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Relationship between habitual physical activity and gross motor skills is multifaceted in 5- to 8-year-old children

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Adequate motor skills are essential for children participating in age-related physical activities, and gross motor skills may play an important role for maintaining sufficient level of physical activity (PA) during life course. The purpose of this study was to examine the relationship between gross motor skills and PA in children when PA was analyzed by both metabolic- and neuromuscular-based methods. Gross motor skills (KTK – Körperkoordinationstest für Kinder and APM inventory – manipulative skill test) of 84 children aged 5–8 years (53 preschoolers, 28 girls; 31 primary schoolers, 18 girls) were measured, and accelerometer-derived PA was analyzed using in parallel metabolic counts and neuromuscular impact methods. The gross motor skills were associated with moderate-to-high neuromuscular impacts, PA of vigorous metabolic intensity, and mean level of PA in primary school girls ($0.5 < r < 0.7$, $P < 0.05$), and with high impacts in preschool girls ($0.3 < r < 0.5$, $P < 0.05$). In preschool boys, moderate impacts, light-to-vigorous PA, and mean level of PA were associated with gross motor skills ($0.4 < r < 0.7$, $P < 0.05$). In conclusion, the result emphasizes an important relationship between gross motor skills and PA stressing both metabolic and neuromuscular systems in children. Furthermore, PA highly stressing neuromuscular system interacts with gross motor proficiency in girls especially.

The acquisition of adequate motor skills is an essential developmental task in childhood. Exploration of the environment and new tasks require a wide scale of gross and fine motor skills (Shumway-Cook & Woollacott, 2012), and delays in the development of motor skills have been linked to lower perceived physical competence (Robinson, 2011) and weaker academic achievement (Kantomaa et al., 2013). Also, motor skills have been associated to health-related measures such as body mass index (BMI) and waist circumference (Okely et al., 2004; D'Hondt et al., 2011; Lopes et al., 2012b), and fitness (Hands et al., 2009).

In previous studies, the total amount of physical activity (PA) and moderate-to-vigorous PA (MVPA) have typically correlated positively and sedentariness negatively with the level of gross motor skills in children (Fisher et al., 2005; Wrotniak et al., 2006; Williams et al., 2008; Burgi et al., 2011). In longitudinal designs, the level of gross motor skills has weakly or moderately predicted relationship with the level of PA (Barnett et al., 2009; Lopes et al., 2011). In these previous studies, examining the relationship between objectively measured habitual PA and gross motor skills in children, PA has been primarily assessed by metabolic basis. This is due to the fact that the accelerometer data have been categorized into different PA intensities using counts cutoff points typically defined on the basis of energy consumption (Evenson et al., 2008).

A major contributor to the enhancement of motor performance, fitness, as well as proficiency of gross motor skills, is the ongoing neuromuscular development. Neuromuscular development refers to the maturation of both neural and muscular systems and includes the integration of these systems (Kellis & Hatzitaki, 2012, p. 50). The neuromuscular efficiency is expressed as greater force production, which along with other domains of growth and maturation, can be seen as an essential prerequisite for skill acquisition (Haywood & Getchell, 2009). Therefore, the assessment of PA in relation to gross motor development should take into consideration the amount and quality of neuromuscular loading, i.e., forces acting on the body.

The neuromuscular loading can be examined via real-time assessment of acceleration forces caused by bodily movements. The use of real–time-based accelerometer signal has been previously recommended for bone studies in children (Rowlands, 2007) and it could be considered to supplement the typical metabolic-based analysis of habitual PA also in studies regarding the relations between PA and gross motor skills in children. This is especially important because habitual PA in children is known to be transitory in nature (Baquet et al., 2007), and about 95% of PAs last less than 15 s (Bailey et al., 1995).

Consequently, we hypothesized the parallel analysis of both metabolic and neuromuscular loading of PA would enable more comprehensive evaluation of the association between gross motor skills and habitual PA in children. Therefore, the purpose of this study was to examine the relationship between habitual PA and gross motor skills in 5–8-year-old children when the accelerometer signal was processed by both (a) metabolic counts and (b) neuromuscular impact-based methods.

