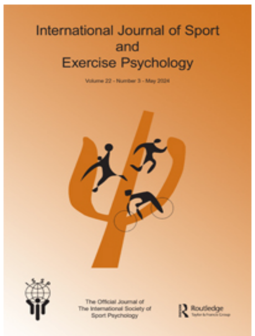

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Effects of 8-week endurance, strength, and coordination exercise interventions on attention in adolescents: a randomised controlled study

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ABSTRACT

The aim of this study was to test the effect of 8-week endurance, resistance, and coordination training programmes on adolescents' attention. Adolescent students ($N = 96$) aged 15–18 years were randomised to one of three exercise intervention groups (endurance, strength, coordination) or to a non-exercise, control group. The random assignment to the study groups was stratified according to participants' age and gender. The intervention lasted for eight consecutive weeks, with two 50-min training sessions per week. Before and after the exercise intervention, all participants completed the d2-test of attention. A 4×2 repeated measures ANOVA with contrast-coded test was used as the main analysis method. The analysis revealed that attentional test performance increased from before to after the exercise intervention for all exercise groups, as compared with the control group. The coordination group showed the highest, and the strength group the lowest, improvements in attentional performance. These results indicate that long-term exercise intervention is in general beneficial for adolescent students' attention, with the greatest effects being observed in the coordination exercise group. Physical education teachers are encouraged to enrich their lessons with coordinative tasks.

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Physical activity; chronic effect; school; attention; D2 test

Cognitive skills and attention are crucial for academic performance (Alloway & Alloway, 2010; Best et al., 2011), and are supported by a variety of brain regions that continue to mature throughout adolescence (Luna, 2009). Prominent developmental transformations in this period of the lifespan are seen in the prefrontal cortex and limbic brain regions (Johnson et al., 2009; Spear, 2000), with structural and functional changes including synaptic pruning, myelination, and integration of cortical areas, which results in fine tuning of cognitive abilities to perform complex tasks, be more precise, and control distraction (Luna, 2009). Adolescence is thus a period of great opportunity to promote

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cognitive development and learning through enriched environmental conditions such as, for example, physical activity and exercise (Chim et al., 2021; Hawley et al., 2014).

Physical exercise has been described as a type of physical activity which is planned, structured, and repetitive for the aim of better fitness and health (Caspersen et al., 1985). Yet the exercise benefits are not limited to improved fitness and health; improvements in cognitive skills and attention are also evident (Chaddock-Heyman et al., 2014; de Sousa et al., 2018; Landrigan et al., 2020). This study especially focuses on attention which has been broadly defined as the ability to selectively focus on an object or task (Rueda et al., 2015). It can be viewed as the learning foundation, which in time would influence most human activities, from the simplest tasks to the most complex ones. Because adolescents experience frequent external distractions (Stawarczyk et al., 2014), we need to understand how to best promote their ability to concentrate. Literature indicates that both acute and long-term exercise interventions have positive effects on people's attention (de Sousa et al., 2018). The effects of long-term interventions are particularly relevant here, as the regular engagement in physical exercise, rather than a single bout of exercise, might especially contribute to cognitive development in adolescents. Indeed, higher levels of physical fitness, which typically results from regular physical exercise (Poitras et al., 2016; Thomas et al., 2020), have been associated with better scores on various tests of attention (Reigal et al., 2020; Westfall et al., 2018) and higher academic performance in children and adolescents (Santana et al., 2016). The implication is that long-term physical exercise may be an effective strategy to promote the development of attentional skills in adolescent students.

In general, researchers distinguish different modes of exercise training, such as endurance, strength, and coordination, all of which may have an effect on adolescents' attention (de Sousa et al., 2018). Endurance and strength exercises are known to enhance people's aerobic capacity and improve cardiac performance (Spalding et al., 2004), which may facilitate attentional performance by increased blood and oxygen flow to the brain (Chang et al., 2012; Hillman et al., 2003; Pereira et al., 2007) and elevated levels of peripheral catecholamines and brain-derived neurotrophic factor (Ferris et al., 2007; McMorris et al., 2016; Moreau & Conway, 2013). Coordination exercise improves the body's control and is characterised by a closely coupled activation of the prefrontal cortex and the cerebellum (Stoodley et al., 2012), which requires (and promotes) a great deal of cognitive and attentional involvement (Budde et al., 2008; Netz, 2019; Serrien et al., 2006).

