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PHYSICAL ACTIVITY, HEALTH AND EXERCISE

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Multivariate physical activity association patterns for fundamental motor skills and physical fitness in preschool children aged 3–5 years

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ABSTRACT

Physical activity (PA) is important for children's development of fundamental motor skills (FMS) and physical fitness (FIT) but evidence regarding which intensities are associated with these outcomes in early childhood is limited. The aim of this study was to determine the cross-sectional multivariate PA intensity signatures associated with FMS and FIT in children aged 3–5 years. We used a sample of 952 Norwegian preschoolers (4.3 years, 51% boys) who provided data on PA (ActiGraph GT3X+), at least one FMS (locomotor, object control and/or balance skills) or FIT (speed agility, standing long jump, and/or handgrip strength) outcome, body mass index, and socioeconomic status in 2019–2020. We created 17 PA intensity variables (0–99 to ≥15000 counts per minute) from the vertical axis and used multivariate pattern analysis for analyses. The PA intensity spectrum (including sedentary time) was significantly associated with all outcomes. Associations for PA intensities were positive (negative for sedentary time), strongest for moderate and vigorous intensities, and were significant across sex and age groups. Our findings show that the PA intensity spectrum is associated with FMS and FIT in young children and that promotion of PA, in particular moderate- and vigorous-intensity activity, from an early age benefits children's physical development.

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Motor development; gross motor skill; intensity spectrum; multivariate pattern analysis; accelerometer; early childhood

Introduction

Fundamental motor skills (FMS) are vital to enable young children to participate in physically active play, sports, and to live healthy lives (Cools et al., 2009; Robinson et al., 2015). As FMS do not develop naturally through maturation, but depend on a variety of movement experiences (Stodden et al., 2008), children need to be given movement opportunities from an early age to stimulate the development of FMS. Due to many preschool children's low physical activity (PA) (Bornstein et al., 2011; Hnatiuk et al., 2014; Nilsen et al., 2019), low FMS (Bolger et al., 2021; Dobell et al., 2020), and low physical fitness levels (FIT) (Smith et al., 2019; Stodden et al., 2015; Timmons et al., 2012), early childhood has been highlighted as an important period for promoting PA, and as such, improving FMS and FIT (Goldfield et al., 2012; Stodden et al., 2008). PA can be defined as any bodily movement produced by skeletal muscles that results in increased energy expenditure (Caspersen et al., 1985). Specifically, moderate- to vigorous intensity PA (MVPA) is essential for physical health, cognitive development and psychosocial health in young children (Carson et al., 2017; Poitras et al., 2016). FIT, defined as a set of attributes that people have or achieve that relates to the ability to perform PA (Caspersen et al., 1985) is closely related to FMS (Cattuzzo et al., 2016; Utesch et al., 2019), and is a powerful marker of health that underlies PA performance (Ortega et al., 2008). An individual's FIT can be characterized by attributes across multiple domains, as for example muscular strength (e.g., measured through exercises such as standing long jump and hand-grip strength) or motor fitness (e.g., expressed through a speed agility running test) (Ortega et al., 2008, 2015).

Several studies have investigated the cross-sectional relationship between PA and FMS in preschoolers; most studies found weak to moderate associations (Figueroa & An, 2017; Jones et al., 2020; Xin et al., 2020). A recent systematic review that included 26 studies in preschool children (22 of which used accelerometry to asses PA) summarized the evidence for associations between intensity-specific PA and domain-specific FMS (Xin et al., 2020). Weak to moderate positive associations for MVPA with total FMS and object control skills were found, but associations between locomotor skills and MVPA were inconsistent (Xin et al., 2020), underlining the need for further research on this relationship. The relationship between light PA (LPA) and locomotor skills showed a non-significant association, whereas LPA in association with object control- and balance skills were uncertain (Xin et al., 2020). Moreover, few studies have investigated the relationship between vigorous-intensity PA (VPA) and FMS (Figueroa & An, 2017; Jones et al., 2020; Nilsen, Anderssen, Loftesnes, et al., 2020; Xin et al., 2020). One study used multivariate pattern analysis across the entire PA intensity spectrum and found that PA of vigorous intensities

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was most strongly associated with FMS in preschoolers, specifically for locomotor and object control skills (Nilsen, Anderssen, Loftesnes, et al., 2020). Further, there is scarce evidence on the relationship between PA and balance (Xin et al., 2020). Thus, more evidence is needed to determine how the PA intensity spectrum is associated with locomotor, object control and balance skills in young children.

Some studies have examined the association between PA and different FIT measures in young children (i.e., muscular fitness, motor fitness, cardiorespiratory fitness). The literature shows favourable associations, particularly for higher PA intensities (Bürgi et al., 2011; Carson et al., 2017; Fang et al., 2017; Riso et al., 2019; Serrano-Gallén et al., 2022; Smith et al., 2019), whereas associations for lower intensities are less explored. With regard to muscular strength and motor fitness, the evidence is mixed for LPA (Fang et al., 2017; Serrano-Gallén et al., 2022; Smith et al., 2019) and MPA (Leppänen et al., 2016; Serrano-Gallén et al., 2022; Smith et al., 2019), but consistent (and favourable) for VPA (Leppänen et al., 2016; Riso et al., 2019; Serrano-Gallén et al., 2022; Smith et al., 2019). Associations between FIT and SED were negative or non-significant (Leppänen et al., 2016; Riso et al., 2019; Serrano-Gallén et al., 2022). Thus, the current evidence on associations between intensity-specific PA and FIT is mixed among preschoolers (Carson et al., 2017; Smith et al., 2019; Timmons et al., 2012). More research on the relationship between intensity-specific PA (including SED) and both FMS and FIT are therefore needed to extend our evidence base, preferably including the full PA intensity spectrum that provides a nuanced picture of association patterns.

Previous studies that have investigated associations for device-measured PA with FMS and FIT in young children have applied different methodologies for analysing the data, and sample sizes are often low, limiting comparison of findings across studies (Cain et al., 2013; Kim et al., 2012; Migueles et al., 2018). For example, both choice of epoch length and intensity cut points for accelerometry may influence associations substantially (E. Aadland & Nilsen, 2022; Cain et al., 2013; Kim et al., 2012), and most studies have examined FMS in relation to pre-decided PA intensity categories, such as LPA, total PA (TPA), and MVPA (Figueroa & An, 2017; Jones et al., 2020; Logan et al., 2015; Xin et al., 2020). Different epoch lengths can confuse findings and interpretation regarding young children's time used across the intensity spectrum and corresponding associations with outcomes (E. Aadland et al., 2019; Nilsen, Anderssen, Loftesnes, et al., 2020). Because children's movement patterns are often sporadic and include many short periods of PA (Bailey et al., 1995; Vale et al., 2009) a short epoch has been proved to better capture information about PA for both cardiometabolic health (E. Aadland et al., 2019) and motor skills (Nilsen, Anderssen, Loftesnes, et al., 2020) than longer epoch lengths in schoolchildren and preschool children, respectively. Due to these challenges, the evidence for which PA intensities correlate most strongly with FMS and FIT in young children remains unclear. An additional challenge when including the whole intensity spectrum of PA from accelerometry is multicollinearity of the PA intensity variables (E. Aadland et al., 2019a). Multivariate pattern analysis can solve the multicollinearity issue of intensity-specific accelerometer data (E. Aadland et al., 2018; Kvalheim & Karstang, 1989; Wold et al., 1984), but only one previous study has determined association patterns for PA intensities with FMS in preschoolers using this approach (Nilsen, Anderssen, Loftesnes, et al., 2020), and we are not aware of any study that has examined relationships between PA and FIT using multivariate pattern analysis. The aim of this study was to investigate cross-sectional associations between the whole PA intensity spectrum and FMS (locomotor-, object control-, and balance skills) and FIT (speed agility, standing long jump, and handgrip strength) measures in a large sample of 3–5-year-old Norwegian preschoolers using multivariate pattern analysis.

