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Year: 2024

Version: Published version

Please cite the original version:

Syväoja, H. J., Sneck, S., Kukko, T., Asunta, P., Räsänen, P., Viholainen, H., Kulmala, J., Hakonen, H., & Tammelin, T. H. (2024). Effects of physically active maths lessons on children's maths performance and maths-related affective factors : Multi-arm cluster randomized controlled trial. British Journal of Educational Psychology, Early View. https://doi.org/10.1111/bjep.12684

Received: 25 May 2022 | Accepted: 8 April 2024

DOI: 10.1111/bjep.12684

ARTICLE

the british psychological society
promoting excellence in psychology

Effects of physically active maths lessons on children's maths performance and maths-related affective factors: Multi-arm cluster randomized controlled trial

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Funding information
Finnish Ministry of Education and Culture, Grant/Award Number: OKM/66/626/2016, OKM/66/626/2017 and OKM/79/626/2018; Research Council of Finland, Grant/Award Number: 355350; The Strategic Research Council (SRC) established within the Research Council of Finland, Grant/Award Number: 353361

Abstract

Background: Physical activity (PA) may benefit academic performance, but it is unclear what kind of classroom-based PA is optimal for learning.

Aim: We studied the effects of physically active maths lessons on children's maths performance and maths-related effects, and whether gender and previous mathematical or motor skills modify these effects.

Sample: A total of 22 volunteered teachers and their pupils with signed consent (N = 397, mean age: 9.3 years, 51% females) participated in a 5-month, teacher-led, multi-arm, cluster-randomized controlled trial.

Methods: The intervention included a PAL group (20 min of physically active learning in each 45-min lesson), a breaks group (two 5-min PA breaks in each 45-min lesson) and a control group (traditional teaching). Maths performance was assessed with a tailored curriculum-based test. Maths-related enjoyment, self-perceptions and anxiety were measured with a self-reported questionnaire. The individual-level intervention effects were tested via covariate-adjusted linear mixed-effect models with school classes serving as random effects.

Results: Changes in maths performance or self-perceptions did not differ between the intervention groups. Maths anxiety in learning situations increased in the PAL group (effect .28, 95% CI = .01–.56); there was no change in the other

groups. Subgroup analyses suggested that maths anxiety increased in the PAL group among children in the two lowest tertiles of motor skills. It decreased in the highest tertile. Enjoyment decreased in the breaks group among pupils in the lowest motor skill tertile.
Conclusions: Physically active maths lessons did not affect maths performance or self-perceptions but had divergent effects on maths anxiety and enjoyment, depending on motor skills.

KEYWORDS
anxiety, enjoyment, physical activity breaks, physically active learning, self-perceptions

BACKGROUND

Although mathematics plays a marked role in success related to education, working life and economics in Western societies, performance and interest in maths have declined (Kennedy et al., 2014; Stokke, 2015). Attitudes begin to become increasingly negative in the first school years (Metsämuuronen & Tuohilampi, 2014). At the same time, children are not physically active enough to maintain good health (Bull et al., 2020; Tremblay et al., 2016); school days and academic lessons largely consist of seated practices (Kallio et al., 2020). In response, new ways of teaching have been developed to support learning and decrease long periods of sitting at school.

Almost all children go to school, which is therefore an important environment for enhancing physical activity (PA), health and well-being (Daly-Smith et al., 2020; Physical Activity Guidelines Advisory Committee, 2018). Although school-based interventions have been able to only modestly increase PA (Hartwig et al., 2021), PA has the potential to improve brain health, cognitive function and academic performance in children and adolescents under 18 years of age (Chaput et al., 2020; Donnelly et al., 2016; Singh et al., 2019). This has encouraged the implementation of physically active classroom practices in school. PA has been reported to support learning mathematics in particular (Singh et al., 2019; Sneck et al., 2019). According to Singh et al. (2019), 86% of the methodologically high-quality studies reported beneficial effects of PA on maths performance in 3- to 16-year-olds. Furthermore, school-based interventions have been shown to have a small positive effect on mathematics in children aged 4–16 (Sneck et al., 2019). In these studies, PA was implemented in various ways in the school environment (Sneck et al., 2019), for example, through PA breaks in lessons and using physically active learning (PAL). In PAL, PA is integrated into the learning content in subjects other than physical education (Daly-Smith et al., 2020). It remains unknown what type, time and frequency of PA is the most appropriate for learning. More high-quality studies examining the effects of PAL and PA breaks in authentic learning environments are needed (Singh et al., 2019).

There are many overlapping and interacting theories, such as biological and psychosocial theories, that suggest that PA enhances cognition via multiple pathways, thus improving academic performance (Singh et al., 2019; Tomporowski & Qazi, 2020). However, the theoretical frameworks underlying the effects of PAL and PA breaks can be distinguished (Mavilidi, Ruiter, et al., 2018). Traditionally, the effects of PA breaks on cognition have been explained with physiological and neurobiological theories. Chronic PA may alter brain structure and function by enhancing neurogenesis and increasing biomarkers such as grey matter volume and cerebral blood flow, and peripheral biomarkers such as circulating growth factors (Lubans et al., 2016; Mavilidi, Okely, et al., 2018; Mavilidi, Ruiter, et al., 2018). Regular bouts of PA can support faster cognitive processing and allocation of attentional resources during coding (Donnelly et al., 2016). Recently, it has been suggested that the coordinative and cognitively engaging PA that includes strategic behaviours, complex motor coordination or adaptation to changing task conditions may have larger effects on cognition (Pesce et al., 2016; Schmidt et al., 2015; Tomporowski & Perce, 2019). This idea is based on the cognitive stimulation hypothesis according to which coordinatively demanding and non-automated physical activities activate the same brain regions used to control higher-order cognitive processes (Best, 2010; Pesce, 2012). These processes, such as executive functions, control self-regulatory and goal-directed actions (Best et al., 2011) and are also important for maths performance (Cragg & Gilmore, 2014; Friso-van Den Bos et al., 2013).

PAL, on the other hand, can be considered to be based on cognitive load theory (Paas & Sweller, 2012) or embodied learning theory, which provides evidence of long-term memory facilitation (Tomporowski & Qazi, 2020). The former hypothesizes that primary motor schemas can be utilized to encode secondary, academic material to dimmish working memory load and enhance learning (Paas & Sweller, 2012), whereas the latter proposes that the learning is caused by a dynamical interaction among an individual's body movements, the sensory experiences obtained from the movements and the context of those movements (Barsalou, 2008; Barsalou et al., 2003). What these theories have in common is that learning environments and instructional frameworks can be intentionally designed to link PA to create mental representations (Tomporowski & Qazi, 2020). For example, in mathematics, combining abstract mathematical knowledge with sensorimotor metaphors derived from the human body and its movement can help transform it into concrete events or situations that are familiar to children, and promote maths performance (Mavilidi, Okely, et al., 2018).

Previous studies have mainly examined the effects of PA on cognitive and learning outcomes. However, learning mathematics is a more complex process influenced by myriad factors, including affective factors such as enjoyment, self-perceptions and anxiety. Mathematics itself particularly may cause strong emotional responses (Carey et al., 2017; Hannula, 2019). Maths anxiety is defined as feelings of tension and anxiety stemming from the manipulation of numbers and solving maths problems (Sorvo et al., 2017). Maths self-perceptions represent an individual's belief in their capacity to perform mathematical tasks, while maths enjoyment is a positive affective state that occurs when a person engages in mathematics (Hannula, 2019; Hannula et al., 2014). These mathematics-related affective factors may already influence maths performance at a very young age but also mathematical behaviour later in life (Carey et al., 2017; Hannula, 2019; Hannula et al., 2014; Sorvo et al., 2017). To diminish the possible effect of negative affective factors and promote a positive affective disposition in mathematics, changes in teaching and classroom culture are needed (Liljedahl & Hannula, 2016, 417–446). Children most often find PA fun and enjoyable (Martins et al., 2015), which encourages adding PA in the classroom setting. Especially, if enjoyable and engaging forms of PA can have even more positive effects on students' cognitive and maths performance (Schmidt et al., 2016).

The effects of PAL on enjoyment in maths lessons have been examined to some extent, and the results have been positive in children aged 9–13 (Riley et al., 2017; van den Berg et al., 2019; Vazou & Smiley-Oyen, 2014). The results regarding PA breaks have also been promising among 9- to 11-year-olds (Fiorilli et al., 2021). However, these effects have been examined acutely (Fiorilli et al., 2021; Vazou & Smiley-Oyen, 2014) or after relatively short 4- to 6-week interventions (Riley et al., 2017; van den Berg et al., 2019) but not after interventions with longer duration. The effects of PA on maths self-perceptions and maths anxiety are even less studied. Vazou and Skrade (2017) reported that PAL intervention had no significant effect on perceived maths competence in fourth and fifth graders. Alanazi (2020) showed that PAL decreased math anxiety among first-grade male students, whereas Mavilidi, Ouwehand, et al. (2020) reported that PA breaks had no effect on maths anxiety in children of 11–12 years. Thus, there is a clear need to study the effects of classroom-based PA on maths-related affective factors.