The positive effects of long-term exercise intervention on attention have been mostly reported on endurance exercise training, with fewer studies focusing on effects of strength or coordination exercise trainings (de Sousa et al., 2018). The evidence for endurance training is largely supportive (e.g., Alesi et al., 2016; Hillman et al., 2014; Iuliano et al., 2015), whereas strength training shows less consistent results (e.g., Liu-Ambrose et al., 2010; Nouchi et al., 2014; Vaughan et al., 2014). To directly compare the two, Iuliano et al. (2015) conducted an experimental study and found that only participants involved in endurance training improved their performance on an attention-demanding task. An experimental study on long-term coordination training and attention has not yet been reported (de Sousa et al., 2018), yet indirect evidence from studies on physical fitness, which is a combination of regular physical activity and genetically inherited ability (Ortega et al., 2018), shows that coordination positively correlates with attentional performance (Niederer et al., 2011; Páez-Maldonado et al., 2020; Reigal et al., 2020). A comprehensive meta-regression that compared different types of long-term exercise in relation to overall cognitive (or executive) function showed an overall positive effect of all types of exercise on cognition, with somewhat greater effectiveness of coordination exercise than endurance and strength exercises across various age groups (Ludyga et al., 2020).

The above evidence indicates a positive effect of different types of long-term exercise trainings on adolescents' attention, yet a study that would directly compare the effectiveness of these types of training is still missing from the literature. We thus conducted an evaluation of the different types of exercise to shed more light on which type of exercise activities has the highest potential to facilitate attention in adolescence. The aim of the study was twofold. First, we tested the effect of 8-week endurance, resistance, and coordination exercise interventions on adolescents' attention. Based on the above evidence that long-term exercise improves attention, we hypothesised that the three exercise intervention groups would increase their attentional test performance more than a non-exercise, control group. Second, we tested whether the three exercise interventions would have the same attentional benefits. Based on the consistently reported evidence for endurance training, we further hypothesised that the endurance exercise group would show a higher increase in attention that the strength and coordination exercise groups. Because schools are widely recognised as essential for promoting physical activity in children and adolescents (WHO, 2018), we sampled adolescent students and delivered the interventions in school setting.

Method

Study design

This was a preregistered, randomised intervention study with four groups and two distinct measurement occasions. Data are available on figshare (https://doi.org/10.6084/m9.figshare.23703237), and preregistrations of sample size and primary analyses are available on AsPredicted (https://aspredicted.org/mt9t4.pdf).

Participants

An a priori calculation with G*Power (Faul et al., 2007) for a 4 × 2 (Group × Phase) analysis of variance (ANOVA) with repeated measurements, based on a middle effect size (f = 0.25), power of 0.95, and the alpha level of .05, resulted in a minimal sample size of 76 participants. 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 24 persons with balanced sex distribution. The total sample thus included 96 students (48 women and 48 men). The participants attended between 2 and 5 h of physical education per week and the majority (80%) also reported being active outside the school. The study was approved by the ethics committee of the first author's institution (#00595). Participants and their parents signed an informed consent before taking part in the study.

Procedure

The study consisted of three distinct phases: a pretest, an 8-week exercise intervention phase, and a posttest. The pretest took place one week before the exercise intervention. Participants self-reported their age, gender, sport engagement, and academic grades, and then competed the d2-test of attention. The exercise intervention lasted for eight consecutive weeks, with two 50-min training sessions per week (i.e., 16 sessions in total). Each session consisted of a 10-min warm-up, the specific physical intervention (endurance, strength, or coordination; 25 min), and a cool-down at the end (15 min). The strength and coordination trainings took place in a sports hall, whereas the endurance training was performed on an outdoor-track. Rate of perceived exertion was measured immediately after the first training session using the Borg CR-10 scale. All training sessions were delivered outside of the regular PE lessons and on days when no regular PE lesson took place. In the posttest, one week after completing the exercise intervention, participants performed the d2-test of attention for the second time, were thanked for their participation and dismissed.

