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The association between physical activity during preschool hours and early numeracy

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ABSTRACT: Previous findings suggest positive association between physical activity (PA) and children's cognitive outcomes. Early numeracy (EN) refers to young children's mathematical proficiency, including relational and counting skills. EN has been shown to strongly predict later mathematical and academic achievements. Previous research has mainly focused on school-age children; however, research in early ages is scarce. No previous studies have used device-based measurement of PA with an individual test of EN to understand the associations between preschool PA and EN. The study investigated the relationship between PA during preschool hours and EN in 4-5-year-old children (N = 95, M_{age} = 4.6). PA was measured during 5 consecutive preschool days using hip-worn accelerometers, while EN was assessed using the Finnish Early Numeracy Test. Results revealed no significant correlation between preschool PA level and EN. Furthermore, latent profile analyses identified three profiles with high, medium, and low PA, whereas EN did not significantly differ among the profiles. While the results showed significantly different amounts of PA among children during preschool, the current study suggests no direct relation between preschool PA and EN.

Keywords: *early childhood education, physical activity, early numeracy, latent profile analysis*

Introduction

Early childhood is a crucial period for the development of skills linked to academic achievements (Duncan et al., 2007) and both physical and mental well-being (Janssen & LeBlanc, 2010). Previous studies suggest positive association between physical activity (PA), which is most often measured with accelerometers, and children's academic (Donnelly et al., 2016; St Laurent et al., 2021) and cognitive outcomes (Donnelly et al., 2016; Hillman et al., 2008; Sibley & Etnier, 2003; St Laurent et al., 2021; Zeng et al., 2017), including early numeracy (EN) (Becker et al., 2014). In neuroscientific research, PA has been suggested to positively affect brain areas responsible for higher cognitive functions, such as increased prefrontal cortex activity (Davis et al., 2011), and structural changes in anterior cingulate cortex (Hillman et al., 2008).

While early childhood is an important period for developing a physically active lifestyle (Telama et al., 2014), worrying results have forecasted a trend of decreasing PA in preschool-aged children (Ng & Popkin, 2012). However, some of the more recent studies show reassuring evidence that the national recommendations of 3 hours of total daily PA for preschool-aged children (World Health Organization, 2020) can indeed be met. More specifically, the data collected from Finnish preschools by the Active Early Numeracy project reveals that all preschool-aged children meet the national suggestions (Vanhala et al., 2023). Furthermore, a large-scale report from Finland revealed that over 90% of 4- to 6-year-old children meet this recommendation of total daily PA; however, less meet the recommendation for moderate-to-vigorous PA (Sääkslahti et al., 2021).

EN refers to young children's mathematical proficiency, such as understanding and operating with quantities, number-word sequence, and number relation (Aunio et al., 2004). EN is shown to strongly predict later mathematical competence (Jordan et al., 2007; Morgan et al., 2009) and academic achievement in general (Duncan et al., 2007). Furthermore, low performance in EN has shown to be precursor for later mathematical learning difficulties (Kiss et al., 2019; Mononen et al., 2022; Zhang et al., 2020). Thus, it is important to study and support the development of children's EN.

In Finland, most children spend up to 8 hours a day in preschools (Sääkslahti et al., 2021), where children from 1 to 6 years receive early childhood education (ECE). The ECE is regulated by the Finnish National Core Curriculum for Early Childhood Education and Care (FNCC) (Finnish National Agency for Education [EDUFI], 2018). The findings from a recent report reveal that over 62% of children's total daily PA happens during preschool time (Sääkslahti et al., 2021). Hence, the current study takes a closer look at the association between PA and EN specifically during the time a child spends at a preschool.

Due to the past inconsistency of results regarding PA association to cognitive skills in young children, the results of the study are particularly useful to researchers further investigating the relations between PA and EN in early childhood. Furthermore, previous research has mainly focused on school-age children (Donnelly et al., 2016), while research in early ages is scarce (St Laurent et al., 2021), emphasizing relevance and value of the current research. In addition, while in Finland teachers have the autonomy in planning preschool activities, the overall ECE must comply with the objectives, goals, and values stated in the curriculum guidelines. Thus, the knowledge acquired from the findings is valuable to the policy makers who seek to improve research-based education, and preschool teachers for supporting holistic development of preschool children (Stodden et al., 2023).

Physical activity in early childhood

PA plays an important role in early childhood. PA is defined as any bodily movement that is produced by skeletal muscles and results in expenditure of energy (Caspersen et al., 1985). Such movement, or PA, is an essential part of human life, emerging already in the prenatal stages and continuing throughout life (Gallahue, 2012).

While children's PA has been traditionally assessed using subjective techniques, such as teacher or parent surveys, digital device measurement, such as using accelerometers, offers a more objective evaluation of the PA amount and intensity (Sirard & Pate, 2001). PA can be categorised as light (LPA), moderate (MPA), or vigorous (VPA). In the context of early childhood, LPA includes walking slowly, swinging, or dressing up. Examples of MPA in children include brisk walking, riding a bike, dancing to fast music, or playing with a ball. VPA includes running, jumping, skiing, or climbing up a hill (The Ministry of Education and Culture, 2016).

The importance of studying PA and promoting physically active lifestyle of young children has been suggested by numerous research. Previous studies found positive association between PA and children's both physical and mental health (I. Janssen & LeBlanc, 2010). PA has been shown to have a strong positive association with fundamental motor skills (FMS) (Nilsen et al., 2020; Xin et al., 2020) and physical fitness (Fang et al., 2017; Malina, 2001). It is suggested that FMS (Gallahue, 2012; Logan et al., 2018) and physical fitness (Malina, 2001) create a foundation for more complex physical movements, thus enabling a greater variety and duration of PA, supporting further balance, movement, and active play. Moreover, a physically active routine sets a foundation for a child's future PA in life (Telama et al., 2014).

