Do different cognitive domains mediate the association between moderate-to-vigorous physical activity and adolescents' off-task behaviour in the classroom?

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Background. Accumulating evidence suggests that adolescents' moderate-to-vigorous physical activity (MVPA) is associated with less off-task behaviour in the classroom. However, the contribution of cognitive functions to this relation still remains unclear. Executive function and aspects of social cognition, which appear to be correlated with MVPA, have been found to determine academic behaviours.

Aim. This study examines the direct association between MVPA and off-task behaviour as well as mediations by different cognitive domains.

Sample. Forty-six-male and 67-female adolescents aged 13.0 ± 1.3 years were recruited from local schools.

Methods. Participants recalled their MVPA. Using video cameras, their classroom behaviours were recorded and a 6-min period was rated for off-task behaviour. Additionally, participants completed a modified Flanker task, which assessed both inhibitory control and cognitive flexibility, a Sternberg paradigm, which assessed working memory, and an Emotion Recognition task.

Results. Path-analyses revealed that higher MVPA was associated with less off-task behaviour. Inhibitory control accounted for a partial mediation of this association. The mediating role of inhibitory control was most pronounced for the relation between MVPA and off-task behaviours related to noise.

Conclusion. These findings provide a first indication that curricular and extracurricular physical activities targeting specific improvements in inhibitory control may promise transfer effects to classroom behaviours.

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In addition to social integration and preparation of children and adolescents for an active citizenship, one major aim of schools is to help students achieve their full academic potential (including academic skills, academic achievement, and related domains). Among a variety of ways to achieve this, academic performance is suggested to benefit from the promotion of academic behaviours (Georgiou, Manolitsis, Nurmi, & Parrila, 2010; Stephenson, Parrila, Georgiou, & Kirby, 2008), including on-task behaviour, planning, attendance, scheduling, and impulse control. Longitudinal findings further support that classroom behaviour in adolescence predicts educational attainment, occupational prestige, and income later in life above and beyond intelligence, socio-economic status, and personality (Spengler, Damian, & Roberts, 2018). The classroom is a learning environment that usually requires the maintenance of an on-task focus and the resistance to off-task temptations, because these are related to impairments in motivation and academic achievement (Kilian, Hofer, Fries, & Kuhnle, 2010; Moffett & Morrison, 2020). Off-task behaviour is present when students are not focusing on the instructional activity or the current learning task. It can be observed in the form of fidgeting, producing noise, being passive, and other types of behaviours (Godwin et al., 2016). The field of educational psychology suggests many effective classroom management strategies to promote on-task behaviour (and thereby reduce off-task behaviour), such as the development of classroom rules, the enforcement of positive behaviours, and the use of self-monitoring strategies (Moore, Anderson, Glassenbury, Lang, & Didden, 2013; Ratcliff et al., 2010). However, the attentiveness within the classroom can also be supported by interventions that are performed outside the school curriculum.

Among the interventions that involve a modification of behaviour, meta-analytical findings indicate that physical activity appears to elicit a small, but positive effect on children and adolescents' academic skills (Álvarez-Bueno et al., 2017; Greeff, Bosker, Oosterlaan, Visscher, & Hartman, 2018). Given that cardiorespiratory fitness predicts changes in academic skills over time, a prerequisite for physical activity to be effective may be the promotion of this aspect of fitness (Sardinha et al., 2016; Suchert, Hanewinkel, & Isensee, 2016). In this respect, physical activities at moderate-to-vigorous intensity are known to enhance cardiorespiratory fitness in adolescents (Silva et al., 2013). This might partly explain why moderate-to-vigorous physical activity (MVPA) performed during the school day results in lower rates of off-task behaviour in the classroom (Carlson et al., 2015). Further support for this association is provided by cross-sectional data showing that children, who spent less time sedentary at school, were more likely to belong to a well-adjusted class with a high proportion of on-task behaviour (Brusseau & Burns, 2018). Moreover, interventions that implemented short MVPA bouts into the class or break-time either found an improvement (Goh, Hannon, Webster, Podlog, & Newton, 2016; Norris, Dunsmuir, Duke-Williams, Stamatakis, & Shelton, 2018) or no change in on-task behaviour (Wilson, Olds, Lushington, Petkov, & Dollman, 2016). This discrepancy might partly be due to previous research focusing on physical activity performed throughout the school day rather than considering the overall physical activity levels. Moreover, the current evidence mainly stems from studies with children, but greater benefits for on-task behaviour may be expected in adolescents. This is due to pronounced reductions in MVPA during the transition from childhood to adolescence that lead to a greater reserve for behavioural modifications (Reilly, 2016).