Methods

Study design and recruitment of participants

This was a cross-sectional analysis using baseline data from the Active Learning Norwegian Preschool(er)s Study (ACTNOW), a cluster-randomized, controlled trial conducted in Western Norway between 2019 and 2022 (Aadland, Tjomsland, et al., 2020). Data were collected in September–October 2019 and 2020. A total of 56 preschools from the rural region of Sogn og Fjordane with ≥6 children aged 3–4 years old were invited to participate, of which 46 accepted our invitation (82.1%). All children born between 2014 and 2017 (aged 3–5 years) within participating preschools were invited to take part in the study. Out of 1532 invited children, 1265 parents consented to participate (response rate 82%). Of these, 952 children (51% boys) provided valid data relevant for the current study (Figure 1). Children needed at least one valid outcome measure of FMS (i.e., locomotor, object control and/or balance skills) or FIT (i.e., speed agility, standing long jump and/or handgrip strength), in addition to valid PA, body mass index (BMI), and socio-economic status (SES) data, to be included in the analyses. Missing data were mainly due to non-sufficient accelerometer wear time, that children were not willing to perform some tasks, or missing data on background variables (BMI and/or SES) due to absence or lack of parental report.

Children were informed at their level of understanding, and all testing were conducted in safe and familiar environments at their respective preschools. The Norwegian Center for Research Data (NSD) and the institutional ethics committee at the Western Norway University of Applied Sciences approved the study (ref.nr NSD: 248220). All procedures and methods conform to the ethical guidelines defined by the World Medical Association's Declaration of Helsinki and its subsequent revisions (World Medical Association Declaration of Helsinki, 2018). The ACTNOW study is registered in clinicaltrials.gov 7 August, with identifier NCT04048967 (https://clinicaltrials.gov/ct2/show/NCT04048967?term=actnow&rank=1).

Procedures

A detailed description of the ACTNOW protocol has previously been published (Aadland, Tjomsland, et al., 2020). Only procedures relevant for the current study will be described.

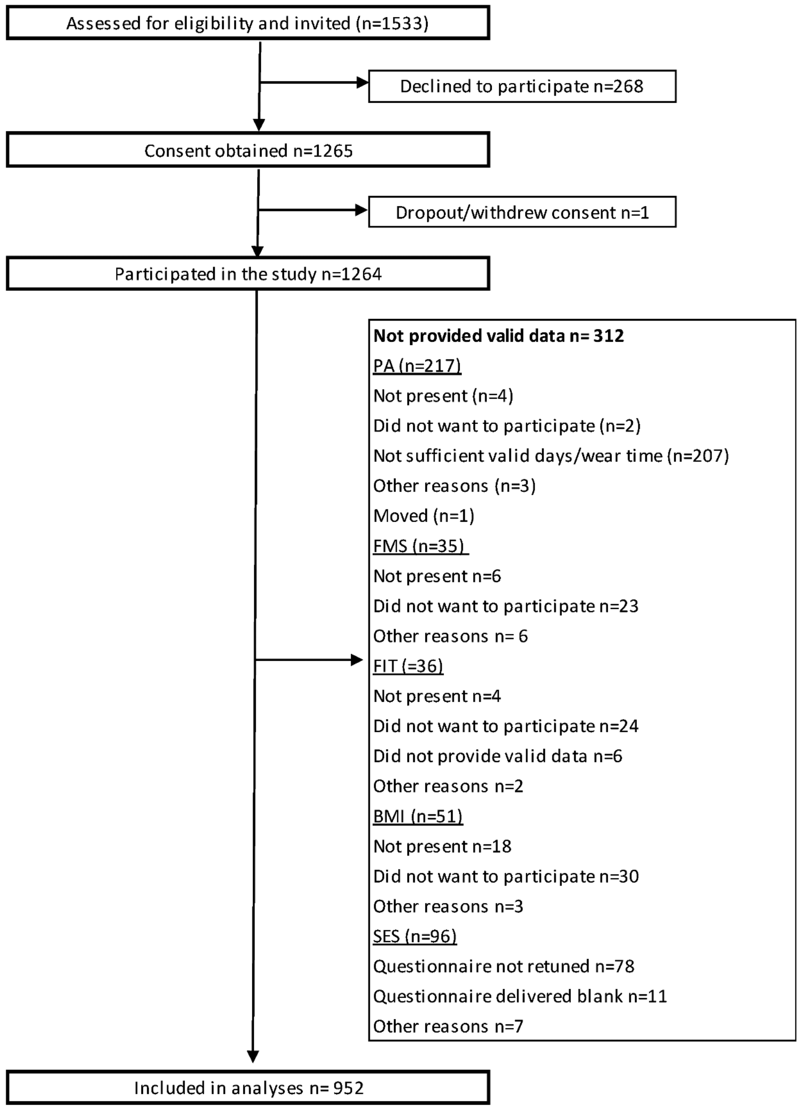

Figure 1. Flow chart of inclusion process and eligible participants.

Physical activity

PA was assessed objectively using ActiGraph GT3X+ accelerometer (ActiGraph, LLC, Pensacola, Florida, USA) (John & Freedson, 2012), which are widely used and validated (De Vries et al., 2009; O'Brien et al., 2018). Children were asked to wear the accelerometer on the right hip 24 h/day for 7 consecutive days (except during water-based activities); however, this study did not include sleep data. Sampling rate was set to 30 Hz and data were analysed using 1-s epochs using a custom-made script in MATLAB (MathWorks, Massachusetts, USA). Non-wear time was defined as consecutive periods of ≥20 min of zero counts (Cain et al., 2013; Esliger et al., 2005). The criterion for a valid day was ≥480 min/day of wear time accumulated between 06:00 and 22:00 hours. To be included in the present analyses, children had to provide ≥3 valid weekdays and ≥1 valid weekend day of PA data (Aadland, Nilsen, et al., 2020). Associations between PA and the outcomes were analysed applying 17 PA variables: 0–99, 100–999, 1000–1999, 2000–2999, . . . , 14 000–14 999, and ≥15 000 cpm; created to capture the entire PA intensity spectrum, including SED. Data from all three axes (vertical, antero-posterior, and medio-lateral) were included. Additionally, we included total PA (counts per minute) and intensity-specific PA and SED as determined by Evenson et al. (Evenson et al., 2008). (Sedentary time (SED) (≤100 cpm), light-intensity PA (LPA) (101–2295 cpm), moderate-intensity PA (MPA) (2296–4011), vigorous-intensity PA (VPA) (≥4012 cpm), and MVPA (min/day) (≥2296 cpm)) for descriptive statistics and bivariate correlation analysis. Our interpretation of the PA intensities derived from the multivariate analysis was based on the criteria by Evenson et al. (Evenson et al., 2008).