As stated in the recommendations of the Ministry of Finnish Education and Culture and the World Health Organization, children under 8 should have at least 3 hours of PA during the day (The Ministry of Education and Culture, Finland, 2016) of which 1 hour is moderate-to-vigorous physical activity (MVPA; World Health Organization, 2019, 2020). According to a recent report from Finland, most children meet the total PA recommendations; however, only 46–85% of 4-6-yearl-old children meet the recommendation for MVPA (Sääkslahti et al., 2021). A more worrying result is shown in a systematic review, including studies from multiple countries, by Tucker (2008), revealing that nearly half of the reviewed articles reported preschool-aged children having less than 60 minutes of PA per day. Moreover, a study by Ng and Popkin (2012) forecasts a trend of global PA decline over the next decades.

The timeliness of the topic of PA in children is further emphasised in the light of the current COVID-19 pandemic. In preventative measures to slow down the spread of the infection, many governments have induced social distancing regulations, such as restrictions in attending schools, leisure or sport centres. While the most recent research demonstrates conflicting results regarding the trend of PA, there appears to be an overall PA decline. Particularly, a longitudinal study in Australia showed no significant change in PA in preschool aged children (Okely et al., 2021). Contrarily, several other recent scoping or systematic reviews and meta-analysis revealed an overall global significant decrease in PA in all age groups, including children, during the COVID-19 pandemic (Rossi et al., 2021; Stockwell et al., 2021; Wunsch et al., 2022).

The variability among children's PA is starting to become visible at the age of 4 (Sääkslahti, 2018). By the age of 6, the least physically active child might have as little as a third of PA in the day as their most active peer (Sääkslahti, 2018). The role and responsibility of helping a child to maintain a physically active lifestyle lies mostly on the guardians and the child's responsible early childhood educators during the preschool hours. On average, 2.5 hours out of 4 hours, accounting to over 62% of total PA, happens at preschool (Sääkslahti et al., 2021). Hence, studying preschool PA enhances the understanding of children's considerable part of daily PA and enables to examine its relation to other skills specifically within preschool context. This in turn could contribute towards ECE development and recommendations.

Early numeracy

EN refers to young children's mathematical proficiency, including understanding and operating with quantities, number relation, one-to-one correspondence, classification, seriation, and number-word sequence (Aunio et al., 2004). Previous research proposes various models and frameworks of EN (Aunio & Räsänen, 2016; Devlin et al., 2022; Fritz et al., 2013; Hellstrand, 2021; Krajewski & Schneider, 2009; Wright, 2006), which is commonly explained by a multifactorial structure (for review see Devlin et al., 2022). In this regard, EN consists of multiple components, seen as a set of subskills or factors that underline the development of numeracy skills (Dowker, 2008). Aunio and Niemivirta

(2010) proposed a two-factor model of measuring EN. This model integrates counting tasks, which correspond to the concept of numbers and counting as the prerequisite of mathematical learning as in work of Fuson (1988), and relational tasks, in reference to the principle that logical thinking underlies mathematical development as described by Piaget (1965), Smith (2002), and Bryant and Nuñes (2014). The counting tasks comprise number words use, structured counting, resultative counting, and the general understanding of numbers while relational tasks comprise comparison, classification, one-to-one correspondence, and seriation (Aunio et al., 2004).

According to Clements and Sarama (2020), the one-to-one correspondence between counting words and objects emerges before the age of 3 and leads to the understanding that one-to-one correspondence of items creates groups with equal quantities by the age of 4. Meanwhile, by the age of 4, children obtain the understanding of cardinal principle, understanding that the last word corresponds to the number of items, which helps to successfully count up to five or even ten items, giving the final result as the answer, i.e. resultative counting (Clements & Sarama, 2020).

As indicated, both relational and counting skills develop in conjunction with each other. It is evident that no skill develops in isolation; however, some skills can start to develop before others. While examining the reliability and validity of the Finnish Early Numeracy Test (ENT), Aunio et al. (2006) discovered that the relational skills in general emerge earlier than the counting skills. This result is supported by Clements and Sarama's (2020) description of learning trajectories of EN. According to Clements and Sarama (2020), a 5-year-old child shows the ability of comparing two sets of objects up to ten along with the use of number words in counting to 30 and backwards from 10, the arithmetic skill to solve addition and subtraction problems with the help of structured counting of physical objects, and the understanding of ordinality, as in identifying and using ordinal numbers, i.e. "first" or "tenth." Later, before the age of 6, the relational skills are mostly formulated, while new aspects of counting skills continue to emerge, such as being able to start counting from a certain number forward, and using fingers or counting on to solve addition and subtraction problems. Hence, it is most suitable to investigate counting and relational skills in 4- to 5-year-old children, as these skills typically begin to develop during these ages. However, it is important to note that the presented learning trajectories of EN development depict average developmental progression. Previous studies revealed large individual differences in EN among early years (Aunio et al., 2015; Jordan et al., 2009).

EN is essential in young children's development and future academic outcomes. EN is shown to strongly predict later mathematical competence (Aunio & Niemivirta, 2010; Duncan et al., 2007; Geary et al., 2018; Jordan et al., 2007, 2009; Krajewski & Schneider, 2009; Nguyen et al., 2016). In addition to promoting mathematical learning, EN are shown to predict academic achievement in other areas, such as reading (Duncan et al., 2007). Moreover, EN have been found to be associated with attention skills and later classroom engagement (Pagani et al., 2010). Therefore, supporting the development of EN in young children supports their holistic learning by aiding cognitive development and setting a foundation for later academic achievement. Thus, exploring the possible factors associated with EN development, such as PA, enables to develop holistic approaches of EN support in preschool context.

Physical activity and early numeracy

Several lines of evidence demonstrate that PA and motor development are positively associated with children's cognitive development in general (Carson et al., 2016; Donnelly et al., 2016; Hillman et al., 2008; Roebers et al., 2014; Sibley & Etnier, 2003; Zeng et al., 2017). Specifically, a meta-analysis (Sibley & Etnier, 2003) suggests significant effectiveness of PA on children's cognitive performance, including achievement in mathematics and language, perceptual skills assessment, evaluations of creativity, and attention. The study included children of age groups ranging from 4- to 18-year-olds, revealing the largest effects of PA on cognition for the middle-school students and elementary-age children aged 4 to 7 (Sibley & Etnier, 2003). Furthermore, PA has shown to significantly slow down cognitive decline in later age (Ratey & Loehr, 2011).