Not all children may benefit from PA in the same way (Singh et al., 2019). Especially for those with learning difficulties, PAL, including both cognitive and motor challenges, may affect differently. It is noteworthy that motor coordination difficulties often overlap with cognitive and learning problems in different academic areas (Asonitou et al., 2012; Visser, 2003) making dual-task learning situations even more challenging (Schott et al., 2016). Furthermore, previously acquired skills are of great importance as they predict future performance. Basic arithmetic skills form the foundation for the more complex maths skills and predict later maths performance (Blume et al., 2021; Butterworth, 2005; Jordan et al., 2009). Likewise, in a motor context, motor skills are a prerequisite for PA and PA enables new motor skills to develop. Also, low motor skills and low perceptions of own motor skills predict lower engagement in PA (Jaakkola et al., 2019; Stodden et al., 2008). Gender differences have been observed in maths performance (e.g., different developmental trends in number-processing skills and arithmetic fluency: girls having a better performance in number-processing skills, whereas boys having a better performance in arithmetic fluency) (Räsänen et al., 2021), PA (e.g., different levels and developmental trends in PA: boys having not only more moderate-to-vigorous PA but also a greater decrease in PA during adolescence than girls) (Hubbard et al., 2016; Kallio et al., 2020) and motor skills (e.g., differences in skill levels in different motor skills: boys having more developed manipulative skills than girls, whereas girls having more developed stability and locomotor skills than boys) (Iivonen & Sääkslahti, 2014; Robinson, 2011). Gender and previous maths and motor skills may modify the effects of PA on maths performance and are therefore important to consider when determining children's responses to physically active interventions. Clearly, potential moderators need to be explored (Singh et al., 2019).

This study investigated the effects of physically active maths lessons on third-grade children's maths performance and maths-related affect. We especially tested the individual-level effects of PAL and PA breaks on curriculum-based maths performance, enjoyment, self-perceptions and anxiety compared to traditional teaching. Moreover, we examined whether gender and the previous mathematical or motor skills level modify the effects on each main outcome. We hypothesized that PAL has a positive impact on children's maths performance and maths-related affective factors. We hypothesized that PA breaks also have positive effects on the main outcomes. Moreover, we hypothesized that gender and previous motor and maths skills modify the effects of both PAL and PA breaks.

METHODS

Study design and participants

In total, 65 schools from Central Finland were contacted. Eligibility rules for schools and reasons for other exclusions are presented in the Enrolment section (Figure 1). From the eligible 13 schools, 22 third-grade teachers participated in the study and 401 children volunteered to participate with informed consent signed by the children and their guardians. One child was excluded for health reasons. The premeditated study design was a three-arm cluster randomized controlled trial with before–after measurements. Parallel classes in each school followed the same teaching method to avoid contamination from different methods. The objective was to attain a 1:1:1 ratio of teachers (and pupils) for the three intervention arms.

However, the participating schools expressed a large variation in the number and size of classes, the size of schools and regional socioeconomic status. Therefore, the standard purely randomized design was expected to be vulnerable, that is, an adequate resemblance of the three arms could not be assumed. Instead, an enhanced design was conducted by organizing the clusters optimally into three groups before randomizing the interventions. Group differences in three cluster characteristics (class size, school size and regional socioeconomic status) were minimized. The minimization was restricted such that schools with three participating teachers were initially allocated to different groups. Subsequently, the schools with one or two participating teachers were added to groups, minimizing the average CV of the three objectives at each step. Finally, the optimized cluster groups were assigned to follow three intervention programmes by a lottery using a random number generator in Microsoft Excel. The optimization, randomization and allocation were done by the statistician. Two children dropped out of the study, and one child was excluded from the analyses due to an individualized educational plan. The final study population consisted of 397 children. This study followed the Consolidated Standards of Reporting Trials Statement 2010 extension for a cluster randomized trial (see the CONSORT checklist in the Supporting Information). The CONSORT flow diagram of the study design is presented in Figure 1. The study protocol was approved by the university's ethics committee. The study was prospectively registered (ISRCTN71844310, registered 10 April 2019, https://doi.org/10.1186/ISRCTN71844310).

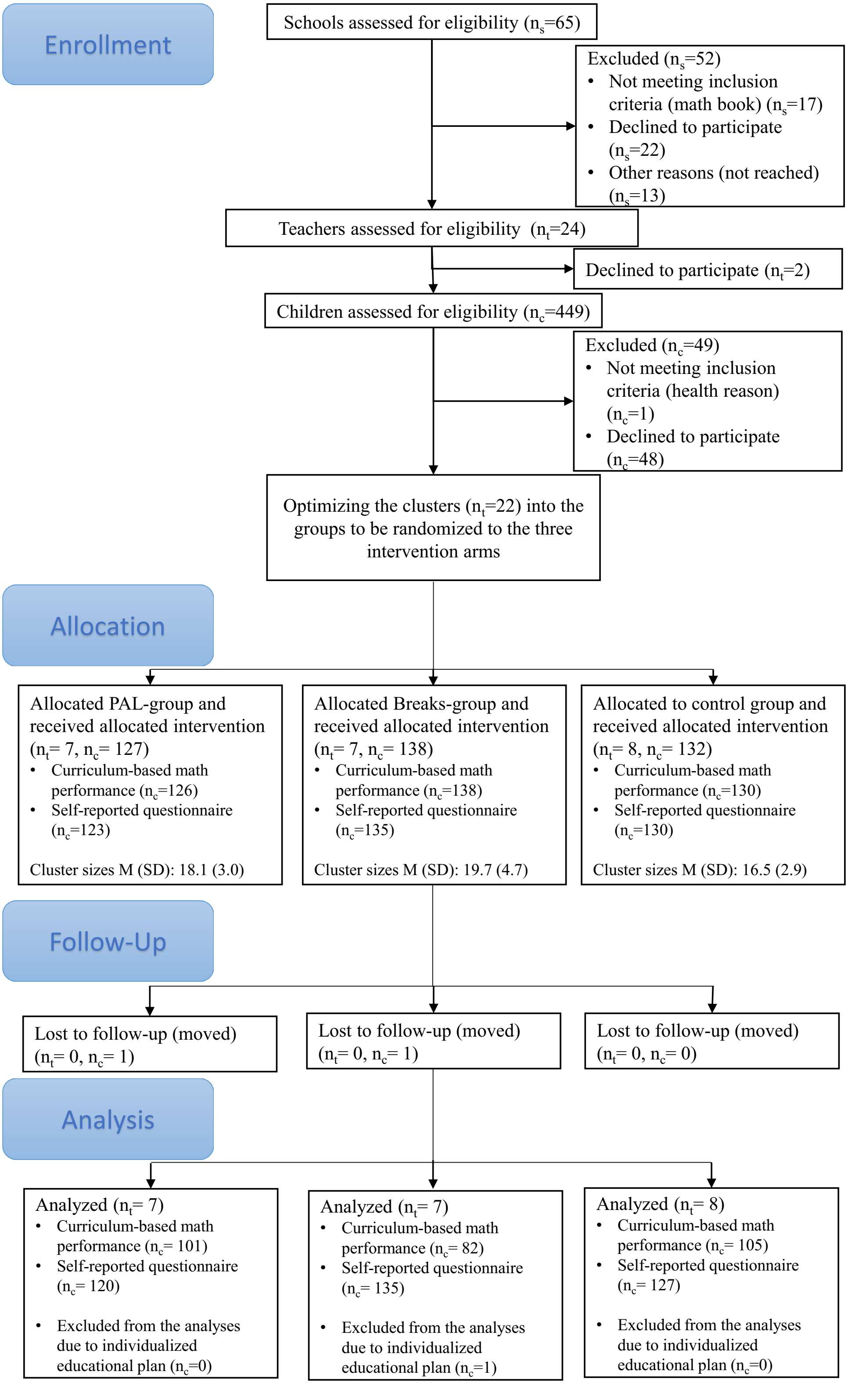

FIGURE 1 CONSORT flow diagram of the study. PAL, Physically active learning.

TABLE 1 The intervention groups' teaching methods and guidelines for physical activity.

	PAL – group	Breaks group	Control group
Aim	To integrate 20 min of physical activity into maths tasks in each 45-min maths lessons for 22 weeks	To add two 5-min physical activity breaks to each 45-min maths lessons for 22 weeks	To continue their usual way of learning mathematics for 22 weeks
Mathematics learning goals	Maths syllabus for third graders comprising, for example, multiplication, division, geometry and the addition and subtraction of numbers 0–10,000	Maths syllabus for third graders comprising, for example, multiplication, division, geometry and the addition and subtraction of numbers 0–10,000	Maths syllabus for third graders comprising, for example, multiplication, division, geometry and the addition and subtraction of numbers 0–10,000
Content of physical activity	Physical activity integrated into maths learning content	Physical activity without maths learning content	No intervention-based physical activity
Realization of the aim[a]	On average, 68% (range: 40%–91%) of the lessons were completed according to the plan (corrected with diary coverage) Due to COVID-19, the intervention lasted 20 weeks[a]	On average, 73% (range: 49%–88%) of the lessons were completed according to the plan (corrected with diary coverage) Due to COVID-19, the intervention lasted 19 weeks[a]	On average, 30% (range from <10% to 100%) of the lessons included physically active breaks. Due to COVID-19, the intervention lasted 18 weeks[b]

Abbreviation: PAL, Physically active learning.

[a]More information about the fulfilment of the planned intervention content is provided in Table S1.

[b]The teaching of the intervention groups was planned to begin periodically due to the timing of the measurements.

Intervention

The interventions were constructed in collaboration with third-grade teachers, special education teachers, physical education teachers and physical activity and learning researchers. The reasoning for the intervention design content and duration is described in the Methods section (Supporting Information).

The 5-month teacher-led multi-arm optimized cluster trial included three intervention arms following different teaching methods (Table 1). All the intervention groups followed the national curriculum-based third-grade maths learning goals and used the same maths book. In the PAL group, PA (20 min) was integrated into these learning goals. The breaks group had PA breaks (2 × 5 min) without maths learning goals. Table 2 provides a description of the teaching methods used for the PAL group and breaks group. The control group was asked to continue learning maths in the usual way and served as a control group for comparison.

