance group* performed a 25-min high-intensity interval training (HIIT) based on Lüthy & Di Potenza (2016). The training consisted of a 90-s warm-up period followed by ten repetitions of hard sprinting for 20 s separated by 40 s of jogging for recovery. After 2 min rest, participants completed another ten repetitions of sprinting and jogging, and concluded with a 90-s cool-down period. Participants in the *strength group* performed a 25-min full-body strength circuit workout based on Rühl and Laubach (2014). The workout comprised seven exercises in a circuit (sit-ups, triceps bench dips, alternating step-ups, reverse flys, push-ups, parallel pull-ups, and plank with arm extensions), with 60 s work and 30 s rest between each exercise. Participants completed the circuit twice with 4 min rest between each circuit. Participants in the *coordination group* performed a 25-min coordination circuit training based on Hunzinker and Weber (2008). The training included ten exercises, with 2 min work and 30 s rest between each exercise. The exercises were: bouncing with two different balls (e.g., basketball and football) simultaneously; throwing and catching with two different balls against wall; throwing a ball over the head and catching it behind the back; throwing a ball high and catching it after having clapped hands several times; bosu ball kneeling and squats; walking on a balance bench; jumping through a ring ladder on the floor; jumping rope with different techniques; throwing a ball high and catching it after having touched the ground; and jumping over long rope. All trainings were led by a physical education teacher and the compliance with training protocol checked by the first author. Participants in the *control group* did not receive any physical intervention and were instead asked to read a book for 25 min.

1.4. Procedure

The study consisted of three distinct phases: a pretest, an exercise intervention phase, and a posttest. Participants were tested in small groups up to eight persons. In the pretest, participants signed informed consent, provided demographics, and completed the d2-test of attention. Thereafter, the exercise intervention was introduced. Participants were given verbal instructions and practical demonstrations how to perform their respective exercises. They were also instructed that they should exercise at their individual pace based on their fitness level. The strength and coordination trainings were performed in a sports hall, whereas the endurance training took place on an outdoor-track. Rate of perceived exertion was measured immediately after the intervention using the Borg CR-10 scale. Participants in the control group were not introduced to any physical exercise intervention, but provided with several books and asked to pick one and read it for 25 min. After the intervention phase, participants had 5 min break in which they could drink and dry off. Finally, in the posttest, participants completed the d2-test for the second time and were then debriefed, thanked, and dismissed.