The utility of physical activity in the promotion of on-task behaviour requires an understanding of the cognitive functions that contribute to this association. The current evidence suggests different cognitive domains to be key determinants of class room related behaviours (Garner, 2010). Executive function (i.e., top–down control of

behaviour) in particular has been found to explain an even greater proportion of variance in academic achievement than intelligence (Samuels, Tournaki, Blackman, & Zilinski, 2016), so that its contribution to academic behaviours appears reasonable. In contrast, other domains, such as attention and processing speed, have not been related to academic outcomes (Peterson et al., 2017). The key role of executive function is corroborated by the finding that executive function mediated the benefits of an after-school intervention for learning-related and problem behaviour in the classroom (Brock, Murrah, Cottone, Mashburn, & Grissmer, 2018). As executive function seems to be a multi-facetted construct, consisting of inhibition, cognitive flexibility, and working memory (Diamond, 2013), students' individual executive function profile may explain inter-individual differences in their off-task behaviour. Cross-sectional data provide support for this hypothesis as children with low inhibitory control were more likely to actively engage with non-relevant materials (e.g., playing with a pen when it is not required), whereas passive behaviour was more frequently reported among students with low working memory (Moffett & Morrison, 2020). In addition to executive function, emotion recognition and knowledge may impact on classroom behaviour due to their predictive value for school-related outcomes (Garner, 2010). This may in part be explained by the longitudinal relation between poor emotion recognition ability and problem-related behaviours (Castro, Cooke, Halberstadt, & Garrett-Peters, 2018). In turn, the accurate recognition of emotions is a pre-requisite of emotional regulation and can therefore improve the effectiveness of positive reinforcement and behavioural adjustments in the classroom (Denham et al., 2012). Moreover, this cognitive function mediates the link between teacher-student relations and perceived school competence (Garner & Waajid, 2012).

Taken together, empirical evidence suggests that executive function and emotion recognition may be pathways, by which academic behaviours can be promoted. These cognitive domains have also been reported to be sensitive to physical activity. Independent from age, recent meta-analytical findings support small improvements of executive function and other cognitive domains in healthy individuals following physical activity interventions (Ludyga, Gerber, Gerber, Pühse, Looser, & Kamijo, 2020). Based on studies combining behavioural and neuroimaging assessments, physical activities that enhance cardiorespiratory fitness (e.g., MVPA) have been found to elicit benefits for executive function by a facilitation of cognitive control processes, such as more effective allocation of attentional resources (Kao et al., 2020), and the promotion of structural properties of brain regions underlying these processes (Lubans et al., 2016). When the setting is considered, executive function seems to benefit from curricular physical activity and sports programs, whereas physical activity integrated in the classroom appears to be ineffective for the elicitation of long-term changes in this cognitive domain (Xue, Yang, & Huang, 2019). This further highlights the need to pay attention to the overall physical activity levels rather than such activities during class or school-day alone, when their influence on classroom behaviours is examined. In contrast to other cognitive domains, less is known about the association between physical activity and social cognition. The limited evidence suggests acute benefits of aerobic exercise for children and adolescents' emotion-recognition skills (Brand et al., 2019). Similarly, higher cardiorespiratory fitness in adults has been associated with a greater ability to label and match emotions from faces (Ludyga, Schilling, et al., 2020). Recalling the beneficial effect of MVPA on cardiorespiratory fitness (Silva et al., 2013), regular engagement in such activities might also be linked to improved emotion recognition among adolescents. Despite the predictive value of executive function and emotion recognition for classroom behaviour and their sensitivity

to MVPA, possible mediating roles of these cognitive functions have not been examined so far.

This study aimed to examine the association between MVPA and off-task behaviours in adolescents and its potential mediation by different cognitive functions, including inhibitory control, cognitive flexibility, working memory, and the emotion recognition aspect of social cognition. Interrelations among the cognitive functions were accounted for to examine their relative contributions to a possible association between MVPA and off-task behaviour. Based on previous findings regarding cognitive correlates of off-task behaviour (Brock et al., 2018; Castro et al., 2018; Moffett & Morrison, 2020), we expected executive function and emotion recognition to mediate the relation between MVPA and off-task behaviour in adolescents.

Method

Participants

Male and female participants were directly recruited from three schools in an urban region of the North-eastern part of Switzerland after they received information on study procedures, possible risks, and benefits. The recruitment was restricted to school classes taught on the highest educational level (i.e., classes included students with high academic performance, who received no special education services). Participants and their legal guardians provided informed written consent. Eligibility criteria comprised an age range of 10–16 years, corrected-to or normal vision, and being able to participate in physical education. Exclusion criteria were injuries of the left or right hand, any acute/chronic disease that posits an elevated health risk during physical activity, and the participation in special education services (e.g., due to mental disorders). Prior to the study, its protocol was submitted to and approved by the local ethics committee (Ethikkommission Nordwest- und Zentralschweiz). All study procedures were in line with the guidelines set forth by the Declaration of Helsinki.