The regular class teachers taught the lessons. Before the intervention, the PAL group and breaks group teachers received 3 h of training led by professionals in education sciences and physical education. The teachers were trained in pedagogic principles (e.g., motivating students, grouping based on educational needs, use of assistant coaches and learning environments), an intervention schedule and teacher tasks during the intervention. Furthermore, teachers were instructed to carry out the physically active maths tasks or PA breaks using guidebooks, pictures and videos. Teachers were given guidebooks with a specific maths lesson plan that followed the Finnish third-grade maths curriculum and study book topics and all the material needed for the intervention. The teachers were given the research staff's contact information and were told they could contact the researchers at any time during the intervention. Additionally, the research staff called and emailed the teachers at least every 2 weeks to ensure everything was going well and help with any problems. Since the parallel classes in each school followed the same teaching method, teachers at the same school had access to peer support.

The intervention was scheduled to last 22 weeks, including four 45-min maths lessons per week (excluding holidays). Due to COVID-19, the intervention was cut short before the schools closed. The interventions for PAL, breaks and control groups lasted 20, 19 and 18 weeks respectively (Table 1). The recruitment of clusters was conducted from May to August 2019 and baseline measurements in September 2019. The intervention lasted from October 2019 to March 2020, and the post-intervention measurements were taken from March to May 2020. The feasibility of the intervention was assessed using teachers' diaries, including questions about how well the physically active tasks were carried out according to the plan.

Main outcomes

Maths performance

The curriculum-based maths performance was assessed at baseline and after the intervention using a curriculum-based pen-and-paper test battery created for the study. The test battery included time-limited tasks for multiplication and division, geometry and time, column methods and problem-solving. The number of correct responses in the whole test was calculated to represent curriculum-based maths performance. For the subgroup analyses, the children were divided into tertile groups (33% in each) according to baseline curriculum-based maths performance. The tests were run at school in calm group sessions guided by educated research personnel. After the intervention, in some schools, the tests were run under the guidance of the class teachers due to COVID-19 restrictions that allowed only school staff to enter schools.

TABLE 2 Description of the content of the teaching methods used for PAL group and breaks group (intervention groups).

	PAL – group	Breaks group
Aim	Twenty min of physical activity was integrated into maths tasks in each maths lesson	Two 5-min physical activity breaks were added to each maths lesson
Mathematics learning goals	Physical activity was integrated into curriculum-based third-grade maths learning goals and aimed at, for example, improving automatization of basic arithmetic skills such as addition, subtraction and multiplication Teachers planned the rest of the lesson, which mainly consisted of teacher-lead instruction, giving and checking homework and individual maths study book work	Physical activity breaks did not include maths learning goals Teachers designed the lesson content with the exception of the physical activity breaks
Content of physical activity	Physical activity was designed to be versatile, enhancing balance, locomotor skills, manipulative skills and strength through active play and games Activities enhancing balance included, for example, standing on one leg, walking along a line and different rotating, rolling and evading movements Activities enhancing locomotor skills included, for example, walking, jumping, running and crawling Activities enhancing manipulative skills included various throws, catches, rolls, bounces and hitting or kicking balls, beanbags and other aids Activities enhancing upper-body, core and lower-body muscle strength, included, for example, squats, sit-ups and push-ups	
	Maths tasks including physical activity were as follows: skipping along a numbered line, relays that activated short-term memory, moving to another place to do maths activities (e.g., using manipulatives such as base ten blocks and dice), integrating mathematics tasks into activities from biathlon, bowling, orienteering, basketball, fetching maths tasks or numbers on paper slips, counting multiplication facts while throwing and catching equipment in circles or in pairs, using stories to move, playful games, pupils using their bodies to illustrate shapes in geometry, measuring objects in the classroom and answering teachers' questions with muscle strength or balance moves	Four different breaks for each interventional week were designed; these breaks were repeated twice during that week (in the first and third lesson breaks [1 and 2] and in the second and fourth lessons breaks [3 and 4]). The breaks enhancing balance and manipulative skills were designed to include less intensive movement but focus more on concentration and coordination, therefore giving a good start to the lesson. In contrast, the breaks enhancing locomotor skills and strength included more moderate-to-vigorous physical activity and allowed for a study break and a 'refresh'. Examples of these activities include walking along a line on toes, heels or in a squat position; jumping or running according to prompts in a story; precision throwing or bowling; doing muscle strength movements in pairs
When	In the middle of each maths lesson (4 × 45-min maths lessons per week), but as necessary, the teachers could split the 20 min into two separate sessions during the lesson	The first break was at the beginning of each maths lesson (4 × 45-min maths lessons per week), and the second break was in the middle of the lesson (20 min after the first one)
Where	Most of the activities were designed to be held in the classroom, but teachers were able to utilize other spaces as well (e.g., corridors)	
With whom	The majority of the activities were performed in small groups, but some were done in pairs, individually or as a whole class	The physical activity breaks were performed individually, in pairs, in small groups or as whole class

TABLE 2 (Continued)

	PAL – group	Breaks group
Assistant coaches	The teachers were encouraged to use pupils as assistant coaches to prepare materials, ensure everyone understood the instructions and lead by example during the tasks	
Motivation	If needed, teachers were encouraged to consider using a group incentive to motivate their pupils participate in the activities	
Authors	The instructions were designed in cooperation with class teachers, a special education teacher and physical activity researchers using both existing ideas for physically active classroom activities and new ideas created particularly for this study	The instructions for the physical activity breaks were designed utilizing the material for practicing motor skills of the Skillilataamo (https://innostunliikkumaan.fi/skillilataamo/). In addition, completely new breaks were developed for this purpose. The instructions were designed in cooperation with physical education teachers, a special education teacher and physical activity researchers
Piloting	About one-third of the physically active tasks were tested in a 9-week pilot study in 2018	
Guidebook	The instructions for the teachers were compiled into a guidebook that was available both as a paper copy and as an online version. The guidebook included pedagogic principles, a schedule, instructions for carrying out/executing the physically active maths tasks or breaks and information on the material and equipment needed during every task/break. In addition, there were online instructional videos. The content was slightly modified after the intervention. The guidebooks are available online in Finnish	
	liikkuen_matikkaa_2021_0.pdf (liikkuvakoulu.fi)	verkkoon_liikuntabreikit_2021.pdf (liikkuvakoulu.fi)
Material toolkit	In addition to the guidebook, the teachers received a toolkit that included movement cards, small and big balls, beanbags, dice, small plastic cubes, a deck of cards and Post-It notes. In addition, the schools provided some equipment of their own: hula hoops, play money, ten-base-system manipulatives, rulers and small learning clocks. For some activities, the teachers needed to photocopy A4 sheets included in the guidebook	In addition to the guidebook, the teachers received a toolkit that included movement cards, small and big balls, beanbags, balloons and floor tape. In addition, the schools provided some equipment of their own: tables, chairs, newspapers, buckets, empty milk cans or plastic bottles and music

Abbreviation: PAL, Physically active learning.

Maths-related affective factors

Three affective factors of mathematics were measured using a self-reported questionnaire before and after the intervention. Enjoyment and self-perceptions were measured with a modified version of the Fennema–Sherman Mathematics Attitude Scale validated for Finnish third-grade students (Metsämuuronen, 2014; Metsämuuronen & Tuohilampi, 2014) (see sample-specific validation in Table S2). Children reported their enjoyment of mathematics with four items (e.g., 'I like to study mathematics') and self-perceptions of mathematics with four items (e.g., 'Mathematics is an easy subject') (Metsämuuronen & Tuohilampi, 2014). A 5-point Likert scale was used for each item concerning both enjoyment and self-perceptions. The averages of the enjoyment and self-perception variables and overall attitude (enjoyment and self-perceptions) were calculated.

Maths anxiety was measured with the Abbreviated Math Anxiety Scale modified for children (mAMAS), which is valid and reliable for children and adolescents aged 8–13 (Carey et al., 2017) (see sample-specific validation in Table S3). The mAMAS consists of nine items – five for maths anxiety in learning situations (e.g., 'Starting a new topic in maths') and four for maths anxiety in evaluation situations (e.g., 'Taking a maths test') (Carey et al., 2017). The children reported how anxious they would feel in these situations using a 5-point Likert scale. The averages for learning and evaluation situation variables and overall maths anxiety were calculated.

Other study variables

Motor skill performance at baseline was assessed with seven tasks selected from validated test batteries: the Körperkoordinationstest für Kinder (KTK) (Kiphard & Schilling, 2007), the Movement Assessment Battery for Children–second edition (MABC-2) (Henderson et al., 2007) and the Eurofit test protocol (Tomkinson et al., 2018). These tasks measured balance (walking backwards (Kiphard & Schilling, 2007) and one-leg balance (Henderson et al., 2007)), locomotor skills (standing broad jump (Tomkinson et al., 2018), jumping sideways (Kiphard & Schilling, 2007) and moving sideways (Kiphard & Schilling, 2007)) and manipulative skills (two aiming–catching tasks (Henderson et al., 2007)). For the subgroup analyses, the children were divided into tertile groups (33% each) according to their overall motor skill performance. The reliability of the composite variables used in the study is presented in Table S4. Arithmetic fluency was measured with four tasks from the FUNA dyscalculia test battery (Räsänen et al., 2021) at baseline and was used as a confounding covariate. The need for educational support (intensified or special support) was assessed using a questionnaire the teachers filled out at baseline; this was used as a confounding covariate. (Regarding the local educational support system, see Björn et al., 2018.) PA, body composition and family background (mother's education and family income) were measured at baseline. Additionally, PA was monitored in the middle of the intervention to quantify the amount and intensity of PA during math lessons and the difference between the intervention groups. PA was measured using accelerometers for a subsample ($n = 172$) of children from all three intervention groups. These measurements are described in the Supporting Information.