1.5. Statistical analysis

To test the homogeneity of groups, separate one-way ANOVAs were

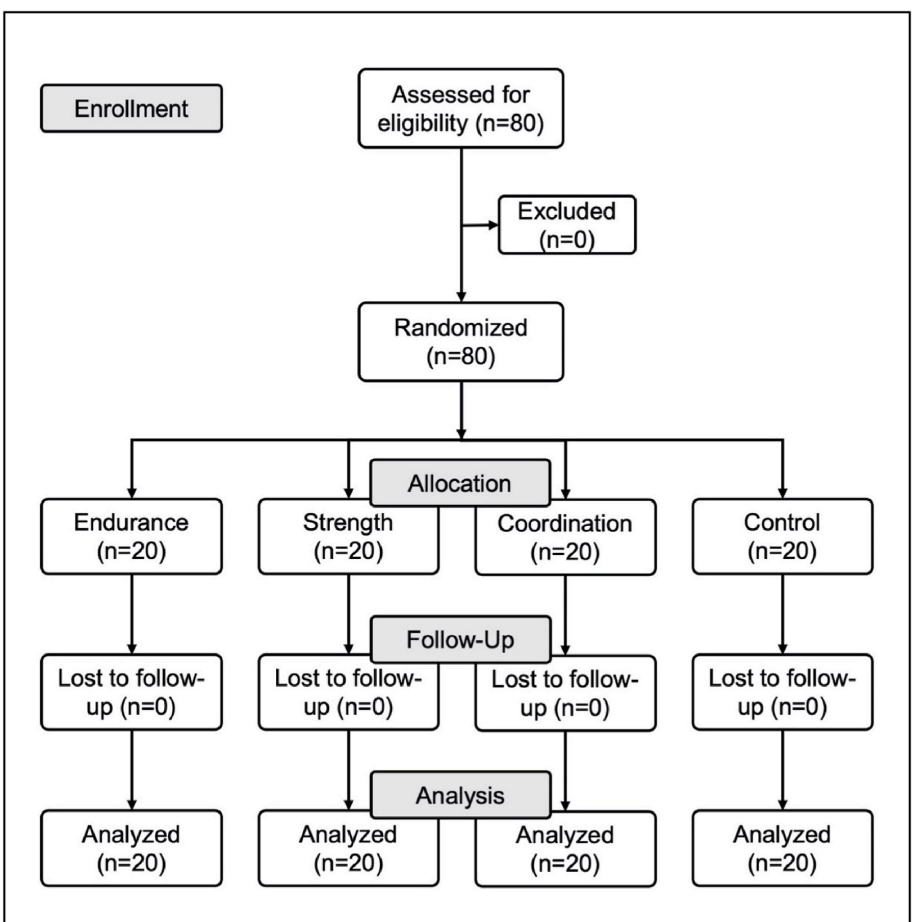

Figure 1. Flow chart showing the experimental design of the study.

conducted on the hours of sport and exercise activities inside and outside of school, and academic achievement. Chi-square tests were used to test differences in the proportion of handedness, sport club membership, and the use of vision correction among the groups. In case of inhomogeneity, the respective variable was tested on its relationship with attention. To check the intensity of exercise intervention, a one-way ANOVA with *post-hoc* tests (Bonferroni corrected) were conducted on the rate of perceived exertion with the three intervention groups. For the study hypotheses, separate 4 (Group) × 2 (Phase) repeated measures ANOVAs were conducted on concentration performance score, error score, and speed score to test whether attention changed from pretest to posttest among the study groups. In case of significant interaction, we conducted two contrast-coded analyses through the specification of L (the test matrix) and M matrix (the transformation matrix). One contrast-coded analysis (LMATRIX +1, +1, +1, −3 for the three intervention groups and the control group, respectively) tested the hypothesis that the three exercise intervention groups would improve attention more that the control group, and the other contrast-coded analysis (LMATRIX -1, −1, +2, 0 for the endurance, strength, coordination, and control group, respectively) tested the hypothesis that the coordination exercise intervention would have a higher effect on attention that the endurance and strength exercise interventions. The M matrix was specified as MMATRIX -1, +1 for the respective pretest and posttest attentional scores. Participants' academic achievement was included as a covariate because it varied among groups and correlated with attention. All analyses were performed with SPSS 26.0 (IBM Corp.; Armonk, NY, United States). The level of significance was set at $p < .05$ (two tailed).

2. Results

Characteristics of the study groups are presented in Table 1. We found no significant differences in the proportion of handedness, sport club membership, and the use of vision correction among the groups. Furthermore, no significant differences emerged among the groups in the hours of sport and exercise outside of school. However, there were significant differences in the hours of physical education per week, $F(3,76) = 5.13$, $p = .003$, $\eta_p^2 = 0.17$, and academic achievement, $F(3,76) = 3.85$, $p = .013$, $\eta_p^2 = 0.13$. Because academic achievement correlated significantly with concentration performance score at the pretest ($r = -0.33$, $p = .003$), we controlled for academic achievement by including it as a covariate in the main analyses. The hours of physical education per week were not correlated with attention and are not discussed any further.

Regarding the intensity of the exercise intervention, the intervention groups differed in the rate of perceived exertion, $F(2,57) = 23.78$, $p < .001$, $\eta_p^2 = 0.46$, with participants reporting higher exertion during the HIIT intervention than during the strength ($p < .001$) and coordination interventions ($p < .001$). The strength and coordination groups did not differ from each other in the rate of exertion ($p = .593$).