Procedure

After being interviewed on physical activity using the 7-Day Physical Activity Recall Protocol and the collection of anthropometrics, participants filled in the Strengths and Difficulties Questionnaire (Goodman & Goodman, 2009) and the Insomnia Severity Index (Morin, Belleville, Bélanger, & Ivers, 2011). Within the same week, but on a separate day, computer-based cognitive tasks were administered to assess inhibitory control, cognitive flexibility, working memory, and emotion recognition. Additionally, on- and off-task behaviours in the classroom were recorded using video cameras. All assessments were performed during a regular school day and inter-individual differences in measurement time points were not allowed to exceed 60 min. Cognitive testing (7–8 a.m.) and classroom behaviour recordings (8–9 a.m.) were both administered in the morning hours.

Classroom behaviour

Classroom behaviour was recorded using two video cameras, which were positioned in a way that allowed the observation of the participants' behaviour and eye gaze from two different angles. Participants were not informed on the purpose of the observation. Instead, they were told that their teachers will use video recordings for

reflection of their own performance. The first 25 min of the class were recorded, of which 6 min were dedicated to the introduction of a new topic. On-task and off-task behaviour was rated for this time period only, so that demands of the selected epoch did not differ between participants. Similar to previously employed observation protocols (Mahar et al., 2006), two trained experimenters independently rated 10 s epochs as either on- or off-task behaviour, which summed up to 36 observations for each participant. The intra-class correlation coefficient for ratings from these two experimenters was 0.86. A third experimenter resolved potential discrepancies between raters. In contrast to direct observations in the classroom (with switching from one participant to another in regular intervals), the present method allowed the comparison of inter-individual differences in on-task and off-task behaviours based on the same time period. On-task behaviour was defined as gaze directed towards the teacher or the study material, any verbal or motor behaviour that is in line with class rules and appropriate for the learning situation. Similar to previous studies, any divergent conduct was rated as off-task behaviour and further categorized into off-task motor (e.g., excessive fidgeting), noise (e.g., speaking out of turn), and passive/other (e.g., gaze that is not directed to the teacher or study material) (Cook, Bradley-Johnson, & Johnson, 2014; Mahar et al., 2006).

Physical activity

Using the 7-day physical activity recall protocol, the time spent in physical activities of moderate and vigorous intensity was recorded for each day of the recall period. The recall protocol has been found to be a valid instrument for the assessment of physical activity (Leenders, Sherman, Nagaraja, & Kien, 2001; Zuazagoitia et al., 2014). Even though ratings may to some extent be affected by a selection bias, the use of this instrument has a significant advantage over objective physical activity assessments (via accelerometers) in children and adolescents. That is, many physical activities typical for these age groups in Switzerland are difficult to assess with accelerometers due to specific requirements (e.g., waterproof accelerometers during swimming) and/or safety issues (e.g., increased risk of injury during ball sports and martial arts). Other concerns that question the validity of accelerometer-based assessments are the dependence on the algorithm used to separate intensities, limited between-studies comparability due to different processing and analysis schemes and the reactivity of adolescents to accelerometers (Dössegger et al., 2014; Pedišić & Bauman, 2015). The recall protocol provides a more realistic/ comprehensive picture of children's general physical activity level. The obtained recall protocols were considered valid and were included in the statistical analyses, if the participants were able to recall the full week and no injury or other circumstances limited their engagement in physical activities. Average time spent in moderate and vigorous physical activities per day was calculated and extracted for statistical analyses.

Cognition

Computer-based versions of the Flanker Task, Sternberg Paradigm, and an Emotion Recognition Task were administered with E-Prime 2.0 (PST, Pittsburgh, PA). Participants completed testing in a seated position, with a viewing distance of approximately 80 cm. The surrounding noise was kept to a minimum and the environmental temperature was 21°C ± 1°C. The testing sequence was identical for all participants (Flanker Task

inhibition blocks, Flanker Task switch blocks, Sternberg Paradigm, Emotion Recognition Task) and lasted 20–25 min, so that no sequence effects due to cognitive fatigue were expected (Ackerman & Kanfer, 2009). Each task included a practice block to ensure participants understood the task. Behavioural performance was assessed from the subsequent blocks. The number of trials that were used to calculate average reaction times and accuracy were 50 for the inhibition and switch blocks in the Flanker Task, 28 for the Sternberg Paradigm and 40 for the Emotion Recognition Task. Reaction time (for response-correct trials) and accuracy were calculated for the different trial and block types.

During the inhibition blocks of the Flanker Task, participants were required to respond to the viewing direction of a centrally presented target fish amidst flanking fish by pressing a button corresponding to left or right. The four flanking fish were either facing in the same (congruent trials) or in a different direction (incongruent trials) as compared with the central target fish. The order of the trials was randomized and the congruency (congruent, incongruent) as well as the directionality (left, right) of the stimuli appeared with equal probability. Following an inter-trial interval that varied randomly between 600 and 900 ms, white fish were presented against black background for 1,900 ms or until a response was collected.

The modified Flanker Task further included blocks demanding task-switching. During the task, either white or blue fish were presented against black background. For white fish, the rules of the previous inhibitory task applied so that participants had to indicate the direction of the central fish (regular trials). In contrast, participants were instructed to respond to the direction of the flanking fish, when these were presented in blue colour (switch trials). Regular and switch trials appeared in a randomized order and with equal probability.

