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Association of Individual Motor Abilities and Accelerometer-derived Physical Activity Measures in Preschool-aged Children

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Abstract

This study explored the relationship between motor abilities and accelerometer-derived measures of physical activity (PA) within preschool-aged children. 193 children (101 girls, 4.2 ± 0.7 years) completed five tests to assess motor abilities; shuttle run (SR), standing long jump, lateral jumping, one leg stand and sit and reach. Four PA variables derived from 7-day wrist-worn GENEActiv accelerometers were analysed including; Moderate-to-Vigorous PA (MVPA, mins), Total PA (mins), percentage of total PA time in MVPA and whether or not children met WHO guidelines for PA. Linear regressions were conducted to explore associations between each PA variable (predictor) and motor ability (outcome). Models were adjusted for age, sex, height, parental education, time spent at sports clubs and wear time. Models with percentage of total PA time in MVPA were adjusted for percentage of total PA time. Regression analyses indicated that no PA variables were associated with any of the motor abilities, but demographic factors such as age (e.g., SR: ß=-0.45, 95%CI: -1.64, -0.66), parental education (e.g., SR: ß=0.25, 95%CI: 0.11, 1.87) or sports club time (e.g., SR: ß=-0.08, 95%CI: -0.98, 0.26) showed substantial associations with motor abilities. Model strength varied depending on the PA variable and motor ability entered. Results demonstrate that total PA and meeting current PA guidelines may be of importance for motor ability development and should be investigated further. Other covariates showed stronger associations with motor abilities such as time spent at sports clubs and should be investigated in longitudinal settings to assess the associations with individual motor abilities.

Keywords: MVPA, Movement, accelerometry, sports club membership, WHO guidelines, motor skills

Association of individual motor abilities and physical activity measures in preschool-aged children

Early childhood (3-5 years of age) presents a critical time for development during which children learn to move through space and acquire fundamental movement skills (FMS) such as running and jumping (Stodden et al., 2008). The development of motor competency is a complex process driven by internal structural and functional changes but is also heavily influenced by environmental factors such as physical activity (PA) (Clark, 1995; Stodden et al., 2008). The complex relationship between PA and motor competency is outlined in a developmental model proposed by Stodden et al. (2008) which suggests that during early childhood, acquisition of FMS is driven by PA. Subsequently, FMS provide the foundation for more complex movements needed for recreational play and sports participation (Gallahue & Ozmun, 2000; Stodden et al., 2008). Accordingly, the model also suggests that during middle to late childhood, motor competency begins to drive PA and therefore, PA during the early years may drive PA during later childhood and adolescence (Stodden et al., 2008).

The relationship between motor competency and PA is critical as we now know that establishing healthy PA habits during early childhood is an important step towards conquering the ongoing childhood obesity epidemic (World Health Organization, 2020). In preschool-aged children, PA, in particular total PA (TPA) and moderate-to vigorous PA (MVPA) has been favourably associated with cardiometabolic health, bone and skeletal health, psychosocial health and both motor and cognitive development (Carson et al., 2017). Despite increased knowledge about the importance of PA, children and youth are spending little time engaging in MVPA (Pate et al., 2015) and continue to score poorly on worldwide PA report cards (Aubert et al., 2018). As this raises concerns for childhood health, PA guidelines targeted towards the early years have become an important area of interest. The World Health Organization (WHO) recently released new guidelines for children under the age of 5, which recommend that children 3-4 years should accumulate a minimum of 180 minutes of any type of PA per day and at least 60 of those minutes should be spent in MVPA (World Health Organization, 2019). For children aged 5-17, the WHO recommends at least 60 minutes of MVPA per day (World Health Organization, 2010).