Attentional scores of the intervention and control groups are displayed in Table 2. Concentration performance score increased significantly from pretest to posttest for all study groups, as indicated by the main effect of Phase, $F(1,75) = 38.36$, $p < .001$, $\eta_p^2 = 0.34$. Moreover, there was a significant interaction, $F(3,75) = 3.16$, $p = .029$, $\eta_p^2 = 0.11$, indicating that the improvement in concentration varied across groups. The main effect of Group was not significant. Contrast-coded analysis (+1, +1, +1, −3 for the three intervention groups and the control group, respectively) was significant, $F(1, 75) = 9.02$, $p = .004$, $\eta_p^2 = 0.11$, indicating that participants in the intervention groups outperformed control participants. A contrast-coded test −1, −1, +2 for the endurance, strength, and coordination groups, respectively, was not significant, $F(1, 75) = 0.58$, $p = .449$, $\eta_p^2 = 0.01$, indicating that the benefits of exercise intervention were the same regardless of the type of intervention.

Error score did not change significantly from pretest to posttest (Table 2). Similarly, neither the Phase × Group interaction nor the main effect of Group were significant.

Regarding speed score, there was an significant main effect of Phase, $F(1,75) = 39.96$, $p < .001$, $\eta_p^2 = 0.35$, and a significant interaction, $F(3,75) = 4.34$, $p = .007$, $\eta_p^2 = 0.15$. The main effect of Group was not significant. Contrast-coded analysis (+1, +1, +1, −3 for the three intervention groups and the control group, respectively) was significant, $F(1, 75) = 12.63$, $p = .001$, $\eta_p^2 = 0.14$, indicating that participants in the intervention groups worked faster than control participants. A contrast-coded test −1, −1, +2 for the endurance, strength, and coordination groups, respectively, was not significant, $F(1, 75) = 0.62$, $p = .433$, $\eta_p^2 = 0.01$, indicating that working speed was the same regardless of the type of intervention.

3. Discussion

The aim of this study was to test the effects of three different modes

Table 1
Characteristics of the study groups.

	Endurance ($n = 20$)	Strength ($n = 20$)	Coordination ($n = 20$)	Control ($n = 20$)	χ^2	F	p	η^2
Age categories, *n* (%)					–		–	
15 years	5 (25)	5 (25)	5 (25)	5 (25)				
16 years	5 (25)	5 (25)	5 (25)	5 (25)				
17 years	5 (25)	5 (25)	5 (25)	5 (25)				
18 years	5 (25)	5 (25)	5 (25)	5 (25)				
Gender, *n* (%)					–		–	
Women	10 (50)	10 (50)	11 (55)	10 (50)				
Men	10 (50)	10 (50)	9 (45)	10 (50)				
Visual correction, *n* (%)					3.75		.290	
Yes	10 (50)	7 (35)	5 (25)	10 (50)				
No	10 (50)	13 (65)	15 (75)	10 (50)				
Handedness, *n* (%)					1.11		.774	
Righthanded	18 (90)	18 (90)	19 (95)	17 (85)				
Lefthanded	2 (10)	2 (10)	1 (5)	3 (15)				
Sports club membership, *n* (%)					4.79		.188	
Yes	7 (35)	10 (50)	4 (20)	5 (25)				
No	13 (65)	10 (50)	16 (80)	15 (75)				
Hours of sport in leisure time per week, *M* (*SD*)	3.35 (3.21)	4.35 (2.60)	4.18 (2.12)	3.05 (2.73)		1.09	.357	0.04
Hours of physical education per week, *M* (*SD*)	3.00 (1.17)	3.50 (1.54)	3.00 (1.17)	2.10 (0.45)		5.13	.003	0.17
Academic grades, *M* (*SD*)	2.57 (1.03)	2.55 (1.08)	2.88 (1.15)	1.83 (0.74)		3.85	.013	0.13
Perceived exertion, *M* (*SD*)	8.00 (0.65)	6.80 (0.83)	6.50 (0.69)	–		23.78	<.001	0.46

Note. Groups stratified according to age and gender; an analysis of age and gender would be redundant. Visual correction refers to wearing glasses or contact lenses. Academic grades range from 1 (best) to 5 (worst). Perceived exertion ranges from 0 (nothing at all) to 5 (heavy) to 10 (very, very heavy).