For the Sternberg Paradigm, the five fish from the Flanker Task remained as visual stimuli, but they were all facing the same direction. The memory array was shown for 2,500 ms and contained fish of different colours, which were matched by intensity and saturation. Following an inter-trial interval of 1,500-ms duration, during which the screen went blank, a single probe was presented in the centre of the screen. The probe was a fish shown either in the same or a different colour than the previously presented fish. Participants were instructed to decide whether the probe was included in the previously presented array of fish by pressing a button corresponding to yes or no. With the onset of the probe, responses were collected within 2,500 ms. The inter-trial interval was fixed to 250 ms.

The Emotion Recognition Task included blocks requiring emotion labelling and matching. During emotion labelling, participants were instructed to select the emotion expressed by a centrally presented face from a pair of emotions written at the bottom of the screen. During emotion matching, the pair of emotions was replaced by two faces and participants had to identify the face expressing the same emotion as the centrally presented face. Participants provided their responses by pressing a button corresponding to the left or right emotion (emotion labelling) or face (emotion matching). The visual stimuli remained on the screen until a response was collected and trials were separated by a 250-ms interval. The faces of male and female individuals used in the task were obtained from the human face database of the Max-Planck Institute (Troje & Bülthoff, 1996). The faces expressed five basic emotions: happiness, sadness, anger, disgust, and fear. These emotions were presented with equal probability and in a randomized order. The emotion labelling and matching trials were administered in two separate blocks, which were averaged to derive reaction time and accuracy.

Statistical analysis

Sample size calculation for testing the direct effect was performed with G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007). Previous cross-sectional studies reported correlations ranging from $r = .17$ to $r = .45$ between MVPA/sedentary behaviour and classroom behaviour (Brusseau & Burns, 2018; Carlson et al., 2015). Based on an average effect size of $r = .30$ and an alpha level of $p = .05$, 84 participants were required to reach 80% power on a bivariate correlation analysis. For testing the mediation model, the conservative approach for path-analysis with no latent variables suggests at least 10 participants per observed variable (Little & Kline, 2016), so that 60 participants were necessary for an uncontrolled model with MVPA as predictor, four potential mediators and off-task behaviour as outcome. Additionally, guidelines for testing mediation models, which were derived from simulations, were used to verify this estimated sample size (Fritz & Mackinnon, 2007). Previous studies observed moderate associations between executive function and classroom behaviour (Brock et al., 2018; Moffett & Morrison, 2020) as well as between MVPA and various cognitive performance outcomes (Willoughby, Wylie, & Catellier, 2018). Given these effect sizes, 74 participants were necessary to reach 80% power on the model provided by Fritz and Mackinnon (2007).

Statistical analyses were performed with SPSS 25.0 (IBM, USA) and the AMOS interface. Following visual inspection, Gaussian distribution of the data was checked using the Shapiro–Wilk test. Variables with a non-normal distribution and skewedness/kurtosis z-values exceeding 3.29 (Kim, 2013) were log-transformed prior to hypothesis testing. To investigate the association between potential confounders (age, sex, psychopathology, sleep, and body mass index), the predictor (MVPA) and outcomes (reaction time and accuracy on cognitive tasks, off-task behaviour), zero-order correlations were calculated. The effect of the recruitment school on the mediators and outcomes was assessed using univariate ANOVAs. Subsequently, path-analyses were employed to examine the association between MVPA and off-task behaviour (Model 1) as well as a possible mediation by cognitive performance (Model 2). Individual mediation paths were added for reaction time on incongruent (indicating inhibitory control) and switch trials (indicating cognitive flexibility) of the Flanker Task, the Sternberg task (indicating working memory) and the Emotion Recognition Task. The likeliness of a speed-accuracy trade-off was investigated by replacing reaction time by accuracy for each cognitive task (Model 3). As inter-relations between the cognitive domains were assumed, covariances between cognitive performance outcomes were estimated. In case of a mediation of the association between MVPA and off-task behaviour by cognitive performance outcomes, additional data-driven models were specified to examine whether the mediation differed between the assessed types of off-task behaviour. These additional models included one mediating variable at a time. In all pre-specified and data-driven models, confounders showing a correlation of $r \geq .15$ and/or a trend towards a statistical significance ($p \leq .10$) based on zero-order correlations were accounted for by covariance estimation. In case of missing data, the full information maximum likelihood approach was applied due to a lower bias and higher efficiency in comparison with other common methods (Enders & Bandalos, 2001). For the paths in each model, the null hypothesis assuming that regression coefficients equal zero was tested and rejected at $p < .05$. The fits of the models to the data were investigated using absolute and relative fit indices, with RMSEA $\leq .08$ and $\chi^2/df \leq 2$ considered as good (Hu & Bentler, 1999; Iacobucci, 2010). When the preliminary univariate ANOVA indicated that off-task behaviour and/ or cognitive performance differed significantly between the recruitment schools, models were calculated and compared between recruitment schools.