The relationship between motor competency and PA has been extensively reviewed (Barnett et al., 2016a; Figueroa & An, 2017; Holfelder & Schott, 2014; Jones et al., 2020; Robinson et al., 2015), and although a relationship is apparent, this association heavily depends on the skills measured and how PA is quantified, as well as the type of analyses conducted, and covariates used. Multiple reviews show a positive relationship between motor competency and PA (Figueroa & An, 2017; Holfelder & Schott, 2014) and a recent meta-analysis of 12 studies indicates a weak but positive correlation between FMS and MVPA and between FMS and TPA (Jones et al., 2020). However, another review conducted by Barnett et al. (2016a) concluded that only certain components of motor competency were related to PA. It is difficult to gain a complete understanding of this relationship due to major inconsistencies in test batteries used to assess motor competency. For example, of 19 studies included in a recent review, ten different assessment tools were used to evaluate motor competency (Jones et al., 2020). Additionally, test items used to evaluate motor competency have also been used to assess other constructs such as fitness (Utesch et al., 2019a; Wrotniak et al., 2006), an issue that is further complicated by the abundance of varying terminologies including; “motor ability”, “motor skills”, “motor coordination” , “motor/movement performance”, and “movement competence” (Robinson et al., 2015). To clarify, the term motor competency is used to describe the proficiency of any goal-oriented form of human movement involving gross body coordination and control (Coppens et al., 2019; Robinson et al., 2015; Utesch et al., 2019b). Thus, during early childhood, fundamental movement skill (FMS) proficiency is often used to evaluate motor competency (Stodden et al., 2008). In contrast, motor abilities can be defined as the general traits or abilities underlying the performance of FMS (Burton & Miller, 1998); examples of motor abilities include speed, endurance, strength, coordination, balance and flexibility and any combination of these abilities, for example speed strength and strength endurance (Burton & Miller, 1998; Klein et al., 2012). In contrast, physical fitness can be defined as “the ability to carry out daily tasks and perform physical activities in a highly functional state” (NCBI, n.d.) as such certain motor abilities such as flexibility may be considered an indicator of good physical fitness. Clinicians, researchers and/or educators may assess these traits through validated movement skills tests such as the Sit and Reach test (Koslow 1987).

Some evidence suggests an association between PA and individual motor abilities in children. Wrotniak et al. (2006) showed that a higher percentage of time spent in MVPA was correlated with faster speed and agility, as well as greater distance jumped (strength/coordination) in 65 children aged 8 to 10-years-old. In 5- to 6-year-olds, a positive association was found between pedometer derived aerobic steps/day and speed, agility and balance (Kambas et al., 2012). Unfortunately, most studies calculate one composite score to reflect motor competency, or alternatively calculate subdomain scores for locomotor and object-control abilities (e.g. throwing and catching) (Figueroa and An., 2017; Olesen et al., 2014; Webster et al., 2019; Williams et al., 2008) rather than specific traits of individual motor abilities. Additionally, many studies use different PA variables (i.e. TPA, LPA, MVPA, VPA) or group all measures of PA together. Although understanding the broad relationship between PA and general abilities is important, research is needed to examine whether PA can impact some specific motor abilities more than others during crucial developmental periods, such as the preschool years. At the present time, little is known about possible associations between PA and individual motor abilities, during the preschool years and how different measures of PA can affect this relationship. The acquisition of proficiency in a variety of motor abilities in the preschool years provides a solid foundation for the development of more complex movement patterns needed later in life, not only for activities of daily living but also for recreational play and participation in sports (Gallahue & Ozmun, 2000; Stodden et al., 2008).

Therefore, the purpose of this study was to evaluate the relationship between individual motor abilities and various objectively assessed PA outcomes within a preschool-aged population. Motor ability tests were conducted to assess speed, strength, endurance, coordination and flexibility. PA measurements included; MVPA (mins), TPA (mins), the percentage of total physical activity spent in moderate-to-vigorous physical activity (%MVPA of TPA) and whether or not children are meeting current WHO guidelines for PA. Based on previous research (Holfelder & Schott, 2014; Kambas et al., 2012; Wrotniak et al., 2006), it was hypothesized that time in MVPA, TPA, %MVPA of TPA or meeting current PA guidelines recommended by the WHO would be positively associated with all five motor ability tests. Insight into associations between healthy PA habits and individual motor abilities in preschool-aged children will provide critical information for parents and early childhood educators responsible for ensuring children are prepared for the level of social and recreational interactions required for a successful entry to the school years.