Motor skills

FMS were evaluated through a modified test battery guided by the "Test of Gross Motor Development 3" (TGMD-3) (Ulrich, 2019) and the Preschooler Gross Motor Quality Scale (PGMQS) (Sun et al., 2010). The test battery combines locomotor- (running, jumping, hopping) and object control (overhand throw, catch, kick) skills from the TGMD-3 and balance skills (single-leg standing, walk on line forward, walk on line backward) from

PGMQS. This modified test battery was developed to reduce the participant- and researcher burden, to include all three domains of FMS, and to include items of relevance for the Norwegian context. The structural validity of the test battery is acceptable, despite great commonality between locomotor and object control skills (K. N. Aadland et al., 2022). FMS was tested and scored according to the TGMD-3 (locomotor- and object control items) and PGMQS (balance items) protocols. Children were evaluated in small groups (3–5 children) during preschool hours to secure a safe environment. During testing, one instructor explained and demonstrated each skill, while a separate assessor scored the performance. Children were scored quantitatively based on evaluation of whether or not the child demonstrate specific process criteria using original scoring procedures and were scored either "0" (not satisfactory) or "1" (satisfactory) depending on their performance (Sun et al., 2010; Ulrich, 2019). Each child had one test attempt per skill before they performed each skill twice in a standardized order. Scores from both trials were summed providing a score of 0–2 points per criteria. Mean score from the total number of scores from two trials were registered for the three domains, meaning a score closer to zero indicates lower motor skill proficiency, whereas a score closer to two indicates higher motor skill proficiency. Inter-rater reliability was performed by scoring of video-taped material of 22 children and was .76–.85 across subdomains after adjusting for assessor (K. N. Aadland et al., 2022).

Physical fitness

The FIT assessments were based on three items: handgrip strength, standing long jump, and speed-agility, according to the Assessing FITness in PREschoolers (PREFIT) test battery (Ortega et al., 2015). PREFIT is an adaption of the ALPHA-Fitness test battery, specifically designed for preschool populations, and has good reliability in young children (Cadenas-Sanchez, Martinez-Tellez, et al., 2016; Castro-Piñero et al., 2010; Ruiz et al., 2011). Handgrip strength was measured twice for each hand with a hand dynamometer (TKK 5001 Grip A, analogue model 577, Takey, Tokio), with standardized grip-span of 4.0 cm (Cadenas-Sanchez, Sanchez Delgado, et al., 2016; Sanchez-Delgado et al., 2015). We used the highest of the four scores (two left hand, two right hand) for analyses. Lower body muscle strength was measured by standing long jump where children were instructed to jump as far as possible from a standing position, with a two-footed take-off and landing. The best of two valid performances were used, reported in cm. A 4×10 m shuttle run test was used to measure motor fitness/speed-agility skills, where children were instructed to run as fast as possible back and forth between cones placed 10 m apart. The test was performed twice, and results were reported in seconds from start to finish in which the fastest time was used for analyses. Cardiorespiratory fitness was not included due to limited space (i.e., field testing).

Anthropometry and demography

Body mass was measured to the nearest 0.1 kg using an electronic scale (Seca 899, SECA GmbH, Hamburg, Germany). Height was measured to the nearest 0.1 cm using a transportable Seca 217 (SECA GmbH, Hamburg, Germany). BMI was calculated as weight (kg) divided by the height squared (m^2). Normal weight, overweight, and obese children were defined according to the age- and sex-specific cut points by Cole et al. (Cole et al., 2000). Waist circumference was measured to nearest 0.5 cm with a Seca 201 ergonomic circumference measuring tape (SECA GmbH, Hamburg, Germany). SES, parental education level (highest of mother or father), was reported by parent(s)/guardian(s) by questionnaire.

Statistical analyses

Participant's characteristics, PA, SED, FMS, and FIT were reported as frequencies, means and standard deviations (SD). Testing for differences between included and excluded children was performed using linear mixed models (continuous variables) or generalized estimating equations (categorical variables). The multivariate PA intensity patterns associated with FMS and FIT were determined using multivariate pattern analysis applied to uniaxial- and triaxial intensity spectra, which has previously been applied to accelerometer data with various outcomes (E. Aadland et al., 2018, 2021; Nilsen, Anderssen, Loftesnes, et al., 2020; Vabø et al., 2022).

Prior to performing the multivariate pattern analyses, we performed linear mixed model regression analysis with all PA, FMS and FIT variables as dependent variables (separate models) including all covariates (sex, age, BMI, SES, accelerometer wear time, and assessor for FMS outcomes) as independent variables, to obtain residuals from these models to adjust the outcomes for these variables and remove confounding. In primary analyses, Partial Least Square (PLS) regression analysis (Wold et al., 1984) were used to determine the multivariate PA signatures associated with the outcome variables (FMS and FIT) including either 17 (uniaxial) or 51 (triaxial) PA variables as explanatory variables, in one joint model. PLS regression decomposes the explanatory variables into orthogonal linear combinations, while simultaneously it maximizes the covariance with the outcome variable. Thus, in contrast to ordinary least squares regression, PLS regression can handle completely collinear variables. The multivariate models were validated using Monte Carlo resampling with 1000 repetitions and keeping half of participants as external validation set (Kvalheim et al., 2018). Target projection was used for each model (Kvalheim & Karstang, 1989; Rajalahti & Kvalheim, 2011), as well as reporting of explained variance (R^2) to show each of the PA variables contribution (E. Aadland et al., 2019; Rajalahti, Arneberg, Berven, et al., 2009; Rajalahti, Arneberg, Kroksveen, et al., 2009). Results were reported using multivariate correlation coefficients with 95% confidence intervals (E. Aadland et al., 2019), which are comparable to Pearson's bivariate correlation coefficient.

In secondary analyses, we used multivariate pattern analysis to determine association patterns for the uniaxial intensity spectre (17 PA variables from the vertical axis) separately for boys and girls and for younger and older children (defined by median split). Additionally, bivariate associations between FMS, FIT, and traditional PA intensity categories (SED, LPA, MPA, VPA and MVPA), and inter-relationships between the 17 PA intensity categories were determined using Pearson's r. Comparison of association patterns across gender (boys, girls) and age (younger, older) were done by performing separate analyses for these subgroups. Testing of moderators was not done in the current study as this is difficult to perform and challenging to interpret for multivariate association patterns that include many explanatory variables. Multivariate pattern analyses were performed by means of the commercial software Sirius version 11.5 (Pattern Recognition Systems AS, Bergen, Norway). All other analyses were performed using IBM SPSS v. 28 (IBM SPSS Statistics for Windows, Armonk, NY; IBM Corp., USA). Statistical significance was set to $p \leq 0.05$.

Results

Children's characteristics

Children's characteristics are presented in Table 1. To be included in the study, children had to provide valid PA, at least one valid outcome of FMS or FIT, BMI, and SES data. Included children did not differ from excluded children ($n = 311$) regarding sex ($p = 0.232$), BMI ($p = 0.123$), weight status ($p = 0.168$), PA or SED ($p = 0.262$–0.603), FMS measures ($p = 0.058$–0.221), or handgrip strength ($p = 0.354$). However, included children were older ($p < 0.001$), had a higher SES ($p < 0.001$), performed better at standing long jump ($p = 0.022$) and speed-agility ($p = 0.003$) and exhibited higher PA levels according to the proportion achieving the PA guidelines when compared to excluded children ($p < 0.001$).

Children had a median of seven valid days of PA registration. There was no difference in MVPA between included children who wore the accelerometer more or less than 7 days ($p = 0.073$). Boys and older children (≥4.3 yr) spent more time in total PA and MVPA than girls and younger children (<4.3 yr) ($p > 0.001$). Boys and younger children spent more time in LPA than girls and older children ($p < 0.001$). Boys were less sedentary than girls ($p < 0.001$), but there was no difference in sedentary time by age. Girls scored higher on locomotor ($p = 0.012$) and balance skills ($p < 0.001$) than boys, whilst boys performed better at object control skills than girls ($p < 0.001$). Boys scored better than girls at standing long jump ($p = 0.002$) and handgrip strength ($p < 0.001$), but not motor fitness ($p = 0.396$). The older children achieved significantly higher scores on all FMS and FIT measures than younger children ($p < 0.001$).