Sample size determination

The study was originally designed to detect at least medium-sized intervention effects (Cohen's $d \geq .5$) with power $1\text{-}\beta = .90$ and significance level $\alpha = .05$, resulting in a naive $n = 85$ children per intervention arm. The pre- and post-intervention measurements, with pre-assumed correlations of about $r = .70$, decreased the required sample size to 44 children per group. The cluster design with a priori cluster size $m = 20$, $CV_m = .25$ and intra-cluster correlations $\rho \leq .10$ (adapted from Resaland et al., 2016) increased the requirement by design effect factor $DE = 1 + ((CV_m^2 + 1) \cdot M - 1) \cdot \rho = 3.03$. Therefore, the aim was to recruit 133 children per intervention arm.

Eventually, with the gathered sample: group sizes $n = 127$–138; average cluster size $m = 18.0$; variation $CV_m = .20$; intra-cluster correlations between .00 and .08; and before–after correlations varying between .55 and .75, the design was assumed to detect even smaller effects, d between .34 and .41, depending on the response variable. However, the COVID-19 pandemic restricted the data collection in some final measurements. Questionnaires measuring the mathematics affective factors were collected mostly without drop-outs, but school lockdowns had a high impact on participation in the post-intervention curriculum-based maths exam, which was taken by only 82 pupils (59%) in the breaks group. The detectable effect size (power .90, significance .05) surged to $d = .53$. Consequently, a lot of careful work was put into the data imputation procedures to regain the lost statistical power to ensure the findings of any medium-sized intervention effects.

Confronting the full complexity of the design, the power to detect significant effects was investigated by simulation-based estimation (Kumle et al., 2021). Cohen's f^2 statistic was used to measure local effects (Lorah, 2018). The power was higher than .99 for small-to-medium ($f^2 = .05$) main effects, and approximately .82 for small-to-medium ($f^2 = .05$) moderating effects within the Monte Carlo–simulated subgroup analysis.

Statistical approaches

The descriptive statistics of the response variables, both pre- and post-intervention and for possible confounding covariates at baseline, were calculated. The differences in the characteristics between the three intervention arms were tested with ANOVA or the test of proportions. All analyses were carried out within R environment (R Core Team, 2020). External R packages lme4 (Bates et al., 2015) and mice (van Buuren & Groothuis-oudshoorn, 2011) were used in further analyses.

Linear mixed-effect models (LME) were fitted separately for each outcome to determine statistically significant effects of interventions: PAL group versus control group or breaks group versus control group (p-value $< .05$). In the LME models, the teachers were assigned random effects, and the intervention groups and adjusting factors had fixed effects. The effects were adjusted by gender, need for educational support and arithmetic fluency. The effects were analysed under the intention-to-treat assumption. All models were run both for complete cases and multiple imputed (MI; $m = 650$; von Hippel (2020)) data sets. The two results were cross-checked for consistency (White et al., 2011), and further inferences were based on the MI models. See 'Statistical approaches' in the Supporting Information. The intra-cluster correlations (ICC) were calculated for all models of the primary response variables.

The subgroup analyses were conducted by adding an excess interaction term one by one for each subgroup variable by the intervention arms to the corresponding LME models. For each response, the statistical significance of the effects on the three subgroups (gender, baseline curriculum-based maths performance tertiles and motor skills tertiles) was tested.

RESULTS

The feasibility of the intervention

Sixty-eight per cent (range 40%–91%) of the 80 lessons were completed according to the plan in the PAL group and 73% (49%–88%) of the 76 lessons in the breaks group, see Table S1.

Baseline characteristics

Intervention group-specific distributions and group differences at baseline in the observed variables are presented in Table 3. Extended descriptive statistics are presented in Table S5. There were mostly no baseline differences between the intervention groups, but the intervention groups differed in the variables of maths enjoyment and height (difference between the PAL group and control group, $d = -.27$, $d = .21$, respectively).

Accelerometer-measured PA

Accelerometer-measured light and moderate-to-vigorous PA, steps and sedentary time during maths lessons (45 min) mid-intervention differed between groups (sub-sample: $n = 172$) (Table 4). In the pairwise comparison, the PAL group had more PA and less sedentary time during maths lessons than the breaks group and control group.

TABLE 3 Descriptive statistics of the independent and dependent variables at baseline.

Variable	*n*	Total	*n*	PAL group	*n*	Breaks group	*n*	Control group	Test of inequality (*p*-value)
Gender (female, %)	397	50.4	127	50.4	138	48.6	132	52.3	.8295
Support in maths (%)	397	5.0	127	7.9	138	2.9	132	4.5	.1718
Support in other subjects (%)	397	11.1	127	8.7	138	12.3	132	12.1	.5729
Mother's education level (high, %)	357	65.3	116	61.2	126	71.4	115	62.6	.1909
Family income level (high, %)	373	55.2	120	50.8	133	60.2	120	54.2	.3174
Age (years)	396	8.8 (.5)	126	8.9 (.4)	138	8.8 (.5)	132	8.8 (.4)	.5016
Height (cm)	395	138.2 (6.4)	126	139.2 (6.3)	138	137.9 (6.7)	131	137.7 (6.1)	.0499*
Weight (kg)	395	33.4 (7.0)	126	34.6 (7.9)	138	32.5 (6.3)	131	33.1 (6.7)	.0933
Body mass index (kg/m^2)	395	17.3 (2.7)	126	17.7 (3.0)	138	17.0 (2.2)	131	17.4 (2.8)	.3677
Body fat per cent (%)	374	17.9 (8.5)	121	18.8 (9.0)	128	17.0 (7.3)	125	18.1 (9.0)	.5353
FUNA dyscalculia test (composite z-score)	353	.00 (1.00)	101	−.12 (1.03)	135	.09 (.98)	117	.00 (.99)	.3950
Motor skills (composite z-score)	369	.00 (1.00)	119	−.19 (1.04)	129	.14 (1.03)	121	.04 (.90)	.0789
Curriculum-based maths exam (0–118 points)	396	35.3 (12.9)	126	35.4 (12.5)	138	36.5 (12.2)	132	34.1 (13.9)	.4097
Attitude, total (Likert scale, 1–5)	388	3.70 (.82)	123	3.58 (.81)	135	3.73 (.83)	130	3.78 (.81)	.0513
Attitude, self-perceptions (Likert scale, 1–5)	388	3.71 (.75)	123	3.68 (.73)	135	3.68 (.74)	130	3.77 (.77)	.3141
Attitude, enjoyment (Likert scale, 1–5)	388	3.68 (1.15)	123	3.47 (1.17)	135	3.77 (1.13)	130	3.78 (1.13)	.0335*
Anxiety, total (Likert scale, 1–5)	388	2.11 (.80)	123	2.14 (.86)	135	2.08 (.82)	130	2.13 (.74)	.8708
Anxiety, learning situations (Likert scale, 1–5)	388	1.86 (.69)	123	1.82 (.76)	135	1.87 (.70)	130	1.90 (.62)	.4073
Anxiety, evaluation situations (Likert scale, 1–5)	388	2.37 (1.05)	123	2.47 (1.07)	135	2.28 (1.09)	130	2.36 (1.00)	.4281

Abbreviation: PAL: Physically active learning.

*$p < .05$.

TABLE 4 Accelerometer-measured physical activity pre-intervention and mid-intervention.

Variable	*n*	Total	*n*	PAL group	*n*	Breaks group	*n*	Control group	Test of inequality (*p*-value)
Pre-intervention (September–October)									
MVPA, total (min per day)	324	69.0 (21.8)	103	66.1 (19.6)	119	72.8 (23.2)	102	67.4 (21.9)	.6664
LPA, total (min per day)	324	272.1 (43.4)	103	270.6 (38.5)	119	274.4 (51.8)	102	271.0 (37.0)	.9464
ST, total (hour per day)	324	7.1 (1.0)	103	7.2 (1.0)	119	6.9 (1.0)	102	7.2 (.8)	.8031
Steps, total (per day)	324	11,237 (2295)	103	11,060 (2201)	119	11,666 (2336)	102	10,914 (2286)	.6537
Mid-intervention (January–February)									
MVPA, total (min per day)	137	60.9 (21.3)	47	62.6 (21.8)	49	65.4 (20.4)	41	53.5 (20.3)	.0545
LPA, total (min per day)	137	255.5 (38.1)	47	259.9 (34.0)	49	251.7 (40.1)	41	255.1 (40.6)	.5368
ST, total (hour per day)	137	7.6 (.9)	47	7.5 (1.0)	49	7.6 (.8)	41	7.8 (.9)	.0670
Steps, total (per day)	137	10,048 (2212)	47	10,095 (2039)	49	10,709 (2132)	41	9206 (2265)	.0760
MVPA during maths lessons (per 45 min)	160	2.2 (1.3)	56	2.9 (1.7)	55	2.0 (.7)	49	1.6 (.8)	.0000***
LPA during maths lessons (per 45 min)	160	11.4 (4.2)	56	13.1 (4.3)	55	9.8 (2.9)	49	11.0 (4.6)	.0064**
ST during maths lessons (per 45 min)	160	31.5 (4.8)	56	29.0 (5.5)	55	33.2 (3.1)	49	32.4 (4.4)	.0001***
Steps during maths lessons (per 45 min)	160	364 (167)	56	488 (201)	55	297 (88)	49	297 (95)	.0000***

Abbreviations: LPA, light physical activity (<2296 counts/min); MVPA, moderate-to-vigorous physical activity (≥2296 counts/min); PAL, Physically active learning; ST, sedentary time (<100 counts/min).

**$p < .01$. ***$p < .001$.

TABLE 5 Results of main effect models of the adjusted interventions.