Methods

Protocol

Data for the current study was collected as part of baseline collection from the "JolinchenKids- Fit and healthy in daycare" study. Children between the ages of three and six years were recruited from 61 daycare facilities across Germany. PA data was objectively measured using accelerometers in a subset of these daycare facilities (23 of 61 centres; due to limited availability of accelerometers) in addition to assessment of motor ability. Ethical approval was obtained by the Medical Association in Bremen (HR/RE-522, April 28, 2016), and the study was registered at the German Clinical Trials Register (DRKS00011065). Full study protocol and additional details have been reported by Steenbock et al. (2017).

Data Collection

Two experienced study nurses completed each child's height and bodyweight measurements while children were barefoot. Height was measured using portable stadiometers (Seca type 213 stadiometer, Invicta Plastics Ltd, Leicester, UK), measurements were recorded to the nearest 0.1 cm. Body weight was measured to the nearest 0.1 kg using the TANITA BC 420 SMA digital scale (TANITA Europe GmbH, Sindelfingen, Germany). Survey data was also collected regarding whether or not the children were members of a sports club and how much time was spent at these sports club weekly. This data was included in our analyses as organized or structured PA has been suggested as an important contributor to motor competency (Burgi, 2011; Jaakkola et al., 2009; Vandorpe et al., 2012) In Germany, having a sports club membership in this young age group generally means that children focus on learning to perform fundamental movements skills (i.e. running, jumping, climbing, swinging, balancing and basics in ball games etc.) rather than sports specific training. Courses in sports clubs usually comprise about 30 to 45 minutes of supervised activities. Because sports club membership is not mandatory in Germany, some children do not attend any sports club while others attend more than one sports club per week. As such, children in this analysis were divided into three categories according to parent reports of average time spent at a sports club per week. These categories were: no time a sports club, 30 min – <90 mins per week or ≥90 mins or above per week. Additional survey data was collected on parental education.

Assessment of Motor Abilities

Motor abilities were assessed using five test items including: shuttle run (SR), standing long jump (SLJ), lateral jumping (LJ), one leg stand (OLS) and sit and reach (SAR); details below. The SR test was used to assess movement speed, measured as time (seconds) taken to run from one marked box to another, placed 4 meters apart, two separate times for a total of 16 meters (4 X 4 meters). Each child performed this test once, a faster time indicates better performance on this test. The SLJ test was used to assess speed strength, measured as the maximal distance jumped (cm) with two feet; distance was measured from the starting line to the back of the heel. Children were given one practice trial then two test trials of which the furthest jump was recorded. The LJ test was used to evaluate strength endurance and coordination and was quantified as the number of successfully completed 2-foot jumps over a beam. Two 15-second trials were completed by each child and the sum of the number of jumps for each trial was recorded. The OLS test was used to quantify static balance, measured as the number of times the free leg touched down within 1 minute while standing on a wooden bar (5 cm high). Each child performed this test once, a greater number of touchdowns on this test would indicate poorer performance. Finally, the SAR test was used to assess hip and hamstring flexibility by recording the furthest distance (cm) reached with both hands while seated and legs extended. Each child performed this test once, a negative distance would indicate that the child did not reach past the level of their feet. All tests were administered according to instructions provided in an assessment manual (Klein et al., 2012) by one of two trained study nurses. The two study nurses were trained in a one-day workshop by two of the co-authors of this study. Approximately five children at a time were asked to enter the movement room to perform the test. These children were then tested individually while the others waited in the same room. Results were recorded separately for each test. Children who successfully completed at least one of the five tests were included in this analysis.