Results

Seven participants were excluded from the full analysis because their accuracy rates on the practice trials of the different cognitive tasks were 50% or lower, resulting in a final sample of $N = 113$ (recruited from three schools and two classes per school). Given the sample size calculation, the study was sufficiently powered. Participants' anthropometric data, psychopathology, sleep, physical activity, and classroom off-task behaviour of are shown in Table 1. Zero-order correlations revealed relations of sex, age, and sleep with the predictor and/or at least one outcome (Table 2). In subsequent path-analyses, these variables were accounted for. As off-task behaviour, $F(2, 113) = 0.96$, $p = .384$, and performances on individual cognitive tasks (Table A1, Appendix A), $F(2, 113) \leq 2.77$, $p \geq .067$, did not differ between recruitment schools, path-analyses were conducted with the full sample only. Participants' reaction time and accuracy on the different cognitive tasks are displayed in Table 3.

Model 1 showed a moderate association between MVPA and off-task behaviour (Figure 1, upper panel), $\beta = -0.29$, $p = .001$, indicating that higher levels of MVPA were related to lower off-task behaviour in adolescents. When the mediation by cognitive performance was included (Model 2), this association decreased, but remained statistically significant, $\beta = -0.21$, $p = .024$. The different cognitive performance outcomes were inter-related, $\beta \geq 0.27$, $p \leq .006$, except incongruent reaction time and reaction time on the Sternberg Task. With regard to indirect effects, only incongruent reaction time was related to both MVPA, $\beta = -0.26$, $p = .006$, and off-task-behaviour, $\beta = 0.34$, $p = .004$. Additionally, a small correlation between reaction time on the Sternberg Task and off-task behaviour was observed, $\beta = 0.20$, $p = .042$.

When reaction time was replaced by accuracy indices (Model 3), the association between MVPA and off-task behaviour was moderate (Figure 1, lower panel), $\beta = -0.29$, $p = .001$, and comparable with the relation found in Model 1. Inter-relations were found between accuracy on the Emotion Recognition task and accuracy on all other tasks, $\beta \geq 0.20$, $p \leq .046$, as well as between accuracy on incongruent and switch trials of the

Table 1. Participants' anthropometric data, psychopathology, sleep, physical activity, and off-task behaviour

	Boys (N = 46)		Girls (N = 67)		Total (N = 113)	
	M	SD	M	SD	M	SD
Age (years)	13.2	1.2	12.9	1.3	13.0	1.3
Body mass (kg)	52.3	15.4	48.8	11.7	50.2	13.3
Body Mass Index (kg m^{-2})	19.5	3.4	19.9	3.5	19.8	3.5
Insomnia Severity Index (score)	4.1	3.5	4.3	3.5	4.3	3.5
SDQ (score)	10.4	3.9	10.1	3.8	10.2	3.8
Moderate PA (min/day)	33.6	27.4	30.6	19.6	31.8	23.0
Vigorous PA (min/day)	26.4	28.8	21.1	28.7	23.2	28.7
Moderate-to-vigorous PA (min/day)	60.0	36.7	51.7	33.1	55.0	34.6
Off-task behaviour (%)	26.3	14.6	26.6	15.0	26.5	14.8
Off-task behaviour (passive) (%)	11.6	11.9	11.2	11.0	11.4	11.3
Off-task behaviour (noise) (%)	10.7	10.1	10.0	11.0	10.3	10.6
Off-task behaviour (motor) (%)	3.9	4.5	5.4	8.7	4.8	7.3

PA, physical activity assessed from 7-day recall protocols; SDQ, strengths and difficulties questionnaire.

Table 2. Zero-order correlations between potential confounders, physical activity, cognitive performance, and off-task behaviour

	Sex	Age	BMI	ISI	MVPA
Sex	–	–	–	–	–
Age	−0.15	–	–	–	–
BMI	0.05	0.26*	–	–	–
SDQ	−0.04	0.04	0.11	–	–
ISI	0.03	0.01	−0.03	0.37*	–
MVPA	−0.12	0.28*	0.03	−0.12	−0.15
Off-task behaviour	0.01	−0.19*	0.03	0.11	0.03
RT Flanker Task (incongruent trials)	0.03	−0.30*	−0.06	0.12	−0.07
RT flanker task (switch trials)	0.19*	−0.03	0.12	−0.07	0.04
RT sternberg task	0.06	0.11	0.05	−0.09	−0.11
RT emotion recognition task	−0.13	−0.15	−0.10	−0.02	−0.19

BMI, body mass index; ISI, Insomnia Severity Index; MVPA, moderate-to-vigorous physical activity assessed from 7-day recall protocols; SDQ, strengths and difficulties questionnaire.
*$p < .05$.