Previous research suggests several perspectives on the possible mechanisms between PA and cognitive performance (Pesce et al., 2021). One possible explanation of their association lies in the context of PA (Pesce et al., 2021). The contextual conditions of PA, such as during sport games, often require the same cognitive processes as executive functions, including social engagement, goal-directed behaviour, and strategic thinking (Best, 2010). The relation has been most evident for cognitively engaging and complex movement, which is believed to be due to the interconnectedness of complex motor skills and cognitive functions in the brain (Best, 2010). In support of this theory, other studies have suggested an indirect link between PA and EN through executive functions (Koepp et al., 2022; Vanhala et al., 2023) and through FMS (Hudson et al., 2021; Shoval et al., 2018). From a neuroscientific perspective, PA has been suggested to benefit neurocognitive functions by positively associating with response speed and amplitude of electrophysiological brain responses related to attention and working memory in adults (Hillman et al., 2004) and, through physical fitness, in pre-adolescence children with mean age of 9.6 years (Hillman et al., 2005). In addition, several studies found PA to be favourably associated with structural and functional changes in brain areas, which are responsible for higher cognitive functions. Namely, an intervention study by Davis et al. (2011) found increased prefrontal cortex activity in 7- to 11-year-old overweight children after about 3 months of 20–40 minute PA sessions each week day. A review by Hillman et al. (2008) concluded that PA has beneficial relation to structural changes in anterior cingulate cortex, which pertain to various functions, including, but not limited to complex motor control and executive functions, such as attention, motivation, and working memory (Bush et al., 2000).

Additionally, various studies demonstrated positive association between PA and cognitive or academic performance. In classrooms, PA among 5- to 13 year-old children was found to show a positive relation with their academic achievement (Donnelly & Lambourne, 2011). In addition, Davis et al. (2011) revealed that overweight children from 7 to 11 years of age who participate in more VPA achieve higher grades, including higher math achievement. On the other hand, several reviews indicate inconsistency in findings regarding children's PA and cognitive functions (Best, 2010; Sibley & Etnier, 2003; Sneck et al., 2019; St Laurent et al., 2021) or academic achievement (Hillman et al., 2008). Nevertheless, as pointed out by another systematic review, no study has found any detriment of PA on children's academic achievement (Carson et al., 2016).

Regarding preschool-aged children, Koepp et al. (2022) found that 3- to 6-year-old children's outdoor PA during preschool predicted higher inhibitory control performance, while higher PA during indoor play was negatively associated with assessed classroom-based executive function. Other previous research has shown that more frequent MVPA during a 30 minute preschool outdoor play time was indirectly associated with higher mathematics achievement through inhibitory control (Becker et al., 2014). However, despite presenting evidence of indirect association between EN and PA, Becker et al. (2014) found no direct statistical significance between the two elements. Moreover, previous studies have predominantly utilized variable-centred approaches, focusing on the general linear associations of PA and EN. Contrarily, a less common person-centred approach, such as latent profile analysis, accounts for the heterogeneity within populations regarding PA levels (Becker & Nader, 2021) and EN (Aunio et al., 2015; Jordan et al., 2009), allowing to examine the structure of their associations within different individuals. Thus, the current study explores this topic further to bring new evidence of PA and EN relation in preschool.

PA and EN in the context of Finnish ECE

The present study explores PA and EN association in the context of Finnish ECE. In Finland, ECE is regulated by the FNCC. The main mission of the FNCC is to "promote children's holistic growth, development and learning" (EDUFI, 2018, Chapter 2) through focusing on general transversal competencies rather than subject-based goals. The pedagogical principles of Finnish ECE include play-based learning, collaboration, and participatory learning approaches.

While the FNCC provides general objectives, the preschool teachers have the autonomy and the responsibility of preparing pedagogical plans in their groups. According to the Act on Early Childhood Education and Care (540/2018), the preschool teachers must hold a university bachelor's degree in education. Other educators include social pedagogues with at least a bachelor's degree in healthcare and social services and a child carer with a relevant vocational upper secondary qualification. The children's group sizes and age composition may vary greatly, provided that the adult-to-child ratio for over 3-year-old children stays within 1 to 7, as stated in the Government Decree on Early Childhood Education and Care (753/2018).

In the FNCC, PA is seen as a fundamental element of children's healthy lifestyles and development. The FNCC advises preschool educators to provide children with many versatile ways to enjoy PA, both indoors and outdoors, as part of their daily routines to "supports children's thinking and learning" (EDUFI, 2018, Chapter 2.7).

EN is portrayed by the FNCC through numerical literacy (EDUFI, 2018, Chapter 2.7), such as understanding and use of mathematical language, and mathematical thinking. The latter includes identifying shapes and amounts, classifying, comparing and ranking objects, problem solving, number sequencing and naming, measuring, and perception of space and plane as part of geometric thinking (EDUFI, 2018, Chapter 4.5).

Research questions

While the benefits of PA on mathematical performance have been suggested by multiple studies, previous research has mainly focused on school-age children (Donnelly et al., 2016). Meanwhile, research in early ages, such as in preschool-aged children, is scarce (St Laurent et al., 2021). No previous studies have used device-based measurement of PA for the duration of the whole preschool day to understand the association between the level of young children's PA and EN. Furthermore, the current study individually evaluates each participating child's EN based on the ENT, rather than assessing it using teachers' estimations or grade point average in mathematics, as in previous studies (Best, 2010), emphasising the relevance and value of the current research.

Thus, our current study focuses on the relationship between PA during preschool hours and EN in children aged 4 to 5 years.

The following research questions are addressed:

1) How are PA intensity levels during preschool hours associated with EN in 4- to 5-year-old children?