Multivariate associations

For the total sample, PA (intensities ≥100 cpm) was positively and significantly associated with all FMS and FIT measures, whereas time spent in 0–99 cpm (SED) was negatively associated with all outcomes. A higher PA level was associated with a better performance for all outcomes. Explained variance for the association of the PA intensity spectrum with FMS was 7.82% for locomotion skills, 4.97% for object control skills, and 1.63% for balance skills. Explained variance for the association of the PA spectrum with FIT was 5.78% for speed agility, 9.31% for standing long jump, and 2.89% for handgrip strength. As illustrated in Figure 2, the strongest associations were found for high-intensity PA (6000–10.000 cpm) and time spent sedentary (0–99 cpm) for all outcomes. The multivariate patterns were

Table 1. Children's characteristics. All results are reported as means (SD) if not otherwise stated.

	Total	Boys	Girls	Younger	Older
	n=952	*n*=488 (51%)	*n*=464	*n*=451 (53% boys)	*n*=501 (50% boys)
Age (years)	4.3 (0.9)	4.3 (0.9)	4.4 (0.9)	3.5 (0.5)	5 (0.4)
BMI (kg/m^2)	16.3 (1.5)	16.3 (1.4)	16.2 (1.6)	16.4 (1.4)	16.1 (1.5)
Weight status (%)					
Normal	83.2	87.3	78.9	84.5	82.0
Overweight	14.1	10.5	17.9	13.3	14.8
Obese	2.7	2.3	3.2	2.2	3.2
SES (parents)					
< University (%)	24.8	26.0	23.5	25.3	24.4
University < 4 years (%)	28.5	29.9	26.9	29.3	27.7
University ≥ 4 years (%)	46.7	44.1	49.6	45.5	47.9
PA					
Wear time (min/day)	763 (69)	766 (69)	759 (68)	756 (67)	769 (69)
Total PA (cpm)	685 (151)	711 (149)	656 (149)	654 (141)	712 (156)
SED (min/day)	538 (64)	532 (63)	545 (64)	532 (61)	544 (65)
LPA (min/day)	150 (21)	156 (21)	144 (20)	154 (21)	146 (21)
MPA (min/day)	37.5 (7.5)	40 (7.6)	35 (7)	36.5 (7)	38.5 (8)
VPA (min/day)	37 (10)	39 (10.5)	35 (9.5)	34 (9)	40 (10)
MVPA (min/day)	75 (17)	79 (17)	70 (15)	70.5 (15)	78 (17)
≥60 min daily MVPA*(%)	82.2%	87.5%	76.7%	76.3%	87.6%
FMS					
Locomotor skills	0.83 (0.38)	0.79 (0.39)	0.86 (0.36)	0.58 (0.28)	1.02 (0.32)
Object control skills	0.70 (0.35)	0.72 (0.38)	0.67 (0.30)	0.51 (0.25)	0.85 (0.35)
Balance skills	0.90 (0.49)	0.81 (0.49)	1.00 (0.48)	0.59 (0.41)	1.15 (0.40)
Fitness (PREFIT)					
Speed-agility (sec)	19.3 (3.2)	19.5 (3.1)	19.1 (3.2)	21.4 (3.1)	17.6 (2.0)
Standing long jump (cm)	79 (25.6)	80.2 (26.6)	77.8 (24.6)	61.7 (22.1)	92.6 (19.3)
Handgrip strength (kg)	8.6 (2.7)	8.8 (2.8)	8.3 (2.5)	6.9 (2.0)	10.1 (2.2)

Values reported as N (%) or mean ± SD, Standard Deviation. BMI: Body Mass Index. Weight status according to Cole et al (Cole et al., 2000). SES defined as highest educational level off child`s mother or father. Physical activity intensity categories defined according to Evenson et al (Evenson et al., 2008). *Achievement of national and international (WHO) guidelines defined as an average of 60 min MVPA per day (The Norwegian Directorate of Health, 2022; World Health Organization, 2020). FMS: Fundamental motor skill, possible mean score between 0 (lower skill) and 2 (higher skill) for each domain. N (all): FMS: *N*=885–910; fitness: *N*=847–935. N (subgroups): FMS: *N*=392–490; fitness: *N*=373–500.

similar for the uniaxial- and triaxial intensity spectra, and we therefore only presented results for the vertical axis (see additional files 2–7 show associations for the triaxial spectrum with all outcomes).

When analyses were split by sex (Figures 3 and 4) and age (Figures 5 and 6), all association patterns remained statistically significant in all subgroups. Association patterns for both FMS and FIT were similar for boys and girls ($r = 0.94–0.99$) and for younger and older children ($r = 0.97–0.99$), despite some variation in explained variances.

Bivariate correlations

Table 2 shows bivariate correlations (Pearsons r) between FMS, FIT, and traditional PA intensity categories defined by cut points suggested by Evenson et al. (Evenson et al., 2008). Correlations between PA and FMS and FIT were equivalent to the findings reported above, showing strongest associations for MVPA ($r = −.24–.29$) and VPA ($r = −.24–.31$). All FMS and FIT variables were significantly positively correlated ($r = .146–.509$). Interrelationships between the 17 PA spectrum variables were strong (see additional file 1). All PA intensities correlated negatively with time spent in 0–99 cpm, whereas other variables generally correlated strongly and positively with each other. Correlations were strongest with proximal variables and weakest with variables at the opposite ends of the PA spectrum.

Discussion

This study examined associations between device-measured PA intensities and a broad set of FMS and FIT measures in preschool children aged 3–5 years. Using the novel multivariate pattern analysis approach, results showed favourable associations between the PA intensity spectrum (and unfavourable associations between time spent in SED) and all FMS and FIT variables. The strongest associations were found for VPA, and marginally weaker for SED for all variables. This association pattern was consistent across age and sex groups.

In line with previous results, our findings show positive associations between PA and FMS (Figueroa & An, 2017; Jones et al., 2020; Nilsen, Anderssen, Loftesnes, et al., 2020; Xin et al., 2020). We found strongest associations for locomotion skills ($R^2 = 7.82\%$), a weaker association for object control skills ($R^2 = 4.97\%$), and a very weak association for balance skills ($R^2 = 1.63\%$). These findings are generally consistent with the only previous study using multivariate pattern analysis to investigate associations between the PA intensity spectrum and FMS in preschoolers (Nilsen, Anderssen, Loftesnes, et al., 2020), although an association with balance skills was not found by Nilsen et al. (Nilsen, Anderssen, Loftesnes, et al., 2020). In the review by Xin et al. (Xin et al., 2020), they found a consistent favourable association between MVPA and object control skills but interestingly an inconsistent association between MVPA and locomotor skills, of which contrasts findings in both the current study and the study by Nilsen et al. (Nilsen, Anderssen, Loftesnes, et al., 2020). where moderate and vigorous