Materials and methods

This report utilizes midline measurements from a parallel group randomized controlled intervention trial (ISRCTN28668090; Finni et al., 2011) examining daily PA and motor skills in children. PA level was assessed during 6 days using three-dimensional (3-D) accelerometer measurements, and gross motor skills were tested using KTK, Körperkoordinationstest für Kinder (Kiphard & Schilling, 2007), and the modified APM inventory, manipulative skill test (Numminen, 1995). An ethics approval for the project was received from the Ethics Committee of the Central Finland Health Care District.

Subjects

An invitation to participate to the study was sent to parents of 601 children who were attending all-day day care in 22 kindergartens and to parents of 454 primary schoolers attending nine different primary schools between April 2011 and April 2012. A total of 103 children (66 preschoolers of 19 kindergartens and 37 primary schoolers of eight primary schools) and their parents accepted the invitation. Ninety-five children participated in the midline measurements. Of them 11 children were excluded because of missing PA measurement (2), refusing to take part to the gross motor skill tests (1), no required PA data from weekday or weekend days (6), and the age of under 5 years (2). In the end, the study group ($n = 84$) consisted of 28 preschool girls (age 5.95 ± 0.47 years) and 25 preschool boys (5.92 ± 0.45 years), and 18 first-grade girls (8.06 ± 0.15 years) and 13 first-grade boys (7.93 ± 0.34 years).

Anthropometry

In the laboratory, height and body weight were measured and BMI (kg/m^2) was calculated for each subject. Approximately 11% of the sample was found overweight on the basis of international cutoff points (Cole, 2000).

PA

PA was measured for an average of 5.47 days (11.60 ± 0.91 h/d) in preschoolers and 5.35 days (12.42 ± 1.28 h/d) in primary schoolers using triaxial X6-1a accelerometers with a dynamic range of $\pm 6\ g$ (Gulf Coast Data Concepts Inc, Waveland, MS, USA). Subjects with recordings longer than 500 min on at least 3 days (2 weekdays and 1 weekend day) were accepted for further analysis (Penpraze et al., 2006). On average 3.72 (11.72 ± 1.10 h/d) and 3.68 (12.57 ± 0.85 h/d) of measured days were weekdays, and 1.75 (11.45 ± 1.06 h/d) and 1.74 (11.53 ± 1.41 h/d) weekend days in preschoolers and primary schoolers, respectively. The device was carried on the anterior waistline in a firmly worn adjustable elastic belt during waking hours, with the exception of water-based activities and bathing. Verbal and written instructions for accelerometry measurement in children were given individually to parents and teachers at the kindergarten.

Motor skills

Gross motor skills were tested in the laboratory, in kindergarten, or at primary school depending on which suited the children and their parents the best. In each case, the testing circumstances were set as similar as possible regarding distractions, floor material, space, and equipment needed in the measurement. Children were tested alone or in small groups of two or three children, and the tasks were performed one child at a time. An oral instruction and a model performance were given for every task, and the tasks were performed in the same order for every child. The same trained researcher (A. L.) assessed all the tests. A pilot study for testing gross motor skills by this protocol was conducted in preschoolers ($n = 7$), separate to this study group. In the pilot, testing sessions were videotaped and analyzed afterward for appropriate arrangement and assessment practices with two senior researchers in the field.