Intervention

We used stratified randomisation to assign participants to one of three exercise intervention groups (endurance, strength, coordination) or to a non-exercise, control group. Participants were first grouped into strata according to their age (15, 16, 17, and 18 years) and gender (male, female). Within each stratum, participants were then assigned to one of the four study groups by using randomisation function in Microsoft Excel (Microsoft, Redmond, WA). During the study, 24 persons (20% of all recruited persons) dropped out due to not completing all training sessions or the posttest. We kept recruiting until we reached 24 persons per group with equal age and gender distribution across groups (Figure 1). All exercise groups completed the same 10-min warm-up and 15-min cool-down at the start and the end of each session, respectively. The specific physical intervention (endurance, strength, or coordination) took place in-between and lasted for 25 min.

Participants in the *endurance group* performed a standardised 25-min high-intensity interval training (HIIT; Lüthy & Di Potenza, 2016). The HIIT started with a 90-second warm-up running and followed with 10 repetitions of hard sprinting for 20 s separated by 40 s of jogging for recovery. After 2 min of active rest (jogging casually), participants completed another 10 repetitions of sprinting and jogging, and concluded with a 90-second cool-down walking. Participants in the *strength group* performed a standardised 25-min full-body strength workout (Rühl & Laubach, 2014). The workout consisted of 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 four minutes rest between each circuit. Participants in the *coordination group* performed a standardised 25-min coordination circuit training (Hunzinker & Weber, 2008). The training comprised 10 exercises in a circuit, with 2 min work and 30 s rest between each exercise. The exercises were: simultaneous bouncing with two different balls (e.g., Soccer and basketball); 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