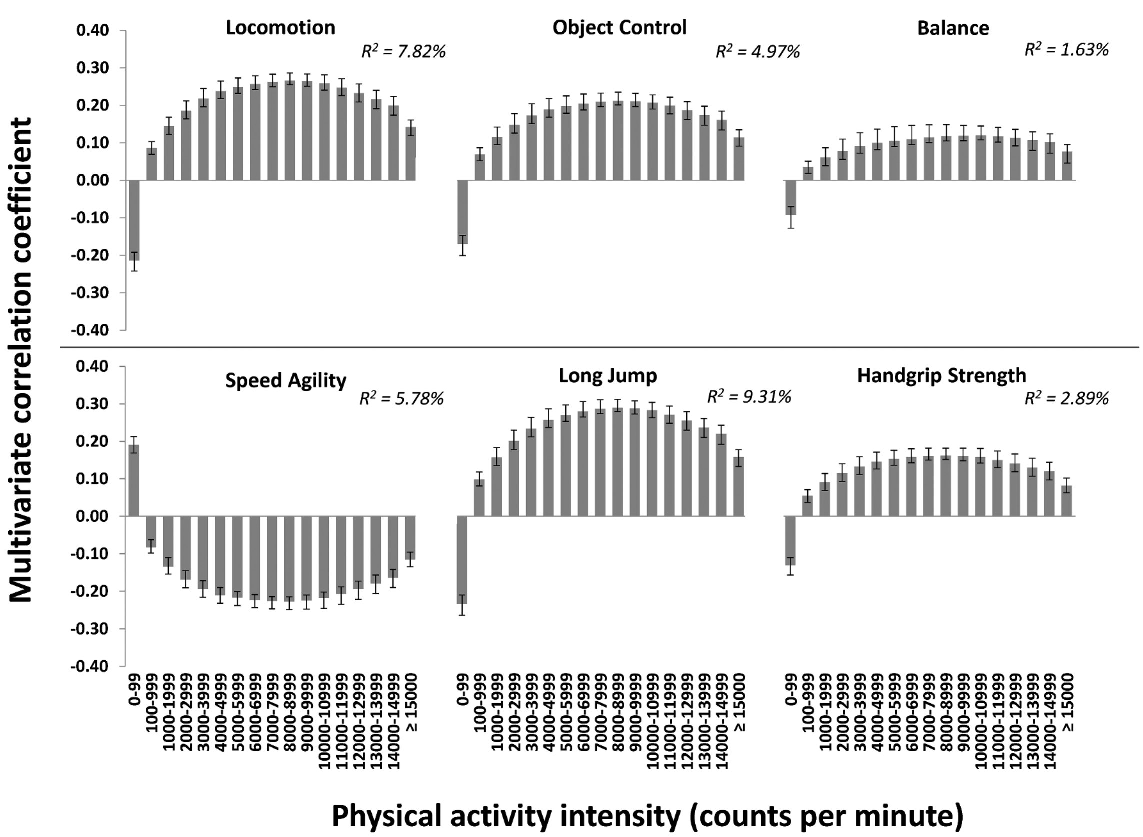

Figure 2. The multivariate physical activity signature associated with FMS and FIT for the total sample. $N = 847–935$. Reported as multivariate correlation coefficients derived from the vertical axis. The models (PLS regression) are adjusted for sex, age, body mass index, socioeconomic status, FMS rater (for FMS outcomes) and accelerometer wear time. A positive bar implies that increased PA is associated with better performance, except for Speed Agility where a negative association implies a faster run time by increased PA.

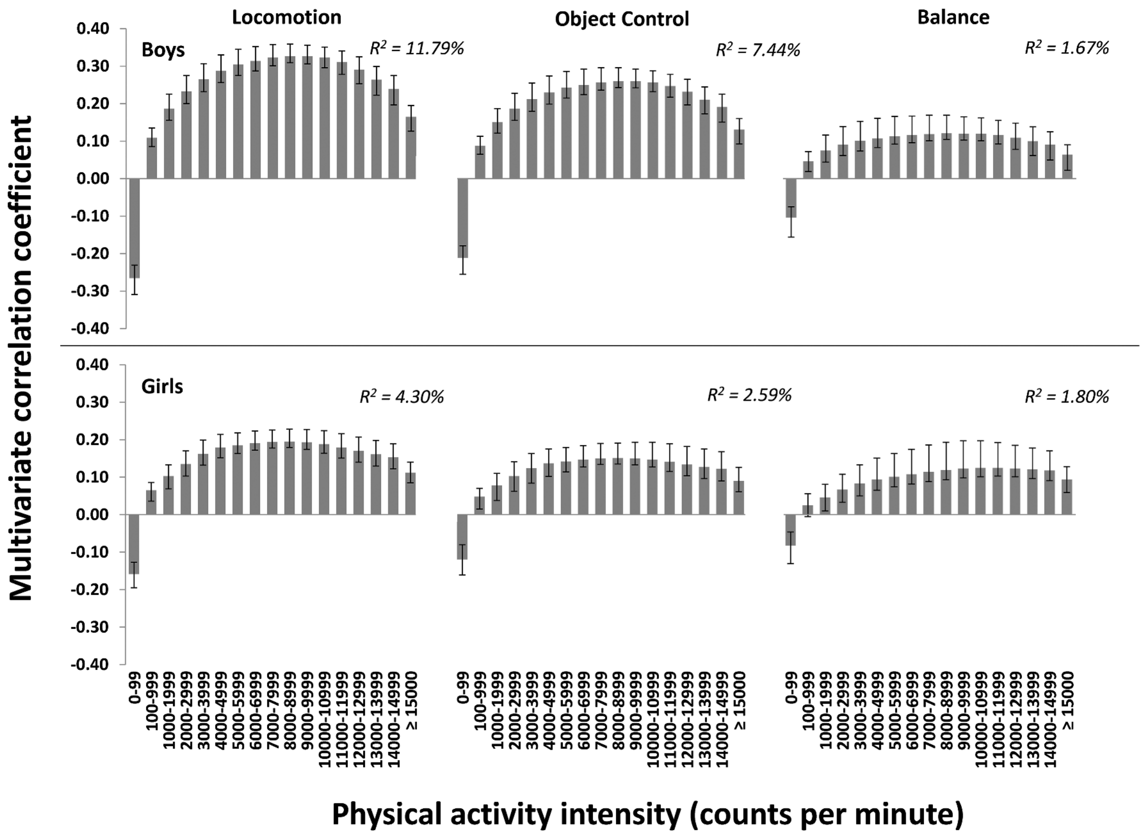

Figure 3. The multivariate physical activity signature associated with FMS for boys and girls (separate models). $N = 441–462$. Reported as multivariate correlation coefficients derived from the vertical axis. The models (PLS regression) are adjusted for sex, age, body mass index, socioeconomic status, FMS rater and accelerometer wear time. A positive bar implies that increased PA is associated with better performance.

intensities were significantly associated with both object control skills and locomotor skills. We have no clear explanation for these differences, but it could be a result of applying different test batteries of FMS (domains) and/or different data reduction algorithms and intensity cut points. Placement of accelerometer could also partially explain weaker results for both the object control domain and balance domain, as the hip-placed monitor do not capture upper body movements correctly resulting in skills like throw and catch to be underestimated (Evenson et al., 2008). Meta-analysis by Jones et al. (Jones et al., 2020) showed positive associations between PA and FMS, but did not investigate individual FMS domains. Future studies should assess separate FMS domains to improve our understanding of any specificity of associations with PA.

We found significant association patterns for the PA intensity spectrum with all FIT variables. These findings are in line with previous studies showing associations for high-intensity PA with muscle strength and motor fitness (Carson et al., 2017; Fang et al., 2017; Leppänen et al., 2016; Riso et al., 2019; Serrano-Gallén et al., 2022; Smith et al., 2019). Leppänen et al. (Leppänen et al., 2016) found that handgrip strength, standing long jump and motor fitness were all associated with VPA, which is in accordance with current study findings. These findings are also in line with findings by Serrano-Gallen et al. (Serrano-Gallén et al., 2022), although they did not find a significant association between PA and handgrip strength. Moreover, Fang et al. (Fang et al., 2017) found associations for MVPA with both speed-agility and standing long jump, but not with handgrip strength. Interestingly, Riso et al. (Riso et al., 2019) found that time spent in MVPA, and particularly VPA, was more strongly associated with standing long jump and motor fitness, whereas MVPA, but not VPA, was associated with handgrip strength. This finding differs from our findings where handgrip strength was most strongly associated with intensities in the typical VPA range. Taken together, the prevailing findings are less consistent for handgrip strength than for lower body muscle strength (Smith et al., 2019), although handgrip strength is considered one of the most valid fitness tests (Stodden et al., 2015) and is deemed a feasible and valid tool among preschool children (Cadenas-Sanchez, Martinez-Tellez, et al., 2016). The inconsistencies regarding upper body strength could possibly be due to the fact that vigorous activities, such as running or hopping, strengthen muscles in the lower extremities more than upper extremities (Leppänen et al., 2016). Further, variation in findings across studies might be expected because of differences in preschool practices and children's movement opportunities (i.e., outdoor areas and available play equipment). Although weaker than lower body strength, current study findings show that upper body strength is associated most strongly with PA intensities in the upper range, suggesting that vigorous activities may be crucial for developing better FIT. Subgroup analyses showed that all association patterns were consistent across sex and age groups, although R^2 generally were higher in boys than in girls. Few studies have investigated sex as a moderator for associations between PA and FMS but the limited evidence are consistent