Based on the previously found associations between PA and EN (Becker et al., 2014; Sibley & Etnier, 2003; Vanhala et al., 2023), we hypothesise that higher PA level during preschool would be positively related to children's ENT scores.

2) What kind of profiles regarding PA intensity levels during preschool hours and EN can be identified among 4- to 5-year-old children?

Due to previously found heterogeneity in PA (Becker & Nader, 2021) and EN (Aunio et al., 2015; Jordan et al., 2009) within children, we anticipate the latent profile analysis to identify several profiles according to children's levels of PA and EN. In line with previous findings, we expect that the scores of ENT would be higher particularly for those children who have more MVPA (Becker et al., 2014) and VPA (Vanhala et al., 2023) during the preschool.

Methods

The current study is part of Active Early Numeracy Project 2019–2022 led by Professor Aunio. The project's main aim was to examine the relationship between EN, executive functions, PA, and motor skills in preschool-aged children and to develop ways to support children's EN. The current study focuses on PA and EN. The project was approved by the University of Helsinki Ethical Review Board, and the study follows the ethical principles of Finnish National Board on Research Integrity. A written informed consent was obtained from the parents of the children participating in the study. Participation in the study was completely voluntary with the right to withdraw at any point with no questions or consequences.

Participants and procedures

The data used in the current cross-sectional study were collected from November 2019 to December 2020. For the Active Early Numeracy project, the participants were recruited from 16 preschools in Helsinki, Finland. Preschools from metropolitan areas were suggested by the municipality of Helsinki to obtain a heterogeneous sample. A total of 345 3- to 5-year-old children participated in the project. The criteria for sample selection for the current study were based on four conditions: 1) a child is 4- to 5-year-old, 2) EN measurements are completed, 3) parent-filled preschool hours diary is present, 4) at least 3 days of accelerometer measurements with at least 3 preschool hours of wear time per each of the preschool day were collected. Additionally, one participant was excluded from the analysis due to irregular accelerometer data. As a result, the sample for this study consists of 95 (44 boys, 51 girls) 4- to 5-year-old children (M = 4.61, SD=0.31) from 14 preschools.

The PA and EN measurements were aimed to be conducted at the individual level as closely together as possible, with the mean difference between the measurements of 3.1 months (SD = 3.5 months). Due to complications caused by COVID-19, the difference ranged from 0.3 to 10.9 months between the measurements.

Measures

Physical activity was measured during 5 consecutive preschool days using hip-worn accelerometers (Actigraph wGT3X-BT). The parents of the participants were instructed to help their children to remove the device before sleep and water-based activities, such as showering, swimming, and sauna.

The accelerometers have been initialised to output the raw data in 15-s epochs. Next, non-wear time criteria of 20 minutes is selected using the Actilife software in accordance with the results of Esliger et al. (2005). The data were then filtered to include only cases with a valid number of days (≥ 3 days) and a valid number of hours per day (≥ 3 hours/day). In their review, Trost et al. (2005) recommend to have at least 3 valid monitoring days for studying weekly PA with adults and a minimum of 4 days in studies with children and adolescence. Bingham et al. (2016), however, found that 3 days of measurement for young children are sufficient for providing a reliable result. The objective of the current study narrows down to examining PA during weekdays only, choosing 3 days as the optimal criteria for the valid number of days. Previous studies have concluded that 6 hours per day (Bingham et al., 2016; Jerome et al., 2009) and 8 hours per day (Aadland & Ylvisåker, 2015) are sufficient as the wear time criterion for a full day PA measurement. Considering that the current research focuses only on the preschool hours, which account to approximately the third of a child's full day or roughly half of the waking hours, the criteria for the valid hours per day is set to be 3 hours. Thus, any cases with less than 3 days of at least 3 hours of measurements have been filtered out.

Then, the PA levels are categorised as sedentary time (ST), light (LPA), moderate (MPA), and vigorous (VPA) physical activity with the cut point criteria of < 100 counts/min for ST, ≥ 100 counts/min for LPA, ≥ 1680 counts/min for MPA and ≥ 3368 counts/min for VPA, in accordance with Janssen et al. (2013). Other variables of combined moderate and vigorous physical activity (MVPA) and a combined light, moderate, and vigorous (Total PA), are created. The result is depicted as the percent of time corresponding to each PA level out of wear time during the child's preschool day.

Early numeracy was assessed individually by trained research assistants during the day at the preschools using the Early Numeracy Test (Van Luit et al., 2006). The ENT consists of a total of 40 questions, evaluating 4- to 7-year-old children's EN. The ENT is comprised of eight sections corresponding to eight aspects of numerical knowledge: comparison, classification, one-to-one correspondence, seriation, number words use, structured counting, resultative counting, and the general understanding of numbers; the first four of the aspects being relational tasks and the latter four – counting tasks (Van Luit et al., 1994). Each question is scored as either 0 points or 1 point, resulting in the minimum test result of 0 points and the maximum of 40 points. The ENT shows a high level of internal consistency (α = 0.846) in the current sample. The sum value of the ENT scores was used in the analysis as the measure of EN.

The information regarding *children's preschool hours* is obtained from parents' diaries, given during the accelerometers wear. *The date of birth and gender* were collected from a parent-filled questionnaires.

Data analyses

The data are analysed using SPSS 28.0.1 and MPlus 8.8 analysis software. Preliminary analyses of raw data were performed prior to the main data analyses. The measurements of PA and EN were conducted on different days, some being up to 11 months apart due to the unexpected challenges and restrictions resulting from the COVID-19 pandemic. Thus, children's age was calculated separately for PA and EN: from date of birth and the accelerometer start date, and from date of birth and the time of EN measurement date, respectively. Age during EN assessment was used for the mean age of the sample.