Table 3. Participants' reaction time and accuracy on trials of the Flanker Task, the Sternberg Paradigm, and the Emotion Recognition Task

	Reaction time (ms)		Accuracy in % correct	
	M	SD	M	SD
Flanker task (congruent trials)	536.8	130.4	97.9	5.0
Flanker task (incongruent trials)	551.4	118.2	96.7	8.3
Flanker task (switch trials)	998.6	124.6	89.0	8.5
Sternberg task	1,223.2	215.4	68.7	12.3
Emotion recognition task	1,786.7	315.3	88.6	6.3

Flanker Task, $\beta = 0.21$, $p = .029$. However, the individual accuracy-based outcomes added as mediators did not show a statistically significant relation with MVPA and/or off-task behaviour. Based on both absolute and relative fit indices, the fits of model 1, RMSEA < 0.01, $\chi^2/df = 0.01$, Model 2, RMSEA = 0.02, $\chi^2/df = 1.05$, and Model 3, RMSEA = 0.07, $\chi^2/df = 1.60$, to the data were good.

As only incongruent reaction time partly mediated the association between MVPA and off-task behaviour, additional data-driven models were specified to examine the type of off-task behaviour that was influenced (Figure 2). Model 4 showed a direct, moderate association between MVPA and noise, $\beta = -0.29, p = .002$, whereas no such relation was observed for the other types of off-task behaviour. When the mediation by incongruent reaction time was added, the standardized regression coefficient for this association decreased but remained still significant, $\beta = -0.17, p = .046$. Model 5 further showed a moderate relation between MVPA and incongruent reaction time, $\beta = -0.27, p = .005$, and a strong relation between this cognitive performance outcome and noise, $\beta = 0.46$, $p < .001$. The fits of model 4, RMSEA < 0.01; $\chi^2/df = 0.13$, and model 5, RMSEA < 0.01; $\chi^2/df = 0.46$, to the data were good.
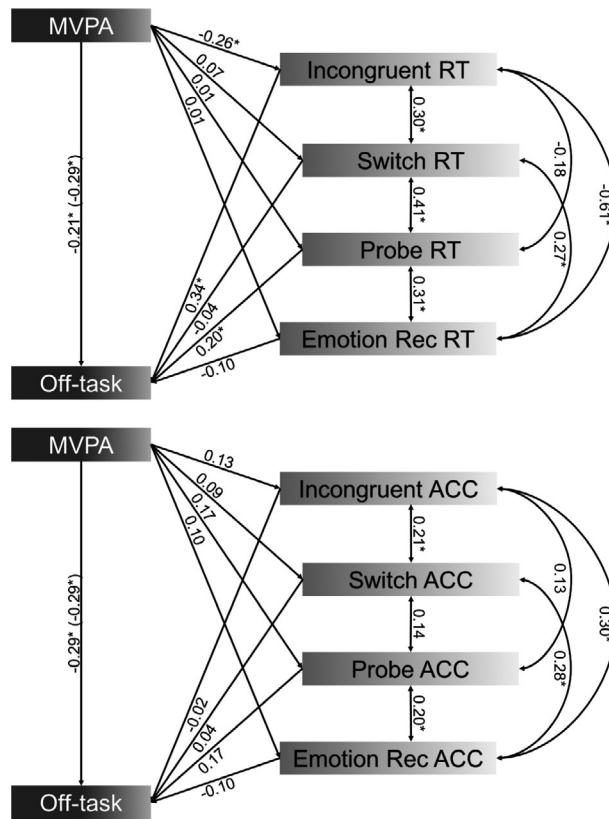
Figure 1. Path-analyses investigating the association between MVPA and off-task behaviour and its mediation by reaction-time based (upper panel) and accuracy-based (lower panel) cognitive performance outcomes, while adjusting for sex, age, and sleep. *Note*: Standardized regression coefficients in brackets indicate the direct association between MVPA and off-task behaviour, when no mediating variables were included (Model 1). All other standardized regression coefficients displayed next to the paths indicate associations, when cognitive performance outcomes were included as mediating variables (Models 2 and 3). ACC, accuracy; Emotion Rec, Emotion Recognition; MVPA, moderate-to-vigorous physical activity; RT, reaction time; *p < .05

Discussion

The examination of the direct association between MVPA and off-task behaviour revealed a moderate inverse correlation, indicating that highly active students show a more favourable classroom behaviour with respect to their attentiveness. When cognitive functions were included as potential mediators, the association between MVPA and off-task behaviour decreased, but remained statistically significant. This was mainly due to the indirect relation of both constructs via inhibitory control. In contrast, cognitive flexibility, working memory, and emotion recognition did not contribute independently to this partial mediation.