Physical Activity Measurements

GENEActiv accelerometers (ActivInsight Ltd. Kimbolton UK) were used to obtain an objective measurement of daily levels of PA. This device contains a triaxial accelerometer with a dynamic range of ±8 g, a 12-bit resolution and has previously been calibrated and used to assess PA in preschool-aged populations (Roscoe et al., 2017; Steenbock et al., 2019). Devices were initialized according to manufacturer's instructions and data was collected at 100 Hz. Written instructions detailing the protocol were given to parents and a logbook was provided for recording periods when the device was not worn (e.g bathing, swimming). Children wore an accelerometer on their left wrist (which is the non-dominant wrist for the vast majority of children; however, previous studies only revealed marginal differences for wearing the accelerometer on the non-dominant vs. the dominant wrist in this age group (Steenbock et al., 2019). The accelerometer was secured with Tyvek wristbands (DuPont de Nemours, Inc., Wilmington, Delaware, United States), for a period of 7 days, 24 hours per day; upon return of the device, data was downloaded using the GENEActiv software (version 2.2; ActivInsight Ltd., Kimbolton United Kingdom). The R software, (version 3.4.3; R Core Team, Vienna, Austria), package "GENEAread" (Fang et al., 2019) was used to process raw data files. First, data collected between 7 pm and 7 am was removed to exclude sleep time from analysis. Following this, periods of non-wear time were identified using range and standard deviation of the raw acceleration value over 60-minute moving windows with 15-minute increments as done previously (Sabia et al., 2014; van Hees et al., 2013). A window was classified as non-wear time if the range of the acceleration value was less than 50mg or if the standard deviation was less than 13.0 mg for at least 2 out of the 3 axes (Sabia et al., 2014). Children with a minimum wear time of 8 hours per day on at least 3 days were included in the analysis as done previously (Barnett et al., 2017). Energy expenditure (EE) in kilojoules was predicted from raw acceleration data using a random forest model trained on data from preschoolers wearing spirometry devices (Steenbock et al., 2019). The resulting estimated EE values were used to determine time spent in TPA (≥7-10 kJ/min) and MVPA (>10 kJ/min). As there are no standardized cutpoints for this age group, these cutpoints were chosen based on previous studies within preschool-aged populations (Brandes et al., 2018; Byun et al., 2016; Roscoe et al., 2017). As current PA recommendations for children highlight the importance of MVPA and TPA, these variables were chosen for part of the analysis. The mean amount of time spent in MVPA and TPA was calculated for each participant. Subsequently, this data was then used to determine whether or not children met the current WHO guidelines for their age group. For children aged 3-4 years, meeting the WHO guidelines required that they acquired a minimum of 180 minutes of any type of PA, of which at least 60 minutes was spent in MVPA. Children aged 5 years were required to have a minimum of 60 mins of MVPA in order to meet WHO guidelines. Lastly, the percentage of total physical activity time that was spent in MVPA (%MVPA of TPA) was calculated as mean MVPA divided by mean TPA multiplied by 100. This variable was chosen to assess whether spending a greater percentage of their active time in higher intensity PA (MVPA) had a different association with motor ability performance than mean minutes of TPA or MVPA. Therefore, our analysis included four different PA variables; mean MVPA (mins), mean TPA (mins), mean percentage of active time spent in MVPA (%MVPA of TPA), and whether or not children met the current WHO guidelines for their appropriate age group.

Study Sample

These analyses include a subsample of the 831 children included in the "JolinchenKids- Fit and healthy in daycare" study for whom accelerometery data was collected (N=217). Of these, 24 children were excluded because they were under 3 years of age (n=4), did not complete any motor ability tests (n=2) or did not meet wear time criterion for the accelerometer data (n=18). Thus, the final sample size for our analyses included 193 children aged 3-6 years old.

Statistical Analyses

Descriptive statistics were calculated to describe the study participant characteristics, motor ability tests and PA variables (proportions; means and standard deviations). We conducted linear regression models to investigate the association between each of the four PA variables (MVPA, TPA, %MVPA of TPA and WHO guidelines) with performance on each motor ability test (SR, SLJ, LJ, OLS, SAR) considered as dependent variables for a total of 20 linear regression analyses. Prior to this step, we conducted linear regressions investigating the association only of age, sex, height, parental education, and time spent at a sports club with each motor ability to illustrate the strength of the association between these covariates and individual motor abilities that are used for adjustment with regard to PA variables. MVPA, TPA and WHO guideline models were adjusted for mean mins of wear time and the %MVPA of TPA model was adjusted for %TPA to account for variation in wear time. Goodness-of-fit was evaluated in terms of adjusted R^2 to compare models before and after inclusion of PA variables. Level of significance was set to $\alpha = 0.05$ to obtain 95% confidence limits

(95%CL) as a precision measure of beta estimates. All statistical analyses were conducted in SPSS (version 26.0; IBM Corp. Armonk, NY, USA).