The age of the children in the current sample ranged from 4.01 to 5.16 years (M = 4.61, SD = 0.31) and was used as the control variable. Previous research has demonstrated an evident effect of age on PA level (Becker et al., 2014) and EN (Aunio et al., 2006; Purpura & Lonigan, 2015). In the current sample, the linear regression analysis revealed a significant effect of age on ENT score (R^2 = 0.07, F(1,93) = 6.95, p < 0.01). Similarly, age predicted the percent of time spend in each level of PA, including ST (R^2 = 0.054, F(1,93) = 5.34, p < 0.05), LPA (R^2 = 0.136, F(1,93) = 14.58, p < 0.001), MPA (R^2 = 0.055, F(1,93) =5.41, p < 0.05), and VPA (R^2 = 0.099, F(1,93) = 10.23, p < 0.01). To control for the effect of age, the age-controlled standardised residual variables for all PA levels and EN were used in further analysis.

Kolmogorov-Smirnov normality test indicated normal distribution for all variables except for MPA (D(95) = 0.09, p = 0.04), while values of skewness and kurtosis for all variables were within +/-2. The data were thus concluded to be suitable for performing parametric data analyses (George & Mallery, 2010).

To answer the first research question of how the PA levels (ST, LPA, MPA, VPA) and the EN are related, a correlation matrix was created for the variables of interest. To test for any other relation between PA and EN, correlations between MVPA and EN as well as between Total PA and EN were calculated.

Taking into consideration the great individual variability in PA levels (Becker & Nader, 2021) and EN (Aunio et al., 2015; Jordan et al., 2009) in preschool-aged children, this study used a person-centred quantitative approach of data analysis to answer the second research question. This was done by identifying children's profiles according to their PA data and EN with latent profile analysis. This method allowed to identify patterns according to PA (ST, LPA, MPA, VPA) and EN (ENT scores) and examine their relationship further. Latent profile analysis entails running analysis for different number of profiles, comparing the results, and selecting the best fitting number of profiles for the data. The evaluation of the best fitted model is conducted according to the Bayesian information criteria (BIC), entropy, Vuong–Lo–Mendell–Rubin likelihood ratio test (VLMR), and the Lo-Mendell-Rubin Adjusted LRT Test (LRT). In theory, the best fitted model results in the lowest BIC value, highest entropy, and significance of VLMR and LRT (Weller et al., 2020).

As the participating children were from different preschools, the effect of the preschool on the results was tested. The intraclass correlation coefficient (ICC) was computed to assess the extent of nesting in our dataset, where children were nested within preschools. The low ICC for EN ($r_{ICC} = 0.15$) and Total PA ($r_{ICC} = 0.04$) suggests that our data does not exhibit a substantial nesting structure, and as such, the assumption of nested data does not significantly impact our findings.

The main effect of profile for the PA levels and EN was tested using ANOVA. First, the means of PA and EN were compared among the profiles using ANOVA. The normality test for variables in each of the three profiles within the four PA levels and EN variables concluded that 14 samples out of 15 are normally distributed with one exception of VPA sample for one of the profiles being non-normally distributed. Thereby, Tukey's post hoc was performed to compare all possible pairs of means, revealing the profile differences for PA levels and EN, thus answering the second research question.

Results

The current sample showed high variability in PA and EN among 4- to 5-year-old children (Table 1). The accelerometer results revealed that children in this sample spend most of their preschool time sedentary and in LPA, followed by MPA, and VPA. The percent of preschool time spent at different PA levels is depicted on Figure 1. The ENT scores ranged from 1 to 35 out of a maximum of 40 scores.

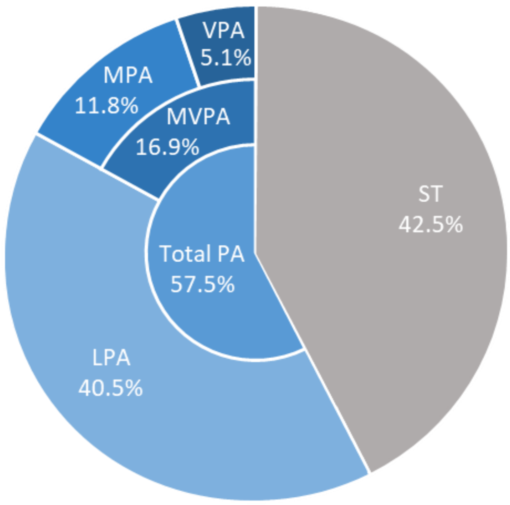

FIGURE 1 The average percent of preschool time spent at each of physical activity level

Note. ST = sedentary time; *LPA* = light physical activity; *MPA* = moderate physical activity; *VPA* = vigorous physical activity; *MVPA* = moderate-to-vigorous physical activity; *Total PA* = total physical activity.

Association of preschool PA with EN

The results of the Pearson's correlation indicate that while PA levels correlate strongly among each other, the correlation between PA during preschool and EN is not significant in preschool ages 4 to 5 (Table 1).

Similar results were obtained when correlating MVPA with EN ($r(93) = -0.026$, $p = 0.799$) and Total PA with EN ($r(93) = -0.029$, $p = 0.777$), finding no significant correlation for any PA with EN. Hence, the analysis suggests that there is no direct linear relation between preschool PA and EN in 4- to 5-year-old preschool children.