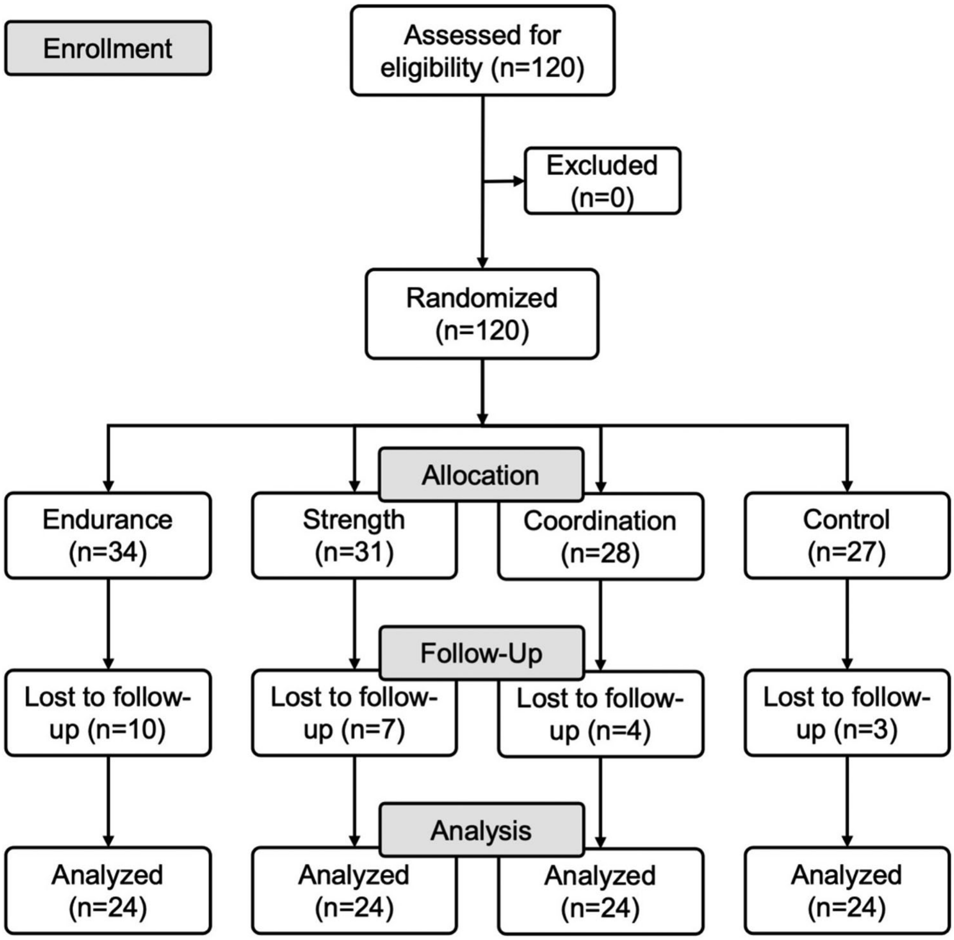

Figure 1. Flow chart showing the experimental design of the study.

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 physical education teachers who were trained in the training protocols. The compliance with the protocols was checked by the first author. Participants in the *control group* did not perform any physical exercise intervention and were instead asked to read a book of their choice. This "reading club" was supervised by a teacher and took place in exact the same time as the physical interventions did, but in a different room.

Measures

Participants self-reported their age, gender, and how frequently they engage in sport and exercise inside and outside of school. For the sport engagement, participants indicated the number of their weekly physical education hours, whether they are also active in sport and exercise outside the school (*yes* or *no*), and, if so, the average number of hours per week they spent doing sport or exercising during the last month. To control for participants' academic achievements, participants also 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 a single academic achievement score.

Attention was measured with the revised d2-test of attention (Brickenkamp et al., 2010), which is a reliable and commonly used measure of concentrative capacities (Steinborn et al., 2018), and easily applicable to school settings (Bölte et al., 2000). The test consists of 14 rows of letters (*d*'s and *p*'s) that are each surrounded with up to four short dashes. Participants' task is to search each row for *d*'s with two dashes 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 includes 57 items and there is a time limit of 20 s per row. Participants were asked to work as fast and accurately as possible while completing the test. Three main scores were computed from the test: the concentration performance score, the error score, and the speed score. The concentration performance score is the absolute number of detected targets minus the number of omission and commission errors, thus reflecting both speed and accuracy. The error score represents the percentage of processed items that were processed incorrectly (either due to omission or commission errors). Finally, the speed score represents the absolute number of detected targets.

Perceived physical exertion was assessed with an adapted version of the Borg CR-10 scale (Foster et al., 2001). The CR-10 scale is a 11-point Likert scale, with the score ranging from 0 (*nothing at all*) to 5 *(heavy)* to 10 (*very, very heavy*) and nominal descriptors attached to the respective intensities.

Statistical analysis

To test the homogeneity of groups, separate one-way ANOVAs were conducted on the hours of sport and exercise activities inside and outside of school, and on academic achievement. 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 whether the three exercise intervention groups would improve attention more that the control group, and the other contrast-coded analysis (LMATRIX +2, −1, −1, 0 for the endurance, strength, coordination, and control group, respectively) tested whether the endurance exercise intervention would have a higher effect on attention that the coordination and strength exercise interventions. In addition, we also conducted the contrast-coded test for the strength group (LMATRIX −1, +2, −1, 0) and the coordination group (LMATRIX −1, −1, +2, 0). The M matrix was specified as MMATRIX −1, +1 for the respective pretest and posttest attentional scores. All analyses were performed with SPSS 26.0 (IBM Corp.; Armonk, NY, United States). For the contrast-coded tests, we used the Bonferroni-adjusted p value of .0125. The significance level for all other analyses was set at $p < .05$ (two tailed).