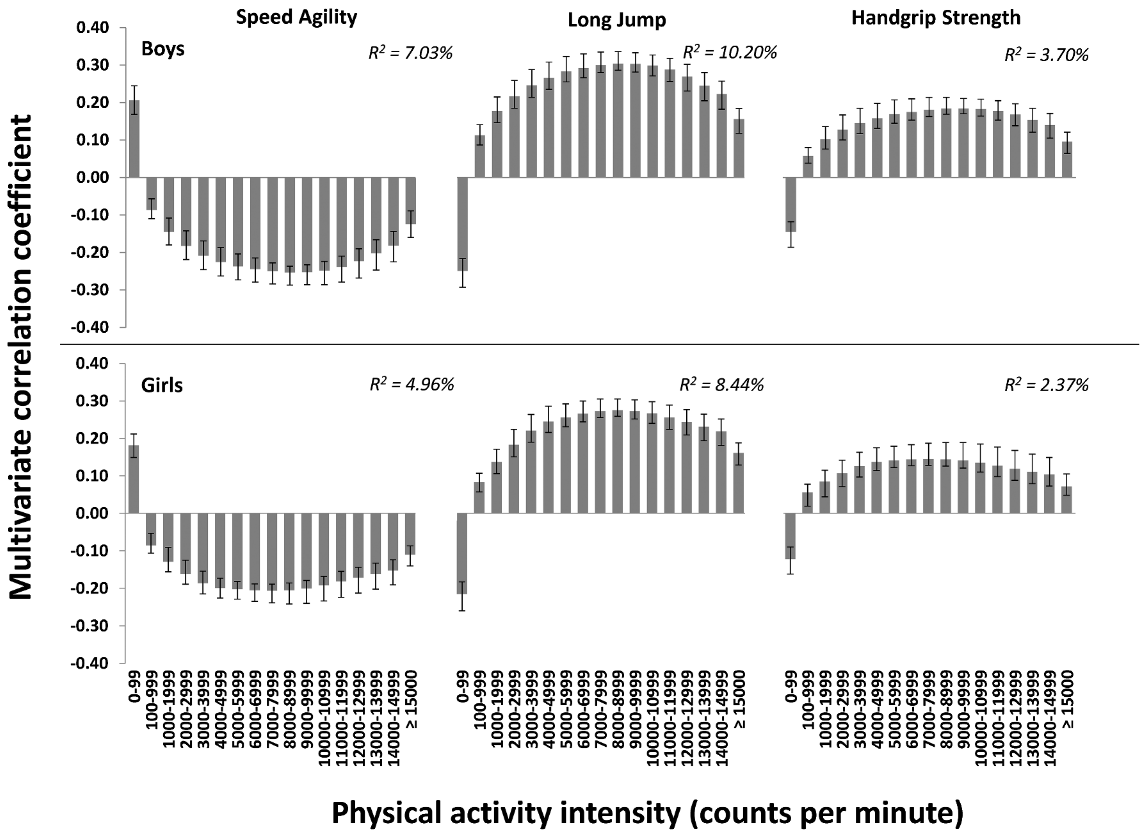

Figure 4. The multivariate physical activity signature associated with FIT for boys and girls (separate models). $N = 421–476$. Reported as multivariate correlation coefficients derived from the vertical axis. The models (PLS regression) are adjusted for sex, age, body mass index, socioeconomic status, and accelerometer wear time. A positive bar implies that increased PA is associated with better performance, except for Speed Agility where a negative association implies a faster run time by increased PA.

with our findings showing that associations in general are stronger for boys than girls (Xin et al., 2020). Only a few studies have performed moderation analyses for FIT showing no differences in associations (Bürgi et al., 2011; Leppänen et al., 2016). Similar associations across age groups in the current study show that associations between PA and FMS and FIT are evident already in early childhood. More research is needed to improve our understanding of potential moderation by sex or age.

Most studies investigating PA relationships usually apply traditional intensity categories (SED, LPA, MPA, VPA and MVPA) decided by specific age-related cut-points, thus limiting the potential of the PA spectrum by reducing it to a few narrow intensity categories. In addition to the loss of PA information, appropriate cut points for preschoolers are not agreed upon (Kim et al., 2012), affecting the classification of PA intensities when studies use different sets of cut-points reducing comparability across studies. Including the full PA intensity spectrum, as done in the current study, has been called for in previous studies (Migueles et al., 2021; Poitras et al., 2016), and resolves the cut-point problem characterizing existing literature. Further, the choice of epoch length varies in the published literature. The current study used a 1-s epoch to capture the children's activity, in opposition to reviews by Xin et al. (Xin et al., 2020) and Dobell et al. (Dobell et al., 2020), where only 3 out of total 36 included studies applied 1-second epochs. Since longer epoch lengths accumulate PA intensities in bulks, higher intensities are underestimated (Aadland, Andersen, et al., 2020; E. Aadland & Nilsen, 2022). Using 1-s epochs will capture higher intensities more correctly since children's movements are naturally sporadic and PA bulks usually last for a maximum of 10 s (Aadland, Andersen, et al., 2020; Bailey et al., 1995). In addition to the choice of cut points and epoch lengths, most studies have small study samples, limiting the strength of results for FMS ($N \leq 550$) (Xin et al., 2020), and for FIT ($N \leq 346$) (Bürgi et al., 2011; Fang et al., 2017; Leppänen et al., 2016; Riso et al., 2019; Serrano-Gallén et al., 2022). We argue that this study's large sample and its novel analytic approach provide strong and nuanced evidence for the relationship between the PA spectrum and FMS and FIT. No other study has investigated relationships between PA and FIT using the multivariate pattern approach, strengthening and extending our understanding of how the complete PA intensity spectrum correlates with each motor skill and fitness measure.