TABLE 1 Descriptive statistics and Pearson correlation matrix for physical activity levels and early numeracy

VARIABLE		*N*	*MEAN*	*SD*	*MIN*	*MAX*	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1. ST	%	95	42.52	5.80	26.88	58.85	1						
	minutes		177.68	33.55	98.06	241.06							
2. LPA	%	95	40.53	4.10	25.59	50.99	-.68**	1					
	minutes		169.48	28.99	85.06	221.00							
3. MPA	%	95	11.79	2.67	5.63	16.93	-.80**	.25*	1				
	minutes		49.34	13.11	20.44	80.67							
4. VPA	%	95	5.15	2.49	1.36	13.54	-.42**	-.27**	.40**	1			
	minutes		21.69	11.53	5.33	56.80							
5. MVPA	%	95	16.94	4.15	7.35	27.65	-.71**	-.01	.82**	.79**	1		
	minutes		71.03	20.62	26.88	114.63							
6. Total PA	%	95	57.48	5.80	41.15	73.12	-1.00**	.70**	.81**	.31**	.71**	1	
	minutes		240.51	41.99	111.94	320.06							
7. EN		95	16.12	7.13	1	35	.03	-.02	-.10	.07	.01	-.06	1

Note. *ST* = sedentary time; *LPA* = light physical activity; *MPA* = moderate physical activity; *VPA* = vigorous physical activity; *EN* = early numeracy; *%* = the percent of total preschool time spent in that level of PA*; minutes* = the average time in minutes spent in that PA level per measured preschool day; *N* = sample size; *SD* = standard deviation, *Min* = minimum, *Max* = maximum.
* $p < 0.05$
** $p < 0.01$

Preschool PA and EN profiles

The latent profile analyses indicated that three profiles was the most optimal number of profiles (Table 2). While the four-profile solution resulted in the lowest BIC value (1293.823), the three-profile solution had the highest entropy (0.896), and fitted the data significantly better than the two-profile solution (VLMR, $p < 0.05$; LRT, $p < 0.05$).

TABLE 2 Summary statistics for latent profile analysis comparing one to four profiles

NUMBER OF PROFILES	*N*	*BIC*	*ENTROPY*	*VLMR*	*LRT*
1	95	1383.424			
2	63, 32	1337.227	0.732	0.3039	0.3145
3	**60, 21, 14**	**1297.280**	**0.896**	**0.0297**	**0.0324**
4	32, 26, 21, 16	1293.823	0.834	0.5763	0.5879

Note. *N* = number of participants in each profile in descending order. *BIC* = Bayesian information criteria. *VLMR* = Vuong–Lo–Mendell–Rubin likelihood ratio test. *LRT* = Lo-Mendell-Rubin Adjusted LRT Test. The chosen model is in bold.

The ANOVA revealed a significant main effect of profile for all levels of PA and no main effect of profile for EN (Table 3). Since there was no significant difference among the profiles for EN, the profiles were named according to their PA levels, as Active, Average, and Passive. The mean age of each group was 4.8 years. As revealed by Tukey's post hoc, the Active group had a significantly lower ST, significantly higher LPA and MPA than all of the other groups, and significantly higher VPA than the Passive group. The Average group had average values for all PA levels, differing significantly from other profiles in ST, LPA, and MPA, but not in VPA. Accordingly, the Passive group spend significantly greater percent of their time being sedentary and had significantly lower light and moderate PA than other profiles. All significant differences are shown on the graph (Figure 2). As the differences between the profiles were explained by the amount of PA, the average percentages of time spent out of a preschool day in each PA level for each of the profiles are presented in Figure 3.

TABLE 3 Means, standard deviations, and one-way analyses of variance in the three profiles

VARIABLE	*PROFILES*						*ANOVA*		
	Active (N = 21)		Average (N = 60)		Passive (N = 14)		F-value	p-value	η^2
	M	SD	M	SD	M	SD			
ST	-1.330	0.453	0.086	0.432	1.626	0.501	186.799	< 0.001	0.802
LPA	0.912	0.594	-0.098	0.821	-0.949	1.091	22.634	< 0.001	0.330
MPA	1.089	0.488	-0.020	0.672	-1.550	0.480	78.264	< 0.001	0.630
VPA	0.507	0.962	-0.027	0.907	-0.647	1.061	6.362	0.003	0.122
EN	-0.347	0.906	0.165	0.993	-0.186	1.028	2.420	0.095	0.050

Note. All values are age-controlled and standardized; *ST* = sedentary time; *LPA* = light physical activity; *MPA* = moderate physical activity; *VPA* = vigorous physical activity; *EN* = early numeracy; *M* = mean value; *SD* = standard deviation.

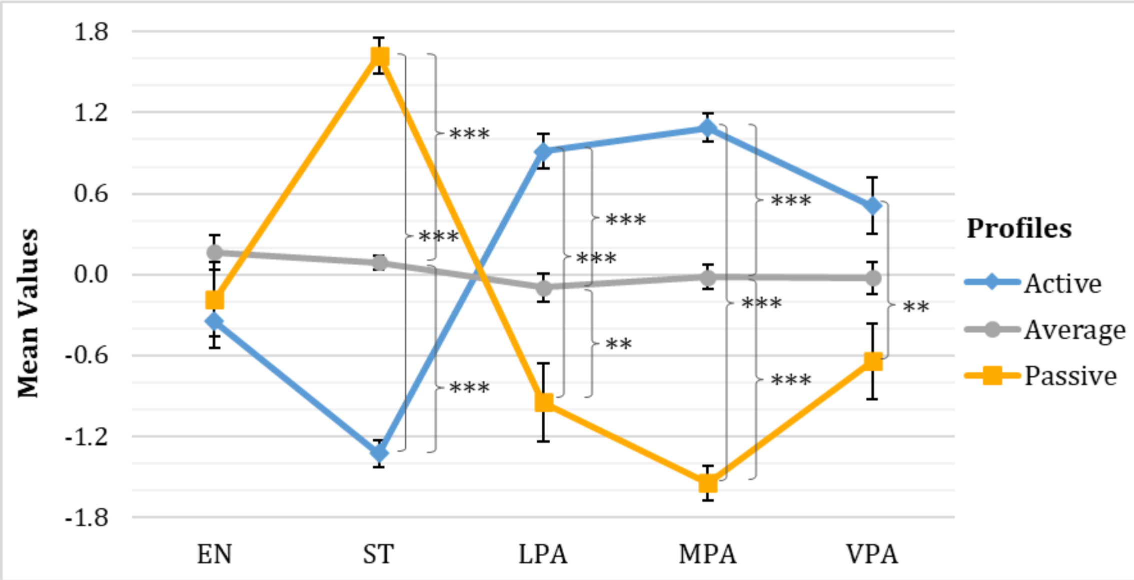

FIGURE 2 Mean comparison of early numeracy and physical activity levels among the three latent profile analysis profiles