Dependent variable	Change in the control group (estimate and 95% CI)	(p-Value)	Effect of PAL group	(p-Value)	Effect of breaks group	(p-Value)	Intra-cluster correlation (95% CI)	Significant subgroup models
Curriculum-based maths exam (0–118 points)	25.32 (18.15, 32.49)	.0000***	−2.72 (−8.37, 2.93)	.3445	.48 (−7.37, 8.34)	.9038	.08 (.00, .17)	(none)
Attitude, total (Likert scale, 1–5)	.088 (−.085, .262)	.3180	−.079 (−.298, .140)	.4767	.073 (−.130, .275)	.4819	.00 (.00, .06)	(none)
Attitude, self-perceptions (Likert scale, 1–5)	.124 (−.073, .321)	.2164	−.103 (−.371, .164)	.4487	.015 (−.227, .258)	.9027	.04 (.00, .11)	(none)
Attitude, enjoyment (Likert scale, 1–5)	.051 (−.186, .289)	.6714	−.056 (−.343, .231)	.7012	.130 (−.135, .394)	.3365	.00 (.00, .00)	Motor skills
Anxiety, total (Likert scale, 1–5)	−.118 (−.275, .039)	.1404	.162 (−.026, .351)	.0916	.071 (−.107, .249)	.4356	.02 (.00, .07)	Motor skills
Anxiety, evaluation situations (Likert scale, 1–5)	−.126 (−.350, .098)	.2686	.119 (−.149, .388)	.3832	.115 (−.142, .372)	.3807	.00 (.00, .03)	(none)
Anxiety, learning situations (Likert scale, 1–5)	−.105 (−.265, .054)	.1942	.203 (.006, .401)	.0434*	.038 (−.146, .223)	.6840	.00 (.00, .01)	(none)

Abbreviation: PAL, Physically active learning.

*$p < .05$. ***$p < .001$.

Mixed models for adjusted intervention effects

There was no significant effect of the intervention on the change in curriculum-based maths performance, enjoyment, self-perceptions or overall maths attitude (Table 5; Figure S1). There was no intervention effect either on the change in overall maths anxiety or maths anxiety in evaluation situations. However, there was a significant effect on the change in anxiety in learning situations: maths anxiety in learning situations increased in the PAL-group (Table 5; Figure S1, standardized regression coefficient $\beta = .28$, CI: .01, .56), but there was no change in the other groups. The intra-cluster correlations ranged from .00 to .08 (Table 5).

Subgroup analysis

There were no subgroup effects of gender, baseline maths performance or motor skills on maths performance or maths-related affective factors (see Table S6). Motor skills also did not have a subgroup effect on maths performance or maths-related self-perceptions. Statistically significant subgroup effects were found only for motor skill tertiles (Intervention Group × Motor Skill tertiles) in overall maths anxiety (local effect $f^2 = .05$) and maths enjoyment (local effect $f^2 = .04$, Table 5). In the PAL group, overall maths anxiety decreased in the highest motor skill tertile, whereas it increased in other motor skill tertiles (Figure 2). The highest tertile differed statistically significantly from the others. There were no differences in changes in overall maths anxiety between the tertiles in other intervention groups (Figure 2). Additionally, in the breaks group, enjoyment decreased in the lowest motor skill tertile, whereas it increased in other motor skill tertiles (Figure 2). The lowest tertile differed statistically significantly from the others. There were no differences in enjoyment in the motor skill tertiles among the other intervention groups (Figure 2).

DISCUSSION

Main findings

This study showed that, although a large part of the maths lessons (40–80 min of the total 180 min/week, depending on the group) was spent integrating PA into maths learning content or was used for PA breaks, the intervention did not affect maths performance or self-perceptions towards maths. That said, integrating PA into maths learning content may increase maths anxiety in learning situations. More specifically, the integration may reduce maths anxiety in children with high levels of motor skills but may increase it in less motorically skilled children. Furthermore, PA breaks may increase maths enjoyment in children with high levels of motor skills while decreasing it in less motorically skilled children.

The effects of PAL and PA breaks

The results showing that PAL did not affect maths performance or maths-related affective factors are inconsistent with previous findings that PAL benefits maths performance (Donnelly et al., 2009; Mullender-Wijnsma et al., 2016) and enhances enjoyment (Riley et al., 2017; van den Berg et al., 2019). Although the effects of PAL have mostly been positive (Norris et al., 2020), zero effects are not unusual. Neither Riley et al. (2017) nor van den Berg et al. (2019) report positive effects on maths performance, even though enjoyment increased. Additionally, Resaland et al. (2016) found no effect of the PAL intervention on academic performance in primary analyses. Furthermore, our results showed that PA breaks had no effect on math performance or affective factors contradicting previous findings (Fiorilli et al., 2021; Mavilidi, Ouwehand, et al., 2020).

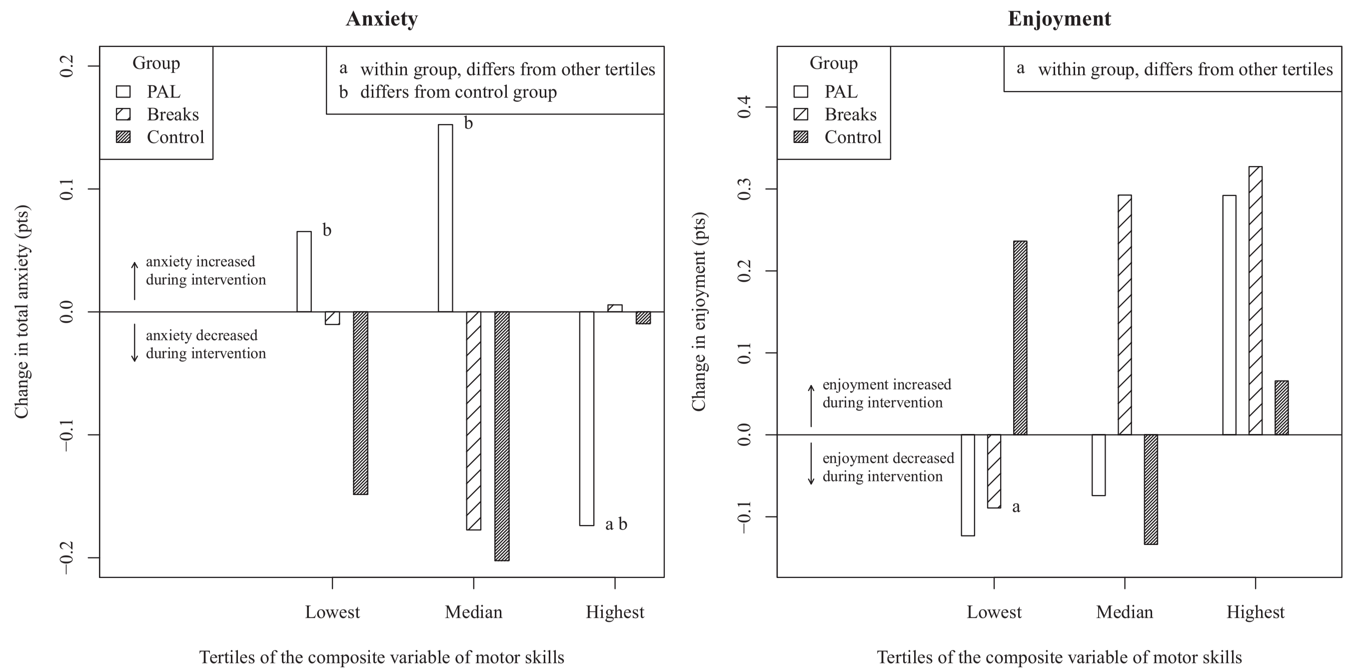

FIGURE 2 The subgroup effects of motor skills on maths anxiety and maths enjoyment. In physically active learning (PAL) group, overall maths anxiety decreased in the highest motor skill tertile but increased in the other motor skill tertiles. In breaks group, maths enjoyment decreased in the lowest motor skill tertile but increased in the other motor skill tertiles.

Since the effects of PA breaks have been explained mainly by physiological and neurobiological theories, these inconsistencies may be due to different types, intensities and amounts of PA breaks added to the lessons in different studies. Moreover, for PAL, the results can also be affected by how and at what level PA is included in the mathematics content to be sufficiently relevant and integrated into the learning task (Mavilidi, Ruiter, et al., 2018). It may not be realistic to add PA to every maths lesson but rather to add it where it best suits particular maths themes and/or during times of the day or week when the children would benefit most from PA. Moreover, 5 months may be too short a period to adapt to a new way of learning. In one previous study, PAL seemed to be too difficult for second graders, and maths performance did not improve as much as in the control group after 1 year (Mullender-Wijnsma et al., 2015a): after 2 years of intervention, children in the intervention group improved their maths performance significantly more than those in the control group (Mullender-Wijnsma et al., 2016).

According to the teachers' questionnaire (Teachers' experiences, Supporting Information), approximately 30% of the maths lessons in the control group included break-type PA. Big differences were not observed in the amount of accelerometer-measured PA between intervention groups. The fact that the control group's maths lessons also included PA may have attenuated the effects of PAL and PA breaks (Resaland et al., 2016). Also, close to the end of intervention, teachers reported using PAL at least weekly in 29% of their subjects (other than mathematics). The overall average use of active breaks was 35.8% (other than mathematics). This carryover effect may have influenced the effectiveness of our interventions. For example, Mullender-Wijnsma et al. (2015b) showed that the physically active lesson enhanced children's engagement in the traditional lesson immediately following it.

As stated earlier, adding enjoyable PA into lessons can have even more beneficial effects on children's maths performance (Schmidt et al., 2016). However, besides the non-significant main effects, subgroup analyses revealed that the effects of PAL and PA break on maths anxiety and enjoyment may diverge, depending on the children's baseline motor skills. The diverging effects on anxiety and enjoyment may have also attenuated the effects on maths performance.