Different association patterns for different FMS domains can have several plausible explanations. Type of activities can stimulate and relate to different PA intensities, depending on the movement certain activities demand (Barnett et al., 2016). Gross motor competence, such as running and hopping, requires higher PA intensity, plays an important role as children develop more complex movements, and explains the stronger associations seen for locomotor skills in the current study. Object control skills are more complex than locomotor skills and therefore learned at

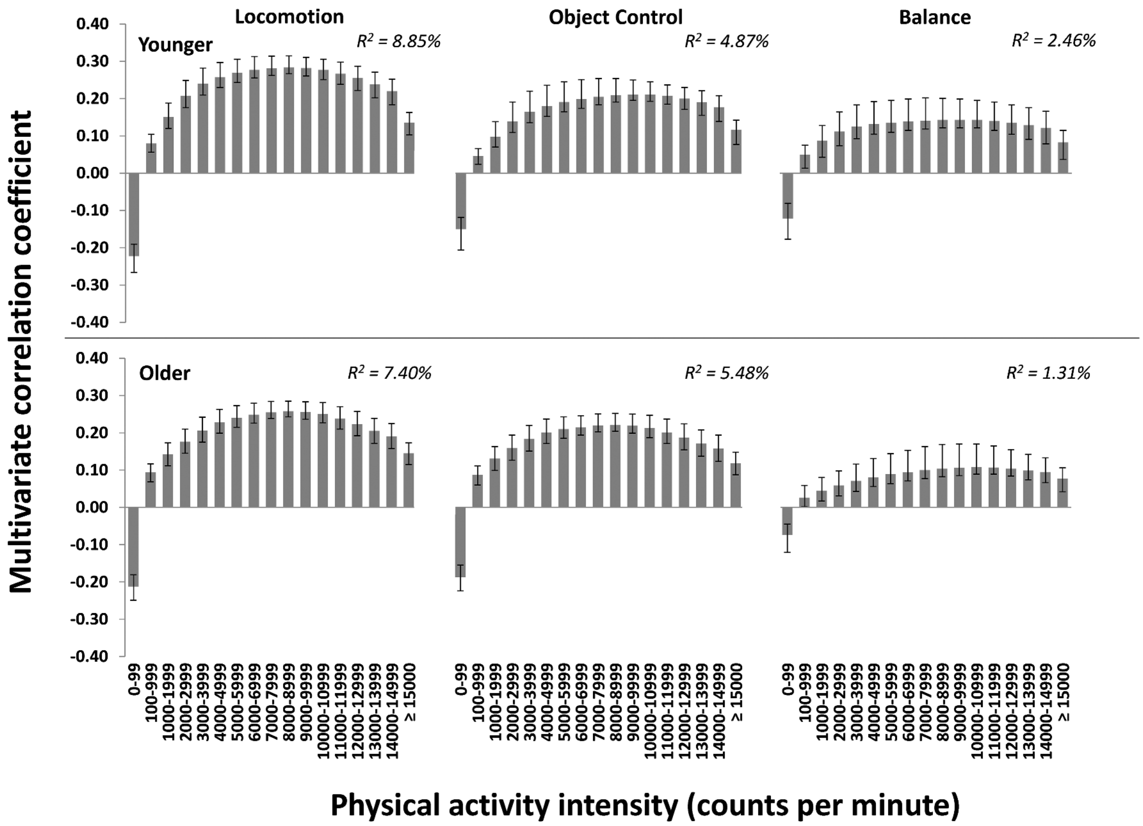

Figure 5. The multivariate physical activity signature associated with FMS for younger and older children (separate models). $N = 392–501$. Reported as multivariate correlation coefficients derived from the vertical axis. The models (PLS regression) are adjusted for sex, age, body mass index, socioeconomic status, FMS-rater, and accelerometer wear time. A positive bar implies that increased PA is associated with better performance.

a later stage (Gallahue & Donnelly, 2003; Goodway et al., 2019), which might explain why object control skills showed weaker associations to PA than locomotor skills. Based on the weaker association pattern for the balance domain, it seems natural that these types of activities will differ from locomotion and object control skills due to having other movement characteristics.

The weak to moderate correlations between FMS and FIT outcomes found herein are in line with previous studies (Cattuzzo et al., 2016; Haga, 2008; Utesch et al., 2019). This correlation is natural for FIT and FMS measure-related movement components (King-Dowling et al., 2018), where a sufficient level of FIT is needed to be able to enable demonstration of motor skills and vice versa (Fjørtoft et al., 2011). Some measures of FMS and FIT are being used interchangeably (Cattuzzo et al., 2016), and participation in PA will therefore stimulate the development of both FMS and FIT (Cattuzzo et al., 2016). Although overlapping constructs, they were evaluated differently in the current study, with FIT-tests being product-oriented and FMS-tests process-oriented, as warranted in the literature (Rudd et al., 2016). How FMS and FIT are operationalized, defined, and measured is of importance if research regarding these constructs is to reach international consensus.

In contrast to the findings by Aadland et al. (E. Aadland et al., 2019b, 2021), where they showed stronger associations for the triaxial intensity spectrum than for the uniaxial intensity spectrum for associations between PA and BMI (E. Aadland et al., 2021), and PA and metabolic health in children (E. Aadland et al., 2019b), we found that uniaxial and triaxial data provided similar information for associations between PA and FMS and FIT. This is in line with Nilsen et al. (Nilsen, Anderssen, Loftesnes, et al., 2020). To simplify reporting of results, we chose to present data based on uniaxial analyses. As there is limited knowledge of which activities and intensities that are captured across the anteroposterior and the mediolateral axes (E. Aadland et al., 2021), more research is needed to investigate the potential of triaxial accelerometry data in revealing information about PA of relevance for different outcomes.

Although studies have showed that high-intensity PA is most optimal for physical health outcomes (E. Aadland et al., 2018; Carson et al., 2017; Poitras et al., 2016; Timmons et al., 2012), the possible benefits of LPA has also been emphasized, and it has been recommended that all intensities should be considered in research aiming to investigate health benefits of PA in youth (Migueles et al., 2021; Poitras et al., 2016). The current study found PA in the LPA range to be associated with both FMS and FIT, but it is important to note that these associations were weaker than for higher intensities. By using multivariate analyses, we can interpret the intensity spectrum irrespective of predefined thresholds, which improves interpretation since no information is excluded. However, to make the study results more understandable in relation to how existing literature presents different PA-intensities, we chose to interpret the PA spectrum using the cut points by Evenson et al. (Evenson