Note. All values are age-controlled and standardized; *ST* = sedentary time; *LPA* = light physical activity; *MPA* = moderate physical activity; *VPA* = vigorous physical activity; *EN* = early numeracy; the error bars represent standard error.
*** = $p < 0.001$
** = $p < 0.01$

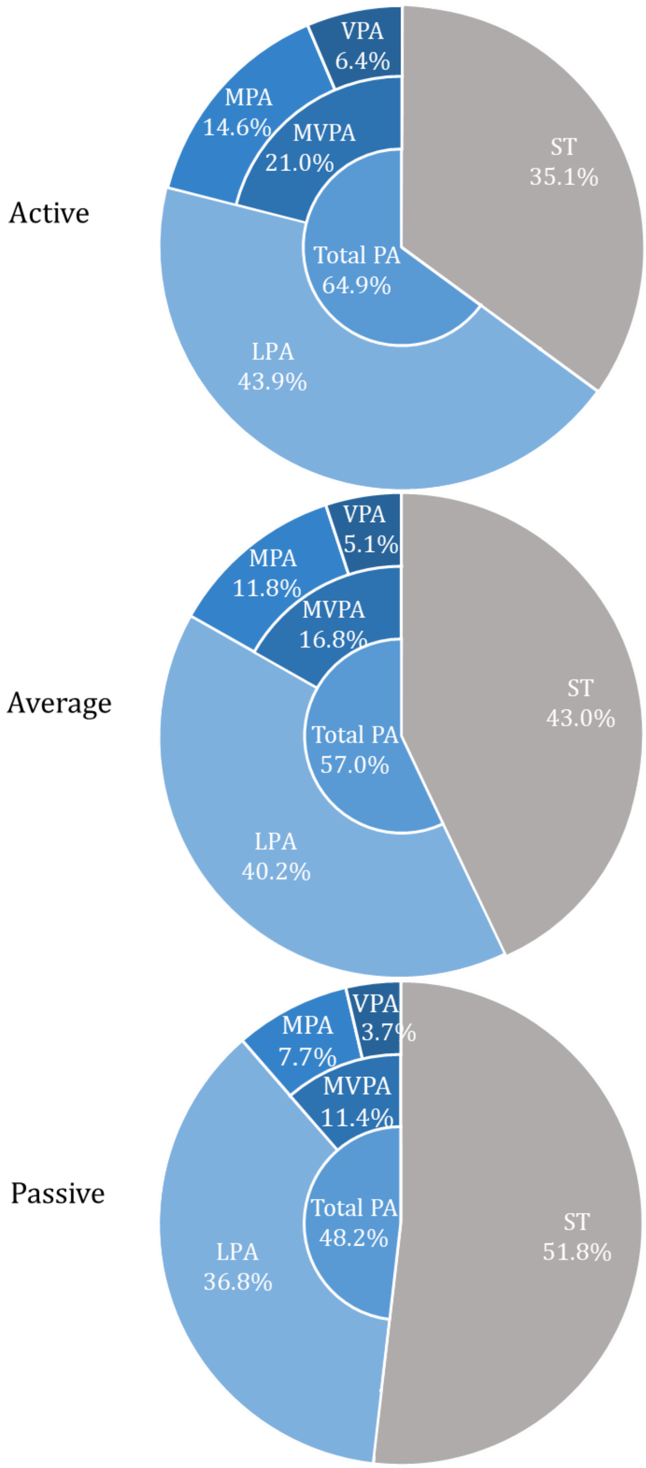

FIGURE 3 The average percent of preschool time spent at each of physical activity level in different profiles

Note. ST = sedentary time; *LPA* = light physical activity; *MPA* = moderate physical activity; *VPA* = vigorous physical activity; *MVPA* = moderate-to-vigorous physical activity; *Total PA* = total physical activity.

Discussion

The current study investigated the relationship between PA during preschool hours and EN in 4- to 5-year-old children. The study resulted in two main findings: the absence of direct association between preschool PA and EN, and the great variability in preschool PA among 4- to 5-year-old children. The results do not support our initial hypothesis that PA intensity during preschool would be positively related to children's ENT scores. We additionally hypothesised, that the latent profile analysis would identify several profiles according to children's levels of PA and EN, which received partial support by the results.

Contrary to our prediction, the first main finding of the study revealed no association between the two measures as suggested by both correlation analysis and latent profile analysis. Firstly, the results show that PA level during preschool does not correlate with EN. There was no association of any of the PA levels independently, neither of the combined moderate and vigorous PA, nor the combined light, moderate, and vigorous PA with EN in the current sample of preschool aged children. Secondly, the profile analysis and comparison of means among the profiles reveals no main effect of profile for EN. The results of the current study are in line with previous research, supporting the absence of direct relationship between PA and EN in ages 4 to 5 (Becker et al., 2014; Becker & Nader, 2021; Vanhala et al., 2023). It is worth noting that while Becker et al. (2014) discovered similar findings, their study assessed PA during a single 30-minute outdoor play time at preschool. Similarly to the current research, Becker and Nader (2021) measured PA during preschool hours for at least 3 days, whereas Vanhala et al. (2023) included whole day waking hours PA. The three studies concluded that PA and EN are not directly related.

On the one hand, some other research reveals a negative association between PA and cognitive functions in preschool children. Specifically, higher amounts of moderate to vigorous PA have been found to be negatively related to working memory (Cook et al., 2019), executive functions (Willoughby et al., 2018), and inhibitory control (Koepp et al., 2022; Vanhala et al., 2023). Further, greater levels of VPA have been negatively associated with EN (Vanhala et al., 2023). It is important to note that indoor and outdoor PA may be differently associated with children's cognitive performance. While outdoor PA was positively related to preschool children's inhibitory control task scores, higher amounts of indoor PA predicted lower assessment scores in attention and in inhibitory control during observed circle time (Koepp et al., 2022). The absence of direct relationship between preschool PA and EN in the current study may be caused by using a combined indoor and outdoor PA activity data. Thus, possible positive effect of outdoor PA may have been obscured by a possible negative effect of indoor PA. As Becker and Nader (2021) suggest, ST may be beneficial to children's development of cognitive skills by providing opportunities to concentrate on educational tasks.