Results

Descriptive characteristics for age, anthropometry, motor ability tests and physical activity of the final study sample are reported in Table 1. In general, boys and girls had similar performance on the motor ability tests, however boys jumped further on the SLJ test (76.0 cm) compared to girls (69.6 cm) and girls reached further on the SAR test (3.8 cm) compared to boys (2.5 cm). Overall, boys had higher amounts of all PA measurements than girls, meaning boys had greater amounts of TPA, MVPA, %MVPA of TPA and met WHO guidelines more often than girls. However, more girls reported having a sports club membership than boys (Table 2).

Results from the regression analyses on the associations between each PA variable and each motor ability test are presented in Table 3. All models for SAR did not show a substantial goodness-of-fit (adj. R^2 ranging from 0.02 to 0.04) and therefore will not be presented and discussed further. TPA, MVPA, %MVPA of TPA and Meeting WHO guidelines were not significantly associated with performance on any of the motor ability tests. Due to the exploratory nature of this study, linear regression models which included only covariates and no measure of PA were examined. They showed a significant association of age with performance on motor ability tests. Time spent at a sports club was a significant contributor for the OLS model, specifically spending 30 -90 mins per week at a sports club was associated with less touchdowns during the OLS test. A higher parental education score showed a significant association with decreased performance on the SR tests and nonsignificant but substantial associations with decreased performance on SLJ, and LJ tests. Overall, goodness-of-fit only marginally improved or did not change at all after inclusion of PA variables in all models (Table 3).

Discussion

The importance of motor competency (Robinson et al., 2015; Stodden et al., 2008) and physical activity (Carson et al., 2017) during early childhood is well established, and a relationship between motor competency and PA in preschool-aged children is apparent (Barnettet al., 2016a; Figueroa & An, 2017; Holfelder & Schott, 2014; Jones et al., 2020). This study aimed to investigate this relationship further with specific analyses to explore the association between individual motor abilities and four different measures of physical activity derived from wrist-worn accelerometers. As outlined in the introduction we view motor abilities as the general traits or abilities underlying the performance of fundamental movement skill while physical fitness refers to the ability to carry out daily tasks and perform physical activities in a highly functional state. Our results showed no statistically significant or rather substantial association between PA variables and individual motor abilities. These findings indicate that the covariates used to adjust the regression model i.e. for age, sex, height, parental education and time spent at a sports club, have a greater impact on the motor abilities in our sample of preschool-aged children.

Results from our study were not similar to previous studies that reported a significant relationship between measures of PA and performance on similar motor ability tests of speed and agility (Kambas et al., 2012; Wrotniak et al., 2006), lower leg explosive strength (i.e. SLJ) (Wrotniak et al., 2006), or balance (Kambas et al., 2012). However, these previous studies were conducted using correlational analyses; clearly when interpreting the relationship between PA and motor abilities, the type of analyses conducted (correlation versus regression) should be carefully considered. Regression analysis can provide greater insight as it enables researchers to adjust the association for multiple confounding factors. Differences in PA measurements also limit the comparability across studies as Kambas et al. (2012) used pedometer derived steps to measure PA and Wrotniak et al. (2006) used a different accelerometer with different cut-off points to determine PA. Additionally, our study population was slightly younger than that of these previous studies as Kambas et al. (2012) studied 5 -6-year olds and Wrotniak et al. (2006) investigated 8 – 10-year olds. Loprinzi and Frith (2017) also found no significant association between meeting PA guidelines and motor skills scores in children aged 3 – 5, however they used composite scores in their regression analyses. Iivonen et al. (2013) also found no significant association between MVPA and performance on the SLJ test in 4-year-old children however, they found that other individual test items, including OLS, were significantly associated with MVPA. Other studies have shown mixed results regarding associations between PA and different measures of motor abilities. One study found that higher total skills score and locomotor skills score was significantly associated with increased time spent in vigorous PA but not MVPA or TPA (Webster et al., 2019) while others reported significant associations between similar tests of motor abilities and measures of PA (Fang et al., 2017; Leppanen et al., 2018). However, these studies slightly differ from ours; for example, Leppanen et al. (2018) derived PA levels from doubly labelled water and Fang et al. (2017) and Webster et al., (2019) used composite motor competency scores in their analysis. Even though Leppanen et al. (2018) administered two of the tests used in the present analysis (shuttle run and standing long jump), they aimed to measure physical fitness which highlights how inconsistent terminology can further complicate comparisons across studies. Furthermore, Webster et al., (2019) used measures of motor competency as the independent variable and PA measures as the dependent variable while our analysis used PA measures as independent variables and motor ability as dependent variables. Although our results showed no significant associations, the tendencies and directions of the associations as well as the strength of our models suggest that certain associations may warrant further investigation. Specifically, associations between TPA and meeting WHO guidelines for PA may be of interest for future research. The relationship between PA and individual skills in preschool-aged children has not yet been fully explored in the literature as authors frequently use composite scores in their analyses which hinders the ability to investigate the effect of PA on the development of specific skills during the early years (Holfelder & Schott, 2014). Comparability across studies which implement different test batteries could be improved if future authors report relationships between PA and similar individual test items.