The meaning of motor skill level in relation to PAL

The study results highlight the important role of motor skill level that should be recognized when implementing PAL, PA breaks or other physically active classroom practices. Combining two cognitively challenging tasks (a motor–cognitive dual task) may be too difficult for children with motor learning problems (Schott et al., 2016) and may create maths anxiety. The challenge of focusing attention on this kind of dual-task PAL has been observed before (Egger et al., 2018; Mullender-Wijnsma et al., 2015a). The dual-task paradigm assumes that central processing capacity is limited and must be divided between the tasks being performed simultaneously. When the processing capacity is exceeded by the demands of concurrent tasks, performance in one or both tasks will decline (Huang & Mercer, 2001; McIsaac et al., 2015; Tomporowski & Qazi, 2020). This increased processing load may make the learning situations less attractive. Our results suggest that the dual-task cognitive load (Paas & Sweller, 2012) raised by both motor and mathematical task demands, especially provokes, learning-related anxiety in mathematics more than test anxiety in children with lower skill levels.

Moreover, the fear of failure and lack of perceived control may cause negative experiences and influence behavioural and emotional engagement in the classroom (Finlayson, 2014; Patrick et al., 1993; Sorvo et al., 2017). Thus, the difficulty in performing movements, the shame associated with incompetence and subsequent feelings of inferiority may affect maths enjoyment even if PA is not integrated into the learning content.

In contrast, in children with better motor skills, performing motor movements during maths tasks may make the tasks more challenging and thus interesting, helping them to focus on the task and therefore reducing maths-related anxiety. Furthermore, PA breaks may make the lessons more pleasant for motorically skilled children, enhance motivation and thus enhance maths-related enjoyment even though the PA does not include learning content.

In light of the present results, when implementing PAL and other physically active classroom practices, it is important that teachers differentiate motor tasks as well so that each learner is given the tasks that best support his or her learning. It is important to be able to identify children with motor learning challenges, provide motorically easy and familiar tasks and thus prevent an increase in anxiety and decline in enjoyment caused by task difficulty. Correspondingly, teachers should know how to increase the challenge for motorically talented children. One way to differentiate the tasks is to offer students tasks of different motor difficulty and the students choose the task that suits them.

Teachers may need extra support, tools and training to differentiate PA content, especially from a motor learning perspective. For example, after the current intervention, the teachers' guidebooks developed in the project were revised to offer different levels of alternatives for motor tasks to help teachers. There are also tools that teachers can use to identify motor learning difficulties. For example, the Motor Observation Questionnaire for Teachers (culturally validated and translated into several languages) is highly recommended (Asunta et al., 2017; Fastame et al., 2023; Schoemaker et al., 2008). Support for identifying and differentiation may reduce the uncertainty of whether children have learned academic content sufficiently (Benes et al., 2016), increase teachers' confidence and positively impact children's maths-related affect. At the same time, potential unpleasant feelings caused by PA would be prevented, and PA would be increased to support children's health and well-being.

Strengths and limitations

This study has several strengths: the strong study design with a heterogeneous study population that included children from different socioeconomic, academic and physical backgrounds; the multidisciplinary research team that planned, piloted and trained the teachers; and a comprehensive approach (including versatile measurements) to study the benefits of physically active maths learning. This study provides important novel information on the moderating role of motor skill levels on maths anxiety and enjoyment in implementing physically active classroom practices in maths lessons. To our knowledge, in previous studies, the motor skill levels and the challenges of dual tasks were not taken into account, and the longer-term effects of PA breaks or PAL on anxiety or enjoyment were not measured.

This study has several limitations. Due to the COVID-19 pandemic, some of the children were not reached for final measurements (Figure 1), which may have attenuated the statistical power of our study. Furthermore, the children's motor skills, fitness or executive functions could not be measured after the intervention. The time on task was not controlled during the lessons. Furthermore, the results may have been affected by the observation that control teachers also added PA in maths lessons, and all teachers used physically active methods in other subjects as well. In addition to the 7 models of main effects, 21 subgroup analyses (3 factors and 7 outcomes) were performed with a constant level of significance. Corrections for multiple comparisons were not applied. To verify the moderating effects of motor skills, more research is needed with a primary focus on the topic. For the subgroup analyses, the division of children into tertiles (lowest/median/highest) was based on sample quantiles. Consequently, the subgroups might not completely reflect any general population, and this limits the interpretation of the results.

Conclusions

The PAL or PA breaks did not affect the maths performance or self-perceptions of third-grade children. However, PAL that integrated maths and motor challenges reduced maths anxiety in children with high motor skills but increased it in less motorically skilled children. Furthermore, PA breaks reduced maths enjoyment in children with low levels of motor skills and increased it in more motorically skilled children. Children's motor skills should be considered when implementing physically active classroom practices, and it is important to provide support and tools to help teachers in this differentiation.

AUTHOR CONTRIBUTIONS

Heidi J. Syväoja: Conceptualization; funding acquisition; methodology; project administration; supervision; visualization; writing – original draft; writing – review and editing. **Sirpa Sneck:** Conceptualization; funding acquisition; investigation; methodology; writing – original draft; writing – review and editing. **Tuomas Kukko:** Formal analysis; methodology; validation; visualization; writing – original draft; writing – review and editing. **Piritta Asunta:** Investigation; methodology; project administration; writing – review and editing. **Pekka Räsänen:** Methodology; writing – review and editing. **Helena Viholainen:** Methodology; writing – review and editing. **Janne Kulmala:** Methodology; writing – review and editing. **Harto Hakonen:** Data curation; writing – review and editing. **Tuija H. Tammelin:** Conceptualization; funding acquisition; methodology; project administration; supervision; writing – original draft; writing – review and editing.

ACKNOWLEDGEMENTS

The authors would like to thank the schools, teachers, children, their guardians and the research personnel who helped us to facilitate this research. We would also like to thank Prof. Charles Hillman from the Department of Psychology and Department of Physical Therapy, Movement and Rehabilitation Sciences, Northeastern University, Boston, and Daniel R. Westfall from the Department of Psychology, Northeastern University, Boston, for their valuable assistance and support in planning and preparing the executive function measurements. The study was funded by the Finnish Ministry of Education and Culture (OKM/66/626/2016, OKM/66/626/2017 and OKM/79/626/2018), Research Council of Finland (355350) and The Strategic Research Council (SRC) established within the Research Council of Finland (353361).

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no relationships/conditions/circumstances that present potential conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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REFERENCES

Alanazi, H. M. N. (2020). The effects of active recreational maths games on maths anxiety and performance in primary school children: An experimental study. *Multidisciplinary Journal for Education, Social and Technological Sciences*, *7*, 89–112.

Asonitou, K., Koutsouki, D., Kourtessis, T., & Charitou, S. (2012). Motor and cognitive performance differences between children with and without developmental coordination disorder (DCD). *Research in Developmental Disabilities*, *33*(4), 996–1005.

Asunta, P., Viholainen, H., Ahonen, T., Cantell, M., Westerholm, J., Schoemaker, M. M., & Rintala, P. (2017). Reliability and validity of the Finnish version of the motor observation questionnaire for teachers. *Human Movement Science*, *53*, 63–71.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Phychology*, *59*, 617–645.

Barsalou, L. W., Simmons, W. K., Barbey, A. K., & Wilson, C. D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends in Cognitive Sciences*, *7*, 84–91.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using Ime4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Benes, S., Finn, K. E., Sullivan, E. C., & Yan, Z. (2016). Teachers' perceptions of using movement in the classroom. *The Physical Educator*, *73*, 110–135. https://doi.org/10.18666/TPE-2016-V73-I1-5316

Best, J. R. (2010). Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. *Developmental Review*, *30*(4), 331–351. https://doi.org/10.1016/j.dr.2010.08.001

Best, J. R., Miller, P. H., & Naglieri, J. A. (2011). Relations between executive function and academic achievement from ages 5 to 17 in a large, representative national sample. *Learning and Individual Differences*, *21*(4), 327–336. https://doi.org/10.1016/j.lindif.2011.01.007

Björn, P. M., Aro, M., Koponen, T., Fuchs, L. S., & Fuchs, D. (2018). Response-to-intervention in Finland and the United States: Mathematics learning support as an example. *Frontiers in Psychology*, *9*, 366732.

Blume, F., Dresler, T., Gawrilow, C., Ehlis, A. C., Goellner, R., & Moeller, K. (2021). Examining the relevance of basic numerical skills for mathematical achievement in secondary school using a within-task assessment approach. *Acta Psychologica*, *215*, 103289.

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J. P., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., … Willumsen, J. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine*, *54*(24), 1451–1462. https://doi.org/10.1136/bjsports-2020-102955

Butterworth, B. (2005). The development of arithmetical abilities. *Journal of Child Psychology and Psychiatry*, *46*(1), 3–18.

Carey, E., Hill, F., Devine, A., & Szucs, D. (2017). The modified abbreviated math anxiety scale: A valid and reliable instrument for use with children. *Frontiers in Psychology*, *8*(11), 1–13. https://doi.org/10.3389/fpsyg.2017.00011

Chaput, J. P., Willumsen, J., Bull, F., Chou, R., Ekelund, U., Firth, J., Jago, R., Ortega, F. B., & Katzmarzyk, P. T. (2020). 2020 WHO guidelines on physical activity and sedentary behaviour for children and adolescents aged 5–17 years: Summary of the evidence. *International Journal of Behavioral Nutrition and Physical Activity*, *17*(1), 1–9.