Table 2
Means (standard deviations), and ANOVA statistics for attentional variables.

	Endurance	Strength	Coordination	Control	ANOVA			
	(n = 20)	(n = 20)	(n = 20)	(n = 20)	Effect	F	p	η^2
Concentration score					P	38.36	<.001	0.34
Pre	137.15 (30.06)	147.15 (34.66)	139.35 (28.54)	151.40 (29.90)	G	0.67	.575	0.03
Post	182.00 (43.55)	194.20 (43.77)	190.10 (34.62)	179.80 (29.30)	P × G	3.16	.029	0.11
Error score					P	1.82	.183	0.02
Pre	9.08 (8.31)	12.78 (11.46)	14.89 (11.93)	8.10 (4.87)	G	1.29	.286	0.05
Post	6.45 (4.45)	8.41 (8.75)	9.49 (9.10)	4.70 (3.14)	P × G	0.65	.587	0.03
Speed score					P	39.96	<.001	0.35
Pre	151.50 (32.21)	169.65 (37.59)	164.30 (30.22)	164.65 (30.62)	G	1.76	.163	0.07
Post	194.50 (45.49)	212.25 (45.16)	211.55 (39.85)	188.40 (30.09)	P × G	4.34	.007	0.15

Note. P = Phase; G = Group; P × G = Phase × Group interaction.

of acute exercise training – endurance, strength, and coordination – on adolescents' attention. We found that concentration performance increased from before to after the training intervention for all exercise groups, as compared with the control group. This is in line with recent evidence that acute exercise leads to higher attention test performance (de Sousa et al., 2018). Positive results have been consistently documented for children and adult samples, while our study extended and replicated these effects for adolescents. This is an important contribution given that adolescents experience frequent external distractions (Stawarczyk et al., 2014), which calls for school interventions for this target group in which the ability to concentrate will be promoted (Budde et al., 2008). We observed attentional benefits for students aged 15–18 years after 25 min of physical exercise. These results indicate that short-term exercise interventions may help adolescents to pay more attention in school and in turn increase learning success. This could be done, for example, by using cancelled lessons or prolonged breaks between lessons. The provision of a daily physical education lesson would also be justified, as adolescents seem to benefit from sport not only physically but also cognitively.

We further hypothesized that the coordination exercise group would show a higher improvement in attentional performance that the endurance and strength exercise groups. This proposition was based on evidence that coordinative tasks require more cognitive involvement than endurance and strength tasks (Budde et al., 2008; Chang et al., 2013). However, we did not find support for this hypothesis; all three exercise groups improved attention to a similar degree. This is at odds with previous studies (Budde et al., 2008; Janssen et al., 2014). This might be due to differences in experimental design. The previous experiments had used exercises of moderate intensity and 10–15 min duration, whereas we used longer exercise interventions (25 min) with moderate to high intensity. It is thus possible that our longer and more vigorous exercises increased blood and oxygen flow to the brain to an extent when the brain activation, including prefrontal structures, was generally high and no longer co-varied with motor complexity (cf. Rooks et al., 2010). Increased prefrontal activation thus emerged for each mode of exercise and the differences in their effects on attention disappeared.