Our results indicated that age was the strongest contributor to models predicting performance on SR, SLJ, LJ and OLS tests; older children had better performance on all of these tests. This is concurrent with the developmental model proposed by Stodden et al. (2008), which proposes that the relationship between PA and motor competency strengthens with age. Previous research has shown positive associations between motor competency during early childhood and PA levels during adolescence (Venetsanou & Kambas, 2017). Therefore, gaining a better understanding of PA levels and motor abilities of preschoolers may be important for understanding PA and motor competency of children and youth (Stodden et al., 2014). Of particular concern was that over half of the children in our study did not meet the current WHO PA recommendations for their age group, which may have consequences for motor competency and PA levels in the future.

An interesting result was discovered during our analyses regarding how much time children spent at a sports club. Spending an average of 30 to 90 minutes per week at a sports club was significantly associated with increased performance on the OLS test and results for SR and LJ tests showed substantial, but non-significant associations in the regression models in line with the age effect, highlighting a complex interplay between these factors. These results are supported in the literature as Klein (2011), Krombholz (2006) and Birnbaum et al. (2016) all found that having a sports club membership was associated with increased performance on similar motor ability tests. As mentioned previously, sports club participation among this young age group in Germany typically represents “gymnastics” or structured exercises geared towards fundamental movements such as crawling, running and jumping rather than sports specific exercises. Consequently, our findings suggest that the structured and guided PA obtained through sports clubs may be beneficial to the development of specific motor abilities during the early years – or expressed in other words: the quality of PA is at least as equally important as the quantity of PA in young children. This is in agreement with recent evidence which suggests that opportunities for guided instruction on specific movements improves motor abilities (Robinson et al., 2015), therefore having a sports club membership, or attending another form of guided PA sessions, may provide important benefits for the development of motor abilities during the early years (Barnett et al., 2016a).

Although our motor ability tests were selected because they require small amounts of time and limited materials, allowing for effective testing of large groups of children (Klein et al., 2012) the product-oriented scoring method only measures the final product of each test (i.e. distance jumped, total speed). This does not allow for qualitative, or "process-oriented" assessment of test performance. The addition of some qualitative measures (i.e. video analysis or subscales of performance on tests) to give more indication of emerging motor abilities may provide a more comprehensive representation of children's motor ability. As suggested by Robinson et al. (2015), both process and product-oriented tests should be implemented in order to gain a more complete measure of children's motor competency. Inclusion of a measure of endurance or aerobic fitness level may be beneficial as cardiorespiratory fitness has also been associated with increased motor proficiency in this age group (Robinson et al., 2015).

Further limitations are presented when working with this age group as certain children may have difficulties understanding the tasks; therefore, performance may have been reduced due to a lack of understanding rather than poor motor ability. As this was an initial concern of study investigators, careful instructions and demonstrations of each test were given to all children by the same trained study nurses to promote consistency across all testing sessions. The addition of perceived motor competency measures could provide further information needed to better understand children's motor ability and participation in PA as studies have shown that children with higher perceived motor competency are more likely to engage in higher levels of PA (Stodden et al., 2014). Due to the complex, multivariate nature of the relationship between motor competency and PA during the early years, future analyses should explore other accelerometer-derived variables such as predicted energy expenditure, bouts of MVPA or TPA, or sedentary time variables may provide additional information about the associations between motor competency and movement behaviours of preschool aged children. Additionally, researchers should investigate other measures of neurological development such as fine motor skills, coordination, dual tasking, as well as cognitive and social emotional development. Lastly, cross-sectional analysis limits the ability to investigate causal links between PA and motor ability. Previous research indicates that changes in motor abilities are driven by PA during childhood (Barnett et al., 2016b; Burgi, 2011) and that the relationship between motor competency and PA strengthens over time (Stodden et al., 2008), therefore longitudinal analyses are required to investigate the impact that motor competency and PA during the early years have later in life. Ultimately, the study sample in the present analysis was underpowered to provide statistical inference on the hypothesized associations.