The current evidence suggests that longer engagement in MVPA and less sedentary time during the school-day is associated with a lower rate of off-task behaviours. The present findings extend previous research by showing a similar association between these constructs, when the overall MVPA levels are considered (Brusseau & Burns, 2018;
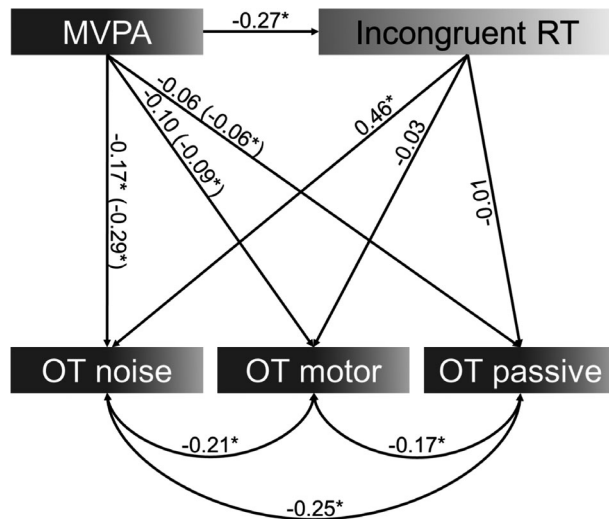
Figure 2. Path-analyses investigating the association between MVPA and types of off-task behaviour as well as its mediation by incongruent reaction time, while adjusting for sex, age, and sleep. *Note*: Standardized regression coefficients in brackets indicate the direct association between MVPA and types of off-task behaviour, when no mediating variable was included (Model 4). All other standardized regression coefficients displayed next to the paths indicate associations, when incongruent reaction time was included as mediating variable (Model 5). MVPA, moderate-to-vigorous physical activity; OT, off-task behaviour; RT, reaction time; *p < .05

Carlson et al., 2015; Goh et al., 2016; Norris et al., 2018). Knowing that school-based interventions often fail to achieve their goal to foster MVPA in the long term (Jones, Defever, Letsinger, Steele, & Mackintosh, 2019), the indication that both curricular and extracurricular MVPA may promise improvements in classroom behaviour is of high practical relevance. However, it should be noted that the relation between MVPA and off-task behaviour appears to be selective rather than general. In this respect, a novel finding was that MVPA was associated with less noise, but not with less passive behaviour or motor restlessness.

The test of the pre-specified mediation model has revealed new insights into the cognitive functions that contribute to the relation between MVPA and different types of off-task behaviour. Among the cognitive performance outcomes, only reaction time on incongruent trials of the Flanker Task accounted for a partial mediation. Testing the mediation model with accuracy-related outcomes verified that this result was not influenced by a speed-accuracy trade-off. Additionally, this model did not support any mediating roles of other cognitive functions. The lack of an indirect association between MVPA and off-task behaviour via cognitive flexibility, working memory, and emotion recognition was not expected, because these outcomes have previously been related with behaviours in and outside the classroom (Brock et al., 2018; Castro et al., 2018; Moffett & Morrison, 2020). However, one possible explanation is that in comparison with previous studies, inter-relations between the cognitive performance outcomes were accounted for in path-analyses. Inspection of the covariance supports weak-to-moderate associations between almost all outcomes of the cognitive tasks. Thus, the mediating role of inhibitory control only might be due to the possibility to separate the independent contributions of specific executive function components and emotion recognition in the pre-specified models.

When the mediation model included different off-task behaviours, path-analysis supported high inhibitory control to be linked with less noise, but not with motor restlessness and passive behaviour. This specific relation may be explained by the subtype of inhibitory control that was assessed with the Flanker task. Interference control involves the control of attention and the ability to suppress pre-potent mental representations (Diamond, 2013). In a classroom setting, this subtype of inhibitory control is considered necessary to resist unwanted thoughts and distractors in the surrounding. On a behavioural level, the association between inhibitory control and noise might therefore be explained by the ability to refrain from starting to talk or to engage in conversations with other students in the classroom setting, which are unrelated to the current learning task. From a neuroscience perspective, changes in neurocognitive correlates of inhibitory control could partly account for the relation between MVPA and off-task behaviour. In children and adolescents, physical activity programs have been found to benefit performance on an inhibitory control task and to increase the P300 component of event-related potentials elicited by this task (Chang, Tsai, Chen, & Hung, 2013; Hillman et al., 2014; Ludyga, Gerber, Herrmann, Brand, & Pühse, 2018). The amplitude of this component, which was increased following the physical activity programs, is assumed to reflect the allocation of attentional resources towards the task (Polich, 2007). Thus, regular engagement in MVPA may promise the recruitment of additional attentional resources within the given level of alertness, which in turn could decrease off-task behaviour by a shift towards a higher attentiveness during class. Moreover, structured physical activity programs involving aerobic exercise have been found to elicit changes in specific brain regions, such as an increased activation of the pre-frontal cortex in response to executive function tasks (Chaddock-Heyman et al., 2013; Davis et al., 2011). Recalling that maturational lags in this region partly account for inter-individual differences in academic achievement, the effect of (fitness-enhancing) MVPA could also contribute to academic behaviours by promoting favourable brain activation patterns.