The above explanation seems plausible when considering that especially speed scores, rather than error scores, improved after the exercise intervention. Participants in the exercise groups worked much faster than those in the control group, while being equally accurate in detecting the targets. Focus on speed rather than accuracy was associated with enhanced baseline activation in the brain areas related to response preparation and execution, including the dorsolateral prefrontal cortex (van Veen et al., 2008). Hence, our results may be explained by enhanced oxygenation and activation of the brain (Chang et al., 2012; Hillman et al., 2003; Pereira et al., 2007). Given that cerebral oxygenation remains elevated for up to 30 min after cessation of physical exercise (Faulkner et al., 2016), it is likely that the participants in the exercise groups took an advantage of the heightened cortical activity during recovery, which translated into improved attentional performance in the d2 task.

Our results showed that an acute bout of exercise was in general beneficial for adolescent students' attention, while the mode of the provided exercise training was not decisive. However, the endurance intervention (HIIT) was scored more demanding than the strength and coordination interventions, which might confound the results. McMorris et al. (2016) proposed that different exercise intensities influence the concentration of catecholamines, and in turn brain functions, consistent with the inverted-U hypothesis (Yerkes & Dodson, 1908). In this regard, moderate increases in catecholamine concentrations should facilitate cognitive performance, whereas excessive concentrations (from high-intensity and/or prolonged exercise) should inhibit cognition instead. Evidence supports this proposition for resistance exercise intensity (Engeroff, Banzer, & Niederer, 2022e exercise intensity. The recent meta-analysis on acute effects of HIIT, which included 147 effect sizes, showed that high-intensity exercise does not impair cognitive functions (Moreau & Chou, 2019). In particular, the meta-analysis found that both high-intensity and low-to-moderate intensity exercising conditions elicited similar gains in cognitive functions and that this facilitating effect was consistent across different exercise durations. Consequently, the higher intensity of the HIIT intervention in our study was unlikely to confound the study results.

The present study has several limitations. First, the study sample was recruited from a private school which requires tuition fees; consequently, participants were presumably from households with higher income. Adolescents from households with higher wealth engage more often in physical exercise outside school (Bann et al., 2019), which might have a positive effect on the participants' motivation and, in turn, the study findings. Future researchers should sample participants from families with different socio-economic status to enlarge the generalizability of our results. Second, we did not measure participants' physical fitness, but only controlled for how frequently participants engaged in sport and exercise inside and outside of school (which did not interact with the effects on attention). Several authors reported that effects of acute exercise may be fitness dependent in terms of greater benefits for more physically fit individuals (Budde et al., 2012; Tsai et al., 2014; Pesce et al., 2011). However, a recent meta-analysis found that the effect sizes for more physically fit individuals were only slightly (and non-significantly) higher than those for less physically fit individuals (Moreau & Chou, 2019). Consequently, it is likely that also participants with lower fitness benefited from the training interventions in our study. Still, future researchers should incorporate a direct test of physical fitness (e.g., VO_{2max} test) into their studies on physical exercise and attention. Finally, we only studied the effect of acute exercise in this study. The question arises whether a long-term exercise will have similar or even greater benefits for adolescent students' attention, and whether these benefits will depend on the mode of exercise. This remains an avenue for future research.

4. Conclusion

We tested whether 25 min of acute endurance, strength, and coordination exercises have an effect on adolescent students' attention. All three exercise interventions in this study led to improvements in post-exercise attentional performance, as compared with pretest and the control group. The magnitude of improvement was equal across the exercise interventions. Given that cerebral oxygenation remains elevated for up to 30 min after exercise (Faulkner et al., 2016), an acute bout of exercise is potentially ideal to stimulate students' learning performance as it promotes their attention. The mode of exercise seems of less importance here, as endurance, strength, and coordination tasks can all have a facilitative effect. School directors and teachers are encouraged to incorporate more exercise-related breaks into their school plan.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. In addition, the authors declare that the research was conducted in absence of any commercial relationships that could be conducted as a potential conflict of interest.

Data availability

Data are available on figshare (https://doi.org/10.6084/m9.figshare.19165883).

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