Cragg, L., & Gilmore, C. (2014). Skills underlying mathematics: The role of executive function in the development of mathematics proficiency. *Trends in Neuroscience and Education*, *3*(2), 63–68. https://doi.org/10.1016/j.tine.2013.12.001

Daly-Smith, A., Quarmby, T., Archbold, V. S. J., Routen, A. C., Morris, J. L., Gammon, C., Bartholomew, J. B., Resaland, G. K., Llewellyn, B., Allman, R., & Dorling, H. (2020). Implementing physically active learning: Future directions for research, policy, and practice. *Journal of Sport and Health Science*, *9*, 41–49. https://doi.org/10.1016/j.jshs.2019.05.007

Donnelly, J. E., Greene, J. L., Gibson, C. A., Smith, B. K., Washburn, R. A., Sullivan, D. K., DuBose, K., Mayo, M. S., Schmelzle, K. H., Ryan, J. J., Jacobsen, D. J., & Williams, S. L. (2009). Physical Activity Across the Curriculum (PAAC): A randomized controlled trial to promote physical activity and diminish overweight and obesity in elementary school children. *Preventive Medicine*, *49*(4), 336–341. https://doi.org/10.1016/j.ypmed.2009.07.022

Donnelly, J. E., Hillman, C. H., Castelli, D., Etnier, J. L., Lee, S., Tomporowski, P., Lambourne, K., & Szabo-Reed, A. N. (2016). Physical activity, fitness, cognitive function, and academic achievement in children: A Systematic Review. *Medicine & Science in Sports & Exercise*, *48*(6), 1197–1222. https://doi.org/10.1249/MSS.0000000000000901

Egger, F., Conzelmann, A., & Schmidt, M. (2018). The effect of acute cognitively engaging physical activity breaks on children's executive functions: Too much of a good thing? *Psychology of Sport and Exercise*, *36*, 178–186.

Fastame, M. C., Spada, E., Cimmino, D., Leban, B., Porta, M., Arippa, F., Casu, G., & Pau, M. (2023). Motor and cognitive skills implicated in the Motor Observation Questionnaire for Teachers (MOQ-T): A multidisciplinary approach. *Heliyon*, *9*(6), e16659.

Finlayson, M. (2014). Addressing math anxiety in the classroom. *Improving Schools*, *17*(1), 99–115.

Fiorilli, G., Buonsenso, A., Di Martino, G., Crova, C., Centorbi, M., Grazioli, E., Tranchita, E., Cerulli, C., Quinzi, F., Calcagno, G., Parisi, A., & di Cagno, A. (2021). Impact of active breaks in the classroom on mathematical performance and attention in elementary school children. *Healthcare*, *9*(12), 1689.

Friso-van Den Bos, I., Van Der Ven, S. H. G., Kroesbergen, E. H., & Van Luit, J. E. H. (2013). Working memory and mathematics in primary school children: A meta-analysis. *Educational Research Review*, *10*, 29–44. https://doi.org/10.1016/j.edurev.2013.05.003

Hannula, M. S. (2019). Young learners' mathematics-related affect: A commentary on concepts, methods, and developmental trends. *Educational Studies in Mathematics*, *100*, 309–316.

Hannula, M. S., Bofah, E., Tuohilampi, L., & Metsämuuronen, J. (2014). A longitudinal analysis of the relationship between mathematics-related affect and achievement in Finland. In S. Oesterle, P. Liljedahl, C. Nicol, & D. Allan (Eds.), *Proceedings of the 27th conference of the International Group for the Psychology of Mathematics Education, 3* (pp. 249–256). PME.

Hartwig, T. B., Sanders, T., Vasconcellos, D., Noetel, M., Parker, P. D., Lubans, D. R., Andrade, S., Ávila-García, M., Bartholomew, J., Belton, S., Brooks, N. E., Bugge, A., Cavero-Redondo, I., Christiansen, L. B., Cohen, K., Coppinger, T., Dyrstad, S., Errisuriz, V., Fairclough, S., … del Pozo Cruz, B. (2021). School-based interventions modestly increase physical activity and cardiorespiratory fitness but are least effective for youth who need them most: An individual participant pooled analysis of 20 controlled trials. *British Journal of Sports Medicine*, *55*, 721–729. https://doi.org/10.1136/bjsports-2020-102740

Henderson, S. E., Sugden, D. A., & Barnett, A. (2007). *Movement assessment battery for children-2. [Movement ABC-2]* (2nd ed.). The Psychological Corporation.

Huang, H., & Mercer, V. S. (2001). Dual-task methodology: Applications in studies of cognitive and motor performance in adults and children. *Pediatric Physical Therapy*, *13*(3), 133–140.

Hubbard, K., Economos, C. D., Bakun, P., Boulos, R., Chui, K., Mueller, M. P., Smith, K., & Sacheck, J. (2016). Disparities in moderate-to-vigorous physical activity among girls and overweight and obese schoolchildren during school-and out-of-school time. *International Journal of Behavioral Nutrition and Physical Activity*, *13*(1), 1–8.

Iivonen, S., & Sääkslahti, A. K. (2014). Preschool children's fundamental motor skills: A review of significant determinants. *Early Child Development and Care*, *184*(7), 1107–1126.

Jaakkola, T., Huhtiniemi, M., Salin, K., Seppälä, S., Lahti, J., Hakonen, H., & Stodden, D. F. (2019). Motor competence, perceived physical competence, physical fitness, and physical activity within Finnish children. *Scandinavian Journal of Medicine & Science in Sports*, *29*(7), 1013–1021.

Jordan, N. C., Kaplan, D., Ramineni, C., & Locuniak, M. N. (2009). Early math matters: Kindergarten number competence and later mathematics outcomes. *Developmental Psychology*, *45*(3), 850–867.

Kallio, J., Hakonen, H., Syväoja, H., Kulmala, J., Kankaanpää, A., Ekelund, U., & Tammelin, T. (2020). Changes in physical activity and sedentary time during adolescence: Gender differences during weekdays and weekend days. *Scandinavian Journal of Medicine & Science in Sports*, *30*(7), 1265–1275.

Kennedy, J., Lyons, T., & Quinn, F. (2014). The continuing decline of science and mathematics enrolments in Australian high schools. *Teaching Science*, *60*(2), 34–46.

Kiphard, E., & Schilling, F. (2007). *Korperkoordinationstest fur Kinder. 2. Uberarbeitete und ergangzte Auflage*. Beltz Test GmbH.

Kumle, L., Võ, M. L. H., & Draschkow, D. (2021). Estimating power in (generalized) linear mixed models: An open introduction and tutorial in R. *Behavior Research Methods*, *53*(6), 2528–2543.

Liljedahl, P., & Hannula, M. S. (2016). Research on mathematics-related affect. Examining the structures of affect and taking the social turn. In Á. Gutiérrez, G. C. Leder, & P. Boero (Eds.), *The second handbook of research on the psychology of mathematics education* (pp. 417–446). Sense Publishers.

Lorah, J. (2018). Effect size measures for multilevel models: Definition, interpretation, and TIMSS example. *Large-scale Assessments in Education*, *6*(1), 1–11.

Lubans, D., Richards, J., Hillman, C., Faulkner, G., Beauchamp, M., Nilsson, M., Kelly, P., Smith, J., Raine, L., & Biddle, S. (2016). Physical activity for cognitive and mental health in youth: A systematic review of mechanisms. *Pediatrics*, *138*(3), e20161642.

Martins, J., Marques, A., Sarmento, H., & Carreiro da Costa, F. (2015). Adolescents' perspectives on the barriers and facilitators of physical activity: A systematic review of qualitative studies. *International Journal of Environmental Research and Public Health*, *30*, 742–755.

Mavilidi, M. F., Drew, R., Morgan, P. J., Lubans, D. R., Schmidt, M., & Riley, N. (2020). Effects of different types of classroom physical activity breaks on children's on-task behaviour, academic achievement and cognition. *Acta Paediatrica*, *109*(1), 158–165.

Mavilidi, M. F., Okely, A., Chandler, P., Domazet, S. L., & Paas, F. (2018). Immediate and delayed effects of integrating physical activity into preschool children's learning of numeracy skills. *Journal of Experimental Child Psychology*, *166*, 502–519. https://doi.org/10.1016/j.jecp.2017.09.009

Mavilidi, M. F., Ouwehand, K., Riley, N., Chandler, P., & Paas, F. (2020). Effects of an acute physical activity break on test anxiety and math test performance. *International Journal of Environmental Research and Public Health*, *17*, 1523. https://doi.org/10.3390/ijerph17051523

Mavilidi, M. F., Ruiter, M., Schmidt, M., Okely, A. D., Loyens, S., Chandler, P., & Paas, F. (2018). A narrative review of school-based physical activity for enhancing cognition and learning: The importance of relevancy and integration. *Frontiers in Psychology*, *9*, 2079.

McIsaac, T. L., Lamberg, E. M., & Muratori, L. M. (2015). Building a framework for a dual task taxonomy. *BioMed Research International*, *2015*, 591475. https://doi.org/10.1155/2015/591475

Metsämuuronen, J. (2014). Challenges of the Fennema-Sherman test in the international comparisons. *International Journal of Psychological Studies*, *4*(3), 1–22. https://doi.org/10.5539/ijps.v4n3p1

Metsämuuronen, J., & Tuohilampi, L. (2014). Changes in achievement in and attitude toward mathematics of the Finnish children from grade 0 to 9 – A longitudinal study. *Journal of Educational and Developmental Psychology*, *4*(2), 145–169. https://doi.org/10.5539/jedp.v4n2p145

Mullender-Wijnsma, M. J., Hartman, E., de Greeff, J. W., Bosker, R. J., Doolaard, S., & Visscher, C. (2015a). Improving academic performance of school-age children by physical activity in the classroom: 1-year program evaluation. *Journal of School Health*, *85*(6), 365–371. https://doi.org/10.1111/josh.12259

Mullender-Wijnsma, M. J., Hartman, E., de Greeff, J. W., Bosker, R. J., Doolaard, S., & Visscher, C. (2015b). Moderate-to-vigorous physically active academic lessons and academic engagement in children with and without a social disadvantage: a within subject experimental design. *BMC Public Health*, *15*(1), 1–9.