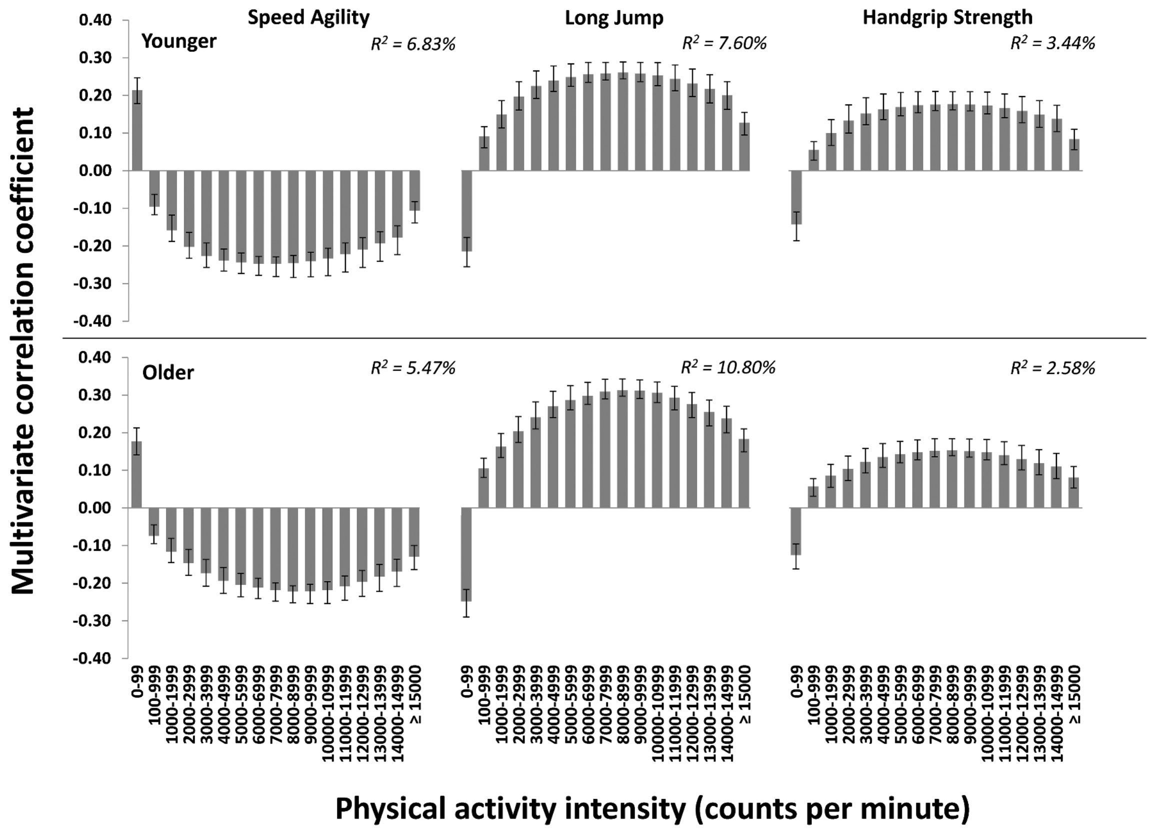

Figure 6. The multivariate physical activity signature associated with FIT for younger and older children (separate models). $N = 373–500$. Reported as multivariate correlation coefficients derived from the vertical axis. The models (PLS regression) are adjusted for sex, age, body mass index, socioeconomic status, and accelerometer wear time. A positive bar implies that increased PA is associated with better performance, except for Speed Agility where a negative association implies a faster run time by increased PA.

Table 2. Bivariate correlations (Pearson's r) between FMS, FIT, and traditional PA intensity categories.

	1	2	3	4	5	6	7	8	9	10	11
1. Locomotion	-										
2. Object Control	**0.38**	-									
3. Balance	**0.29**	**0.26**	-								
4. Speed Agility	**−0.38**	**−0.22**	**−0.28**	-							
5. Long Jump	**0.51**	**0.31**	**0.24**	**−0.41**	-						
6. Hand Grip	**0.22**	**0.16**	**0.15**	**−0.15**	**0.30**	-					
7. SED	**−0.20**	**−0.15**	**−0.08**	**0.18**	**−0.21**	**−0.11**	-				
8. LPA	**0.09**	0.06	0.05	**−0.09**	**0.10**	0.05	**−0.91**	-			
9. MPA	**0.19**	**0.16**	**0.08**	**−0.21**	**0.21**	**0.11**	**−0.91**	**0.72**	-		
10. VPA	**0.29**	**0.23**	**0.12**	**−0.24**	**0.31**	**0.17**	**−0.73**	**0.40**	**0.73**	-	
11. MVPA	**0.27**	**0.22**	**0.11**	**−0.24**	**0.29**	**0.16**	**−0.86**	**0.57**	**0.91**	**0.95**	-

N=816–952. PA variables (7-11) adjusted for sex, age, BMI, SES, and accelerometer wear time. FMS and FIT variables (1-6) adjusted for sex, age, BMI, SES and FMS-rater (for FMS outcomes). SED = Sedentary time. LPA = Light Physical Activity. MPA = Moderate Physical Activity. VPA = Vigorous Physical Activity. MVPA = Moderate to Vigorous Physical Activity. Significant associations at p≤0.05 are highlighted in boldface.

et al., 2008), which are found to be appropriate for children (Janssen et al., 2013; Trost et al., 2011). Regarding the early development of FMS and FIT, it therefore seems that promotion of PA, and specifically VPA, is essential already in early childhood. Although this seems plausible, we cannot claim causal associations from cross-sectional designs.

Strengths and limitations

The large study sample and the high response rate are important strengths of the current study. However, the study was carried out in a rural area and included children differed from excluded children on, for example, SES. Generalizing our findings to a more diverse sample of children may therefore be done with caution. The analytical method applied to handle accelerometer data and investigate association patterns (i.e., multivariate pattern analysis) is innovative in the field of PA research and provides more nuanced evidence for the association patterns for multiple PA intensities with FMS and FIT than traditional approaches. The use of accelerometry is the preferred option for objectively registering everyday PA (De Vries et al., 2009), but it is not without limitations (Cain et al., 2013). Because the instrument is positioned at the waist, it does not correctly capture all types of movement, for example cycling and upper body movements. Also, carrying external loads and incline walking is underestimated (Warren et al., 2010). Even though children's movement patterns often are sporadic and in shorter bouts (Bailey et al., 1995) and therefore difficult to measure precisely, we regard accelerometers being the best option for capturing PA across time and in larger samples. Triaxial accelerometry could potentially capture more information than uniaxial data but provided similar results.

The current study combined items from the TGMD-3 (Ulrich, 2019) and PGMQ (Sun et al., 2010) batteries, and included balance skills in addition to locomotor and object control skills. Combined batteries consisting of both product- and process-oriented assessments could improve understanding of FMS in preschoolers (Xin et al., 2020). However, because we included only selected items from both test batteries of FMS, and because we applied mean scores in contrast to original sum scores (to avoid mislead comparison across studies), results from this study are not comparable to other studies applying the TGMD-3 or PGMQ batteries at the domain level. Because of this, we are not able to determine whether our study sample demonstrated high or low FMS levels in comparison with the reference material. Although this can be considered a limitation, our aim was not to detect children with motor skill deficiencies. FIT was measured with selected items from PREFIT (Ortega et al., 2015), which limits our capability of comparing results. FIT items were chosen based on feasibility (i.e., field testing), and due to lack of space we could not test cardiorespiratory fitness. The inclusion of both FMS and FIT outcomes is considered a strength.

Lastly, the cross-sectional design means causality cannot be inferred from the observed associations, and results should be interpreted with caution regarding the direction of these relationships. Although a previous study in preschoolers showed that PA was more important for the development of FMS, than vice versa (Nilsen, Anderssen, Johannessen, et al., 2020), these associations are likely bidirectional and reinforcing over time (Stodden et al., 2008). Thus, our findings suggest that preschools should focus on promoting PA, FMS, and FIT in early life stages to stimulate and optimize child's physical development.

Conclusion

This is the first study to determine the multivariate association patterns between PA, and a variety of both FMS and FIT variables in preschoolers. Our study applies an innovative approach to handling accelerometer data using the entire PA intensity spectrum. Overall, results showed favourable associations between the PA intensity spectrum and FMS and FIT, and unfavourable associations between time spent sedentary and FMS and FIT. For all outcomes, strongest associations were found for high-intensity PA, indicating that preschool educators and facilitators should focus on promoting PA, especially of moderate and high intensity, to promote FMS and FIT development in early childhood. However, further research should include longitudinal and experimental designs to investigate the direction and causality of these relationships.

Abbreviations

BMI: body mass index; cpm: counts per minute; FIT: physical fitness; FMS: fundamental motor skills; LPA: light physical activity; min: minutes; MPA: moderate physical activity; MVPA: moderate-to-vigorous physical activity; PA: physical activity; SD: standard deviation; SED: sedentary time; SES: socioeconomic status; VPA: vigorous physical activity.

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Disclosure statement

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

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Authors contribution

EAA, KNA and ADO developed the idea, designed the study, and obtained funding for the study. ESH, AKON and KNA performed the data collection. ESH and EAA analyzed the data. ESH wrote the manuscript draft. All authors contributed to the interpretation of data and provided input. All authors read and approved the final manuscript for submission.

Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Parents of all participating children received oral and written information about the study and provided written consent prior to testing. The institutional ethics committee and the Norwegian Centre for Research Data (NSD) approved the study (reference number 248,220). All procedures and methods conform to the ethical guidelines defined by the World Medical Association's Declaration of Helsinki and its subsequent revisions.

Geolocation information

https://goo.gl/maps/Q99w8G3StMwsFKLr7

Trial registration

clinicaltrials.gov, identifier NCT04048967, registered 7 August , (https://clinicaltrials.gov/ct2/show/NCT04048967?term=actnow&rank=1).

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