On the other hand, studies in school-aged children reveal a general positive association between PA and both cognitive function and academic achievement, including math performance (Davis et al., 2011; Donnelly et al., 2016). The discrepancy might be due to the different age of the participants between the above mentioned and the current studies or due to the absence of direct relation between PA and EN, whereas, as suggested by other papers, there might be an indirect relationship (Becker et al., 2014; Becker & Nader, 2021; Chaddock et al., 2010; Davis et al., 2011; Donnelly et al., 2016; Hudson et al., 2021; Jylänki et al., 2022; Koepp et al., 2022; Raine et al., 2018; Shoval et al., 2018; Vanhala et al., 2023). Results from previous studies suggest indirect positive relationship between PA and EN, such as through FMS (Hudson et al., 2021; Jylänki et al., 2022; Shoval et al., 2018), including locomotor skills (Vanhala et al., 2023), through physical fitness level (Becker & Nader, 2021; Chaddock et al., 2010; Donnelly et al., 2016; Raine et al., 2018), self-regulation (Becker et al., 2014), working memory/updating and inhibitory control (Koepp et al., 2022; Vanhala et al., 2023), or effects on brain systems underlying cognition and behaviour (Becker & Nader, 2021; Davis et al., 2011). One possible explanation for the indirect relationship between PA and EN mediated by FMS is that PA facilitates development of FMS (Xin et al., 2020), such as locomotor skills (Nilsen et al., 2020), which in turn support children's cognitive and academic skills (Jylänki et al., 2022). Previous studies have suggested relations between PA and cognitive skills through increased cerebral blood volume or mediated by FMS through various underlying mechanisms like shared functional connectivity in the brain and shared practicing of goal-directed skills (Best, 2010). Further studies examining the relation between children's PA and EN including FMS and executive functions in the model are needed.

The second main finding of the study reveals significant differences in children's PA during preschool hours, in line with our hypothesis, as demonstrated by three distinct PA profiles: active, average, and passive. Children in the active profile spent the least amount of time in sedentary activities during preschool hours while engaging the most in LPA, MPA, and VPA compared to other profiles. The results for children in passive group mirror those in the active group, demonstrating the highest ST and lowest LPA, MPA, and VPA compared to other profiles. Meanwhile, the average total preschool PA for the 4- to 5-year-old children of the current sample is 241 minutes, or approximately 4 hours, and the average MVPA is 71 minutes, or approximately 1.2 hours, which accounts for nearly 17% of their preschool time. According to the data collected, the children meet the national and international recommendations of at least 3 hours of total PA (The Ministry of Education and Culture, Finland, 2016) of which 1 hour is MVPA (World Health Organization, 2019, 2020). The current results for average PA are higher than that of previous studies (Becker & Nader, 2021; Brown et al., 2009), including a study conducted in Finland (Sääkslahti et al., 2021). However, the MVPA ranged from 27 minutes to 115 minutes per preschool day, meaning that some children were getting less than half of the amount of recommended MVPA per day during their preschool hours. The average results for the ENT are consistent with the Finnish ENT norms (Aunio et al., 2006). It is worth noting that the absence of association between preschool PA and EN does not undermine the importance of PA in early childhood. Thus, in line with the recommendations, it is encouraged for the preschool educators to support the least active children in developing physically active lifestyles.

Limitations and future studies

The current study added valuable knowledge of children's PA during preschool and its relation to EN. The main strengths of the study are in studying these associations in preschool-aged children, in applying a person-centred approach to capture the relations of distinct profiles within the heterogeneous population, in using the intensive digital device measurement of PA during the full preschool day and in conducting individually performed ENT. However, the study also has certain limitations which must be addressed. It is important to note that the validity of the accelerometer results relies on measurement criteria and statistical analysis of the raw output data, such as the identification and removal of non-wear time (Aadland et al., 2018; Migueles et al., 2017; Vanhelst et al., 2019) and defining the cut point criteria for PA levels (Janssen et al., 2013; Pate et al., 2006). Furthermore, a popular children's outdoor activity, such as swinging, results in high speed detected by accelerometer, while the expenditure of energy can be low (Gao et al., 2018). Nevertheless, the use of ActiGraph accelerometers provides highly informative and often accurate data compared to observational studies (Sirard & Pate, 2001). For future studies, the accuracy of PA measurements could be improved further by combining the accelerometers with video of observational data. Considering the scarcity of previous research on this topic, further research investigating young children's PA and EN relation is necessary. Firstly, more studies with preschool-aged children are needed. Secondly, it is important to acknowledge other possible factors that according to previous research might have affected or contributed to EN performance, such as parental education (King & Purpura, 2021) or income (Jordan et al., 2006), child's language skills (King & Purpura, 2021; Zhang et al., 2020), and inattention (Aunio & Niemivirta, 2010). Finally, it would be beneficial to conduct future studies with a larger and more diverse dataset encompassing a broader range of regions across Finland.

Conclusion

In the current study, no association between PA and EN performance could be demonstrated. Answering the first research question, the study suggests that the PA intensity levels during preschool hours are not directly associated with EN performance in 4- to 5-year-old children. No significant correlation between preschool PA and EN was observed. For the second research question, three profiles regarding PA intensity levels during preschool hours were identified, named as the active, the average, and the passive groups. The results suggest a variability in PA levels among 4- to 5-year-old children during preschool hours. However, ANOVA showed no main effect of profile on EN. Thus, in this study, the profiles related to PA levels alone could not explain EN performance in this age group. This study suggests that in the age group of 4- to 5-year-old preschool children, PA during preschool hours per se is not, or is not yet, associated with EN. Further studies are needed to investigate the relation between PA and EN in preschool aged children.

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