From the KTK test battery, the children performed all the four items:

1. Walking backwards (WB) on balance beams (length 3 m; height 5 cm) with different widths of 6.0, 4.5, and 3.0 cm, starting from the widest one. A maximum test score possible was 72 steps, which accumulated from three trials per each beam, and a maximum of eight successful steps for each trial.
2. Hopping for height (HH), one foot at a time, over an increasing pile of soft mattresses (width 60 cm; depth 20 cm; height 5 cm each). The first, second, or third trial of each height was awarded by three, two, or one point(s), respectively. A maximum test score was 39 points (ground level + 12 mattresses) for each leg, summed to the maximum of 78 points with both legs.
3. Jumping sideways (JS) from side to side over a thin wooden lath ($60 \times 4 \times 2$ cm) on the jumping base (100×60 cm). Two trials of 15 s were performed and a total of successful jumps were summed.
4. Moving sideways (MS). The children had two identical wooden plates (size 25×25 cm; height 5.7 cm) and after stepping to one, they had to transfer another one sideways for the next transition. The total of transitions was summed over two 20-s trials. Transitions were performed to the same direction on both trials.

The reliability of the KTK has been shown to be high (Kiphard & Schilling, 2007). The raw test scores of the KTK test items were transformed into gender- and age-standardized values and into a measure indicating overall gross motor coordination (MC) according to the KTK manual. The MC is classified as follows: “not possible” (values under 56), “severe motor disorder” (values 56–70), “moderate motor disorder” (values 71–85), “normal” (86–115), “good” (116–130), and “high” (131–145).

In addition, manipulative skills were measured by underarm throw and catch a ball (TCB) test of an APM inventory. APM inventory has been validated in 1800 Finnish children of 1–7 years of age and shown to be highly reliable (Numminen, 1995). In TCB for preschoolers, a softball (circumference 65.4 cm; weight 228 g) was thrown underarm 10 times to a target (10-cm wide piece of distinguishable tape) at a height of 1.30 m on the wall from a distance of 2 m and caught after a bounce on the floor. TCB was modified for primary schoolers so that it was performed in two separate parts with a higher degree of difficulty. In the first part, the ball was thrown 10 times from a distance of 3 m and caught after a bounce on the floor. Additionally, hits that rose over the marked upper limit of a height of 2 m on the wall were failed. In the second part, the ball was thrown 10 times from a distance of 3 m and caught without a bounce on the floor. No marked upper limit on the wall existed on the second part. The number of catches (maximum of 10 in preschoolers and 20 in primary schoolers) was summed (marked as TCB_raw). Finally, the TCB_raw was transformed into age-standardized value (TCB) by the averaged sum scores of the age groups (5-, 6-, and 7–8-year-olds) in this study sample. Performing the KTK and TCB took approximately 20–30 min per child.

Data analysis

A resultant vector $(x^2 + y^2 + z^2)^{0.5}$ of the 3-D accelerometer signal was composed, band-pass filtered (0.25–11 Hz), and values below 0.05 *g* were threshold filtered. All these phases of analysis are similar as in typical Actigraph analysis. The neuromuscular loading of PA was assessed via real-time g-force impacts that were recorded up to 6 *g*. The percentage of measurement time and accumulated minutes per day spent at different g-force impact categories were analyzed in the intervals as follows: 0–0.05, 0.05–0.2, 0.2–0.4, . . . , 5.6–5.8, and 5.8–6.0 *g*. For assessing the metabolic loading, PA counts were calculated by summing over 15-s epochs and multiplying by a device-specific factor that was derived from simultaneous recordings with the X6-1a and ActiGraph GT3X (Actigraph LCC, Pensacola, FL, USA) in three children during normal daily living. Additionally, mean counts per minute (CPM) values, referring to the mean level of PA, were calculated.

In this study, the time spent at counts intensity categories was analyzed using the following cutoff points: sedentary, under 373; light, 373–585; moderate, 585–881; and vigorous, over 881 (Van Cauwenberghe et al., 2011). While Van Cauwenberghe et al. used uniaxial accelerometer and in the present study a triaxial device was used, there is an agreement between uniaxial and triaxial accelerometers to classify PA into intensity categories in children (Robusto & Trost, 2012).

Non-wearing time was defined as 20 min or longer continuous zero signal and was cut out. In addition, midday nap time was cut out from further analysis in children attending kindergarten. Nap times were marked to the diary by the kindergarten teachers.