Despite certain limitations, the present study addresses a current gap in the literature as we provided a detailed analysis of the relationship between multiple measures of PA and individual motor ability tests which is in line with recommendations from Jones et al. (2020) and Holfelder and Schott (2014). An additional strength of this study is the use of objectively measured PA, as energy expenditure was predicted from raw accelerometer data using a model that was developed from children of the same age and country (Steenbock et al., 2019).

Conclusion

In conclusion, this study did not find statistically significant associations between multiple measures of PA and motor abilities, but other factors such as age and time spent at sports clubs seemed to be important factors. Further investigation is warranted to examine the development of motor abilities and whether environmental factors such as PA, parental education, and sports club membership can influence the process of motor ability development. We also recommend that future research should always include the quality of PA, and not only rely on quantity, especially when associations between PA and motor abilities is targeted.

Table 1: Descriptive characteristics for the entire sample and by sex

		ALL *(n = 193)*			GIRLS *(n = 101)*			BOYS *(n = 92)*		
	n	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Age	193	4.2	0.7	3.0 to 5.9	4.2	0.7	3.0 to 5.9	4.3	0.7	3.0 to 5.9
Height (cm)	193	106	6.7	89.4 to 124	105	6.7	89.4 to 123	106	6.7	89.8 to 124
Weight (kg)	193	16.8	3.2	10.1 to 34.2	16.5	2.8	10.1 to 29.5	17.1	3.5	11.0 to 34.2
BMI z-score	193	- 0.62	1.3	- 5.0 to 3.4	- 0.56	1.1	- 2.8 to 2.6	-0.69	1.4	- 5.0 to 3.4
Motor Ability Performance										
SR (seconds)	192	11.1	1.9	8.1 to 16.7	11.1	1.8	8.2 to 16.6	11.1	2.0	8.1 to 16.7
SLJ (cm)	192	72.7	22.8	8 to 129	69.6	23.1	10.2 to 129	76.0	22.1	8 to 123
LJ (# of jumps)	189	15.2	6.9	0 to 41	16.0	6.8	1 to 33	14.7	6.9	0 to 41
OLS (# of touchdowns)	178	10.3	6.7	0 to 29	10.1	7.1	0 to 29	10.5	6.1	0 to 27
SAR (cm)	192	3.2	4.1	-10 to 12	3.8	4.0	- 9 to12	2.5	4.2	-10 to 11
Accelerometer Data										
MVPA (min/day)	193	72.4	29.0	22 to 184	63.0	22.2	23 to 147	83.8	32.0	22 to 184
TPA (min/day)	193	249	61.2	129 to 451	242	58.1	154 to 451	255	64.0	129 to 442
Wear Time (min/day)	193	616	37.5	503 to 703	615	39.4	503 to 695	617	36.1	522 to 703
% TPA	193	40.3	9.7	20.8 to 74.2	39.4	9.5	24.6 to 74.2	41.3	10.0	20.8 to 67.5
% MVPA of TPA	193	28.8	7.5	10.8 to 47.0	26.1	6.6	10.8 to 43.1	32.0	7.2	13.1 to 47.0

Note. negative values for SAR indicate that the children did not reach past their toes

Table 2: *Frequencies for parental education, sports club membership, PA guidelines*