The key finding that inhibitory control partly explained the association of MVPA and off-task behaviour was revealed by path analyses that examined several cognitive mediators at a time. The strength of this approach was the investigation of relative contributions of different core components of executive function and emotion recognition to this association, while accounting for their inter-dependencies. Moreover, classroom behaviours were recorded and categorized in different types of off-task behaviours, so that the specific relation of MVPA to noise could be detected. Despite these strengths, the partial mediation suggests that inhibitory control alone does not fully explain their indirect relation. As the present study assessed executive function and the emotion recognition aspect of social cognition only, a mediating role of other cognitive domains cannot be ruled out. Beyond cognitive function, there are other determinants of academic behaviours, including value-orientations, motivation and self-determination (Jang, Kim, & Reeve, 2012; Kilian et al., 2010), which might also be sensitive to MVPA. Moreover, the present findings should be interpreted with caution since the cross-sectional design does not allow causal inferences and does not exclude the possibility of an alternative mediation model. For example, MVPA could also act as mediating variable for the association between executive function and off-task behaviour, since this cognitive domain has been found to influence health-related behaviours (Gray-Burrows et al., 2019). However, this is unlikely as adolescents' motivation for physical activity encompasses a variety of factors, but rarely the goal of health promotion (Sterdt, Liersch, & Walter, 2014). With regard to methodological

limitations, the present study used 7-day recall protocols rather than accelerometer-based assessments of physical activity. This approach ensured that not only all types of physical activity could be considered, but also relied on the participant's ability to recall all activities conducted within the last 7 days and might introduce a social desirability bias. The choice to use MVPA was based on previous research (Brusseau & Burns, 2018; Carlson et al., 2015; Goh et al., 2016; Norris et al., 2018) and the idea of a general association with off-task behaviour. Thus, no conclusions could be drawn on whether specific types of physical activity showed more pronounced relations with classroom behaviours. This also applies to aspects of physical fitness, since cardiorespiratory fitness is a well-known correlate of MVPA (Silva et al., 2013). Another methodological limitation was the lack of control for socio-economic status and intelligence, but it should be noted that variables sharing variance with these confounders (e.g., psychopathology and body mass index) were accounted for (O'Dea, Dibley, & Rankin, 2012; Tong et al., 2010). Additionally, participants were recruited from classes taught on the highest educational level, which was expected to reduce variability in intelligence. However, this also affects the generalizability of the results, so that future studies need to test whether the associations found in this study can also be observed in students with other performance levels. This also applies to different age groups and individuals with different baseline physical activity levels.

Conclusion

Adolescents with high MVPA levels show less off-task behaviour, especially inappropriate noise, in the classroom. A mechanism that partly accounts for this association is increased inhibitory control in students with greater engagement in MVPA. In contrast, other aspects of executive function and social cognition do not seem to have influence on the relation between MVPA and off-task behaviour. These findings should encourage teachers to promote curricular (e.g., physically active breaks and lessons) and extracurricular physical activities (e.g., cycling to school and engage in after-school exercise programs) that target improvements in inhibitory control. Although this applies to physical activities of at least moderate intensities, other qualitative and quantitative characteristics of physical activity may also determine its influence on inhibitory control. The systematic examination of these characteristics in experimental studies is required to derive further recommendations on how physical activities should be designed to effectively reduce off-task behaviour in the classroom.

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Conflicts of interest

All authors declare no conflict of interest.

Author contribution

Wenke Möhring (Formal analysis; Methodology; Resources; Writing – review & editing)
Uwe Pühse (Conceptualization; Methodology; Resources; Supervision; Writing – review

& editing) Serge Brand (Investigation; Methodology; Resources; Writing – review & editing) Sebastian Ludyga (Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Visualization; Writing – original draft; Writing – review & editing) Markus Gerber (Conceptualization; Methodology; Resources; Writing – review & editing).

Data availability statement

Data will be made available on request.

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Appendix A:

Table A1. Participants' reaction time and accuracy on trials of the Flanker Task, the Sternberg Paradigm, and the Emotion Recognition Task

	School	Reaction time (ms)		Accuracy in % correct	
		M	SD	M	SD
Flanker task (congruent trials)	1	492.1	82.3	98.8	2.2
	2	557.5	168.2	96.7	7.4
	3	553.9	107.9	98.4	2.9
Flanker task (incongruent trials)	1	513.6	74.9	97.2	4.7
	2	571.8	145.8	94.7	12.4
	3	562.6	109.8	98.4	2.6
Flanker task (switch trials)	1	992.4	119.6	91.0	7.2
	2	983.7	131.1	87.5	9.0
	3	1,021.4	121.9	88.8	8.8
Sternberg task	1	1,201.2	224.8	70.9	9.9
	2	1,232.6	194.0	67.4	13.9
	3	1,232.7	234.0	68.2	12.3
Emotion recognition task	1	1,634.9	242.6	89.6	6.1
	2	1,733.7	306.1	86.7	6.8
	3	1,755.7	219.8	89.8	5.5