Results

Characteristics of the study groups are presented in Table 1 and attentional scores are in Table 2. The study groups did not differ in academic achievement and the hours of sport and exercise inside and outside of school. Regarding the intensity of the intervention, the intervention groups differed in perceived exertion, $F(2,69) = 9.03$, $p < .001$, $\eta_p^2 = .21$, with participants reporting higher exertion during the endurance intervention than during the strength intervention ($p < .018$) and the coordination intervention ($p < .001$). The strength and coordination groups did not differ in the rate of perceived exertion ($p = .563$).

Concentration performance score improved from pretest to posttest for all groups, as indicated by the main effect of Phase, $F(1, 92) = 306.80$, $p < .001$, $\eta_p^2 = .77$. Moreover, the interaction effect was significant, $F(3, 92) = 10.07$, $p < .001$, $\eta_p^2 = .25$, indicating that the improvement in attention varied across groups. Contrast-coded test (+1, +1, +1, −3 for the three intervention groups and the control group, respectively) was significant, $F(1, 92) = 20.36$, $p < .001$, $\eta_p^2 = .18$, indicating that participants in the intervention groups improved more than control participants. Separate contrast-coded tests for the intervention groups revealed a significant contrast for the strength group, $F(1, 92) = 8.64$, $p = .004$, $\eta_p^2 = .09$, a marginally significant contrast for the coordination group, $F(1, 92) = 5.84$, $p = .018$, $\eta_p^2 = .06$, and a non-significant contrast for the endurance group, $F(1, 92) = 0.28$, $p = .601$, $\eta_p^2 = .00$. The coordination group showed the highest, and the strength group the lowest, improvement in concentration performance.

Error score declined significantly from pretest to posttest, $F(1, 92) = 158.97$, $p < .001$, $\eta_p^2 = .63$, yet the level of decline varied across groups, $F(3, 92) = 8.06$, $p < .001$, $\eta_p^2 = .21$. Contrast-coded analysis for the three intervention groups versus the control group was significant, $F(1, 92) = 12.63$, $p = .001$, $\eta_p^2 = .12$, indicating that participants in the intervention groups made fewer errors than control participants in the posttest. Contrast-coded tests for the intervention groups yielded significant results for the coordination group, $F(1, 92) = 8.80$, $p = .004$, $\eta_p^2 = .09$, and the strength group, $F(1, 92) = 8.53$, $p = .004$, $\eta_p^2 = .09$, but no significant result for the endurance group, $F(1, 92) = 0.002$, $p = .965$, $\eta_p^2 = .00$. Participants in the coordination group showed the highest, and participants in the strength group the lowest, improvement in their accuracy by detecting the targets.

Table 1. Characteristics of the study groups.

	Endurance ($n = 24$)	Strength ($n = 24$)	Coordination ($n = 24$)	Control ($n = 24$)	F	p	η^2
Hours of sport in leisure time per week, *M* (*SD*)	6.05 (1.81)	6.22 (2.29)	6.27 (2.86)	7.44 (2.43)	1.29	.283	0.05
Hours of physical education per week, *M* (*SD*)	3.25 (1.33)	3.25 (1.33)	3.25 (1.33)	3.25 (1.33)	0.00	1.00	0.00
Academic grades, *M* (*SD*)	2.42 (0.62)	2.61 (0.56)	2.61 (0.69)	2.86 (0.92)	1.57	.201	0.05
Perceived exertion, *M* (*SD*)	7.67 (0.82)	6.96 (0.81)	6.63 (0.97)	—	9.03	<.001	0.21

Note: Groups are stratified according to age and gender; each study group includes three women and three men of each age category (15, 16, 17, and 18 years). 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 ($n = 24$)	Strength ($n = 24$)	Coordination ($n = 24$)	Control ($n = 24$)	ANOVA			
					Effect	F	p	η^2
Concentration score					P	306.80	<.001	0.77
Pre	149.79 (20.69)	162.25 (23.52)	149.92 (22.49)	157.40 (23.26)	G	1.73	.166	0.05
Post	190.87 (15.37)	192.25 (14.00)	197.04 (10.66)	175.99 (21.97)	$P \times$ G	10.07	<.001	0.25
Error score					P	158.97	<.001	0.63
Pre	11.54 (4.76)	9.65 (5.13)	13.85 (5.86)	10.14 (5.74)	G	1.11	.350	0.04
Post	4.32 (2.62)	4.76 (2.17)	4.21 (2.90)	6.95 (4.34)	$P \times$ G	8.06	<.001	0.21
Speed score					P	151.33	<.001	0.62
Pre	169.54 (23.05)	179.33 (22.64)	173.71 (21.31)	174.52 (20.81)	G	1.62	.189	0.05
Post	199.58 (16.19)	201.83 (13.54)	205.88 (12.59)	188.92 (19.87)	$P \times$ G	3.96	.011	0.11