Mullender-Wijnsma, M. J., Hartman, E., de Greeff, J. W., Doolaard, S., Bosker, R. J., & Visscher, C. (2016). Physically active math and language lessons improve academic achievement: A cluster randomized controlled trial. *Pediatrics*, *137*(3), e20152743. https://doi.org/10.1542/peds.2015-2743

Norris, E., Van Steen, T., Direito, A., & Stamatakis, E. (2020). Physically active lessons in schools and their impact on physical activity, educational, health and cognition outcomes: A systematic review and meta-analysis. *British Journal of Sports Medicine*, *54*, 826–838. https://doi.org/10.1136/bjsports-2018-100502

Paas, F., & Sweller, J. (2012). An evolutionary upgrade of cognitive load theory: Using the human motor system and collaboration to support the learning of complex cognitive tasks. *Educational Psychology Review*, *24*(1), 27–45.

Patrick, B. C., Skinner, E. A., & Connell, J. P. (1993). What motivates children's behavior and emotion? Joint effects of perceived control and autonomy in the academic domain. *Journal of Personality and Social Psychology*, *65*(4), 781–791.

Pesce, C. (2012). Shifting the focus from quantitative to qualitative exercise characteristics in exercise and cognition research. *Journal of Sport and Exercise Psychology*, *34*(6), 766–786.

Pesce, C., Masci, I., Marchetti, R., Vazou, S., Sääkslahti, A., & Tomporowski, P. D. (2016). Deliberate play and preparation jointly benefit motor and cognitive development: Mediated and moderated effects. *Frontiers in Psychology*, *7*, 349. https://doi.org/10.3389/fpsyg.2016.00349

Physical Activity Guidelines Advisory Committee. (2018). *2018 physical activity guidelines advisory committee scientific report*. U.S. Department of Health and Human Services.

R Core Team. (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.r-project.org/

Räsänen, P., Aunio, P., Laine, A., Hakkarainen, A., Väisänen, E., Rajala, T., Laakso, M.-J., & Korhonen, J. (2021). Effects of gender on basic numerical and arithmetic skills: Pilot data from 3rd to 9th grade for a large-scale online dyscalculia screener. *Frontiers in Education*, *6*, 211. https://doi.org/10.3389/feduc.2021.683672

Resaland, G. K., Aadland, E., Moe, V. F., Aadland, K. N., Skrede, T., Stavnsbo, M., Suominen, L., Steene-Johannessen, J., Glosvik, Ø., Andersen, J. R., Kvalheim, O. M., Engelsrud, G., Andersen, L. B., Holme, I. M., Ommundsen, Y., Kriemler, S., van Mechelen, W., McKay, H. A., Ekelund, U., & Anderssen, S. A. (2016). Effects of physical activity on schoolchildren's academic performance: The Active Smarter Kids (ASK) cluster-randomized controlled trial. *Preventive Medicine*, *91*, 322–328. https://doi.org/10.1016/j.ypmed.2016.09.005

Riley, N., Lubans, D., Holmes, K., Hansen, V., Gore, J., & Morgan, P. (2017). Movement-based mathematics: Enjoyment and engagement without compromising learning through the EASY minds program. *EURASIA Journal of Mathematics Science and Technology Education*, *13*(6), 1653–1673. https://doi.org/10.12973/eurasia.2017.00690a

Robinson, L. E. (2011). The relationship between perceived physical competence and fundamental motor skills in preschool children. *Child: Care, Health and Development*, *37*(4), 589–596.

Schmidt, M., Benzing, V., & Kamer, M. (2016). Classroom-based physical activity breaks and children's attention: Cognitive engagement works! *Frontiers in Psychology*, *7*, 1474.

Schmidt, M., Jäger, K., Egger, F., Roebers, C. M., & Conzelmann, A. (2015). Cognitively engaging chronic physical activity, but not aerobic exercise, affects executive functions in primary school children: A group-randomized controlled trial. *Journal of Sport and Exercise Psychology*, *37*(6), 1–44.

Schoemaker, M. M., Flapper, B. C., Reinders-Messelink, H. A., & de Kloet, A. (2008). Validity of the motor observation questionnaire for teachers as a screening instrument for children at risk for developmental coordination disorder. *Human Movement Science*, *27*(2), 190–199.

Schott, N., El-Rajab, I., & Klotzbier, T. (2016). Cognitive-motor interference during fine and gross motor tasks in children with developmental coordination disorder (DCD). *Research in Developmental Disabilities*, *57*, 136–148.

Singh, A. S., Saliasi, E., van den Berg, V., Uijtdewilligen, L., de Groot, R. H. M., Jolles, J., Andersen, L. B., Bailey, R., Chang, Y. K., Diamond, A., Ericsson, I., Etnier, J. L., Fedewa, A. L., Hillman, C. H., McMorris, T., Pesce, C., Pühse, U., Tomporowski, P. D., & Chinapaw, M. J. M. (2019). Effects of physical activity interventions on cognitive and academic performance in children and adolescents: A novel combination of a systematic review and recommendations from an expert panel. *British Journal of Sports Medicine*, *53*, 640–647. https://doi.org/10.1136/bjsports-2017-098136

Sneck, S., Viholainen, H., Syväoja, H., Kankaapää, A., Hakonen, H., Poikkeus, A., & Tammelin, T. (2019). Effects of school-based physical activity on mathematics performance in children: A systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *16*(1), 109. https://doi.org/10.1186/s12966-019-0866-6

Sorvo, R., Koponen, T., Viholainen, H., Aro, T., Räikkönen, E., Peura, P., Dowker, A., & Aro, M. (2017). Math anxiety and its relationship with basic arithmetic skills among primary school children. *British Journal of Educational Psychology*, *87*(3), 309–327. https://doi.org/10.1111/bjep.12151

Stodden, D. F., Goodway, J. D., Langendorfer, S. J., Roberton, M. A., Rudisill, M. E., Garcia, C., & Garcia, L. E. (2008). A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. *Quest*, *60*(2), 290–306.

Stokke, A. (2015). What to do about Canada's declining math scores. https://www.cdhowe.org/sites/default/files/attachments/research_papers/mixed/commentary_427.pdf

Tomkinson, G. R., Carver, K. D., Atkinson, F., Daniell, N. D., Lewis, L. K., Fitzgerald, J. S., Lang, J. J., & Ortega, F. B. (2018). European normative values for physical fitness in children and adolescents aged 9–17 years: Results from 2779165 Eurofit performances representing 30 countries. *British Journal of Sports Medicine*, *52*, 1445–1456. https://doi.org/10.1136/bjsports-2017-098253

Tomporowski, P. D., & Perce, C. (2019). Exercise, sports, and performance arts benefit cognition via common process. *Psychological Bulletin*, *145*(9), 929–951. https://doi.org/10.1037/bul0000200

Tomporowski, P. D., & Qazi, A. S. (2020). Cognitive-motor dual task interference effects on declarative memory: A theory-based review. *Frontiers in Psychology*, *11*, 1015. https://doi.org/10.3389/fpsyg.2020.01015

Tremblay, M. S., Barnes, J. D., González, S. A., Katzmarzyk, P. T., Onywera, V. O., Reilly, J. J., Tomkinson, G. R., & Global Matrix 2.0 Research Team. (2016). Global matrix 2.0: Report card grades on the physical activity of children and youth comparing 38 countries. *Journal of Physical Activity and Health*, *13*(Suppl 2), 343–366.

van Buuren, S., & Groothuis-oudshoorn, K. (2011). MICE: Multivariate imputation by chained equations in R. *Journal of Statistical Software*, *45*(3), 1–67.

van den Berg, V., Singh, A. S., Komen, A., Hazelebach, C., van Hilvoorde, I., & Chinapaw, M. J. M. (2019). Integrating juggling with math lessons: A randomized controlled trial assessing effects of physically active learning on maths performance and enjoyment in primary school children. *International Journal of Environmental Research and Public Health*, *16*(16), 2452. https://doi.org/10.3390/ijerph16142452

Vazou, S., & Skrade, M. A. B. (2017). Intervention integrating physical activity with math: Math performance, perceived competence, and need satisfaction. *International Journal of Sport and Exercise Psychology*, *15*(5), 508–522. https://doi.org/10.1080/1612197X.2016.1164226

Vazou, S., & Smiley-Oyen, A. (2014). Moving and academic learning are not antagonists: Acute effects on executive function and enjoyment. *Journal of Sport and Exercise Psychology*, *36*(5), 474–485.

Visser, J. (2003). Developmental coordination disorder: a review of research on subtypes and comorbidities. *Human Movement Science*, *22*(4–5), 479–493.

von Hippel, P. T. (2020). How many imputations do you need? A two-stage calculation using a quadratic rule. *Sociological Methods & Research*, *49*(3), 699–718. https://doi.org/10.1177/0049124117747303

White, I. R., Royston, P., & Wood, A. M. (2011). Multiple imputation using chained equations: Issues and guidance for practice. *Statistics in Medicine*, *377–399*, 377–399. https://doi.org/10.1002/sim.4067

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How to cite this article: Syväoja, H. J., Sneck, S., Kukko, T., Asunta, P., Räsänen, P., Viholainen, H., Kulmala, J., Hakonen, H., & Tammelin, T. H. (2024). Effects of physically active maths lessons on children's maths performance and maths-related affective factors: Multi-arm cluster randomized controlled trial. *British Journal of Educational Psychology*, *00*, 1–23. https://doi.org/10.1111/bjep.12684