	ALL *(n = 193)*		GIRLS *(n = 101)*		BOYS *(n = 92)*	
	n	%	n	%	n	%
Parental Education Score						
Low	16	8	13	13	3	3
Medium	104	54	59	58	45	49
High	65	34	25	25	40	44
Missing	8	4	4	4	4	4
Sports club membership						
Yes	94	49	54	54	40	55
No	97	50	46	45	51	44
Missing	2	1	1	1	1	1
Time at sports club (mins/week)						
No time	97	50	46	47	51	55
>=30 mins - <90 mins	55	29	30	31	25	27
>=90 mins	35	18	21	22	14	15
Missing	6	3	4	4	2	2
WHO guidelines						
yes	111	58	47	47	64	70
no	82	42	54	54	28	30

Note. WHO guideline for 3-4 years = 180 mins of PA/day, including at least 60 mins of MVPA
WHO guidelines for 5+ years = at least 60 mins of MVPA per day
Whether or not children met WHO guidelines was determined using their average PA data

Table 3: *Linear regression models regressing all measures of PA on each motor ability test*

	SR (seconds)				**SLJ** (cm)				**LJ** (# of Jumps)				**OLS** (#of touchdowns)			
	ß	B	95% CI	Adj R^2	ß	B	95% CI	Adj R^2	ß	B	95% CI	Adj R^2	ß	B	95% CI	Adj R^2
Model 1: No PA variable				.38				.42				.45				.24
Age	-0.45	-1.15	-1.64, -0.66		0.54	16.7	11.06, 22.42		0.71	6.51	4.89, 8.14		-0.47	-4.21	-6.10, -2.31	
Sex	0.01	0.47	-0.42, 0.51		-0.14	-6.22	-11.65, -0.79		0.05	0.62	-0.94, 2.18		-0.04	-0.45	-2.31, 1.40	
Height	-0.19	-0.06	-0.11, -0.002		0.12	0.40	-0.22, 1.02		-0.09	-0.09	-0.27, 0.09		-0.04	-0.04	-0.25, 0.17	
Parental Education																
Medium score	0.22	0.84	0.002, 1.67		-0.13	-6.08	-15.83, 3.68		-0.18	-2.37	-5.17, 0.42		0.05	0.63	-2.70, 3.95	
High score	0.25	0.99	0.11, 1.87		-0.15	-6.98	-17.24, 3.28		-0.17	-2.38	-5.31, 0.56		0.02	0.25	-3.23, 3.72	
Sports Club Time																
≥30 - < 90mins	-0.03	-0.12	-0.64, 0.40		-0.01	-0.41	-6.46, 5.64		0.07	1.07	-0.68, 2.81		-0.18	-2.65	-4.73, -0.57	
≥90mins	-0.08	-0.36	-0.98, 0.26		0.04	2.34	-4.89, 9.56		0.11	1.84	-0.23, 3.91		-0.01	-0.15	-2.53, 2.23	
Model 2: MVPA (mins) [a]				.40				.42				.45				.24
	-0.04	-0.003	-0.01, 0.06		0.02	0.02	-0.09, 0.13		0.04	0.01	-0.02, 0.04		0.03	0.01	-0.03, 0.04	
Model 3: TPA (mins) [a]				.40				.42				.44				.25
	-0.004	0.00	-0.004, 0.004		-0.06	-0.02	-0.07, 0.02		0.02	0.002	-0.01, 0.01		0.10	0.01	-0.04, 0.03	
Model 4: %MVPA of TPA [b]				.38				.43				.44				.24
	-0.04	-0.01	-0.05, 0.03		0.13	0.42	-0.04, 0.87		0.04	0.04	-0.09, 0.17		-0.08	-0.08	-0.23, 0.08	
Model 5: Meeting WHO guidelines [a]				.40				.42				.44				.24
	-0.04	-0.14	-0.61, 0.33		0.07	3.11	-2.51, 8.73		0.02	0.26	-1.36, 1.87		-0.03	-0.33	-2.25, 1.58	

Note. [a] Adjusted for Age, Sex, height, parental education, sports club time and Wear Time (mean mins)
[b] Adjusted for Age, Sex, height, parental education, sports club time and %TPA
Reference category for sex is Male, Reference category for Parental Education is “low” score.
Reference category for sports club time is no time spent at sports clubs
ß = Standardized Coefficients Beta, B = Unstandardized coefficients Beta, 95% CI = 95% Confidence Interval

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