Note: P = Phase; G = Group; $P \times$ G = Phase $\times$ Group interaction.

Regarding speed score, there was an significant main effect of Phase, $F(1, 92) = 151.33$, $p < .001$, $\eta_p^2 = .62$, and a significant interaction, $F(3, 92) = 3.96$, $p = .011$, $\eta_p^2 = .11$. Contrast-coded analysis for the three intervention groups versus the control group was significant, $F(1, 92) = 8.70$, $p = .004$, $\eta_p^2 = .09$, indicating that participants in the intervention groups increased their working speed to a higher degree than control participants. Separate contrast-coded tests for the intervention groups yielded no significant results, indicating that the improvement in working speed was the same regardless of the type of intervention.

Discussion

The aim of this study was to test the effects of three different modes of long-term exercise training – endurance, strength, and coordination – on adolescents' attention. As hypothesised, we found that concentration performance improved after the 8-week training intervention (two sessions/week) for all exercise groups, as compared with the control group. In contrast to hypothesis, we further found that participants involved in coordination training, rather than those involved in endurance training, showed the highest attentional benefits. Participants in the strength group improved attention to the lowest degree. These results indicate that long-term exercise is in general beneficial for adolescents' attention, with coordination exercise training showing the highest impact.

The finding that all three training groups improved their attentional performance is in line with previous evidence showing that exercise training intervention generally results in positive changes in attention (de Sousa et al., 2018). Several studies with children and older adults found that attentional test score increased from before to after a long-term exercise intervention (e.g., Alesi et al., 2016; Hillman et al., 2014; Liu-Ambrose et al., 2010; Vaughan et al., 2014). We replicated this effect for adolescents. This is an important contribution given that adolescence is a sensitive period of maturation, where fine tuning of cognitive functions take places until a mature level of performance is achieved in early adulthood (Luna, 2009). Physical exercise seems to promote this cognitive development and may in turn add to adolescents' psychosocial adjustment and learning (Crone & Dahl, 2012; Santana et al., 2016; Stawarczyk et al., 2014).

We further tested whether different types of exercise differ in their effect on attention. Positive results have been most often reported for endurance exercise training (de Sousa et al., 2018), which let us assume that this type of training would have higher effect than strength and coordination trainings. However, contrast analysis showed that participants involved in coordination training, rather than endurance training, showed the highest improvements in attentional performance. This may be explained by higher demands on cognitive involvement due to higher motor complexity of coordinative tasks. In particular, researchers observed that more complex motor tasks require more prefrontal cortex activity, and thus a higher variety of frontal-dependent cognitive processes, than basic or automatic motor behaviours that are more controlled by the basal ganglia (Netz, 2019; Serrien et al., 2006). Consequently, coordinative exercise may especially facilitate and develop cortical centres responsible for cognitive functions including attention, whereas the less complex endurance and strength exercises might require individuals to perform more automated movements and thus prefrontal structures might not be required to the same extent as in the coordinative tasks (Koutsandreou et al., 2016).

The effect of coordination exercise training is also in line with the recent meta-analysis by Ludyga et al. (2020) who reported greater effect of coordination exercise than endurance and strength exercises on overall cognitive/executive function, as derived from moderator analysis within a meta-regression model. Coordinative tasks may thus bring the highest benefits not only for attention, but for the cognitive function in general. Ludyga et al. further observed similar effects for both endurance and strength training interventions, whereas we found that participants in the strength group benefited least from the intervention. However, this should be interpreted with caution because the mechanisms that trigger benefits of this exercise type for cognition are less clear and the reported effects on attention are mixed (de Sousa et al., 2018). We need more experimental studies that would directly compare different types of long-term exercise in their effects on cognitive function in general, and attention in particular, to allow for a definitive conclusion.

Our exercise intervention lasted for eight consecutive weeks, with two 50-min training sessions per week. This was comparable with prior research on long-term exercise intervention, in which the intervention typically lasted for six weeks or more, with the mean frequency of 2.8 session per week and the mean session duration of 53.9 min (Ludyga et al., 2020; Xue et al., 2019). Prior evidence is inconclusive regarding the dose parameters, with meta-analyses either showing a higher effect of exercise on cognitive performance with shorter (Xue et al., 2019) or longer session duration (Northey et al., 2018), or no association between the effect size and single dose parameters (Ludyga et al., 2020). However, a meta-analysis of results with child and adolescent samples observed the highest benefits in the modalities of curricular physical activity (Xue et al., 2019), indicating that the particular setting the participants were used to might provide the optimal dose parameter. We therefore chose two 50-min session per week because it corresponded to the school setting in which the study was conducted.

The present study has multiple strength, including well-standardised training protocol, a randomised controlled research design, and high statistical power to detect predicted effects. Moreover, the study was enacted under real-life setting (i.e., school), which increases the generalisability of its results. However, this study also has several limitations. First, participants were recruited from a private school which requires tuition fees; consequently, the sample presumably comes from families with higher socio-economic status. Students from households with higher wealth engage more often in physical activity outside school (Bann et al., 2019), which might positively influence the participants' motivation to take part in the study. Future researchers should sample students from families with different socio-economic status to enlarge the generalisability of our results. Second, the coordination exercise intervention also included a component of strength and vice versa, as it is difficult to completely isolate both strength and coordination components. Third, we did not test gender and age differences in our analyses. Our sample size would be too small to include further predictors in the group analyses. Rather, we stratified the intervention and control groups according to participants' age and gender, so that equal number of men and women of each target age were included in each study group. The present results should therefore not be confounded by gender or age differences, yet we cannot conclude whether different gender or age groups benefit more from a particular exercise intervention. Finally, the endurance intervention was scored more demanding than the strength and coordination interventions. While it is plausible to expect that high-intensity interval training will be perceived as demanding, a recent meta-analysis also found no evidence for main effect of exercise intensity on exercise-induced cognitive benefits (Ludyga et al., 2020). Consequently, it is unlikely that the higher intensity of the HIIT intervention in our study confounded the study results.

The results of this research also suggest practical implications. Due to the school regulations, we had to deliver the exercise interventions as an extracurricular activity, yet still in the school context. The participation led to clear benefits for participants' attention. The school setting may thus become a useful place for informal exercise activities, such active breaks between classes or after-school programmes. School directors could even think of allocating a greater portion of curricular time to exercise programmes. This need not necessarily mean to increase the curricular time in an absolute number. Rather, school directors may take time from other, so-called academic subjects. Prior research showed that taking an hour from other subject and allocating it to sport and exercise does not hinder student academic achievement (Trudeau & Shephard, 2008). Consequently, allocating more time to physical exercise activities does not seem to come at the cost of academic performance. In contrast, such activities are likely to promote students' attention which is an indirect but important factor in academic achievement.

Conclusion

This study showed that long-term exercise intervention might be a promising way to promote attention in adolescent students. School directors may thus allocate a greater portion of curricular time to exercise programmes. This may be achieved by taking time from other subjects, even without risk of hindering student academic achievement (Trudeau & Shephard, 2008). The study further indicates that the inclusion of coordination activities might be especially beneficial for adolescent students' attention. Physical education teachers are thus encouraged to enrich their lessons with coordinative tasks.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

Data are openly available at figshare (https://doi.org/10.6084/m9.figshare.23703237). The preregistration can be found under https://aspredicted.org/mt9t4.pdf.

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