Statistical analysis

All analyses were conducted separately for both sexes in preschoolers and primary schoolers in the Statistical Package for the Social Sciences (SPSS) Statistics software (IBM SPSS Statistics 20, SPSS Finland, Espoo, Finland). Descriptives of PA analyzed by neuromuscular- and metabolic-based methods include means and standard deviations of percentage of measurement time and minutes per day spent at different categories. Moreover, means, standard deviations, and ranges of age, height, weight, BMI, and gross motor skill test scores were calculated. The skewed distributions in percentage of time spent at g-force impact categories in preschool girls and boys, and primary school boys were logarithmically transformed. Independent samples *t*-tests were used to examine the differences between boys and girls, and differences between preschoolers and primary schoolers in PA analyzed by neuromuscular- and metabolic-based methods and in anthropometrics and gross motor skill scores. Partial correlation coefficients were calculated between the time spent at g-force impact categories and standardized gross motor skills values and MC, and between the time spent at counts intensity categories and standardized gross motor skill scores and MC. The effect of BMI and age was controlled in all correlational analyses. Because all participants did not display accelerations up to 6 *g*, the correlations were done only up to the g-force category in which every subject within given group had data. Consequently, the upper boundary for g-forces was set to 5.6 *g* in preschool girls, 5.4 *g* in preschool boys, and 6 *g* in primary schoolers. Level of significance was set to $P < 0.05$.

Results

Descriptives for PA analyzed by neuromuscular-based g-force impact method are summarized in Table 1 and by metabolic-based counts intensity method in Table 2. Boys accumulated more time than girls at g-force impact categories ($2.48 < t < 3.64$, $P < 0.05$) and less time at zero g-force (primary schoolers, $t = 2.31$, $P < 0.05$). Similarly, boys spent more time at counts intensity categories ($2.26 < t < 3.33$, $P < 0.05$) and less time at sedentary ($2.79 < t < 2.92$, $P < 0.01$). In general, primary schoolers spent more time at g-force impact categories ($2.15 < t < 3.38$, $P < 0.05$) and counts intensity categories ($2.06 < t < 3.48$, $P < 0.05$) and were less sedentary ($t = 3.09$, $P < 0.01$) than preschoolers. Additionally, mean CPM values, referring to the mean level of PA, were higher among primary schoolers (652 ± 200/min; $t = 3.20$, $P < 0.01$) than preschoolers (532 ± 142/min). The mean CPM was higher in primary school boys (boys: 742 ± 225/min; $t = 2.27$, $P < 0.5$) compared with primary school girls (587 ± 156/min), but no significant difference was found between sexes in preschoolers (girls: 502 ± 115/min; boys: 567 ± 162/min).

As expected, primary schoolers on average were heavier and taller than preschoolers, but there was no difference in BMI (Table 3). No significant sex differences were found in age, height, weight, or BMI in preschoolers or primary schoolers. Gross motor skills were identified both in preschoolers and primary schoolers as normally developed (scores between 86 and 115), and in primary school boys as well developed in JS and MS (scores between 116 and 130) on the basis of KTK classification. In general, primary schoolers performed significantly better in WB, HH, JS and MS, and in MC than preschoolers, regardless of age standardization. Further, preschool boys performed better than preschool girls in MC ($t = 2.44$, $P < 0.05$), HH ($t = 3.22$, $P < 0.01$), and JS ($t = 2.59$, $P < 0.05$). Similarly, primary

Table 1. Percentage of physical activity measurement time (mean ± standard deviation) and accumulated minutes spent per day (mean in parenthesis) in neuromuscular impact-based g-force categories

G-force impact category (*g*)	Preschoolers (5–6-year-olds)		Primary schoolers (7–8-year-olds)	
	Girls (*n* = 28)	Boys (*n* = 25)	Girls (*n* = 18)	Boys (*n* = 13)
0	89.86 ± 1.66 (621.05)	89.27 ± 1.55 (627.50)	89.66 ± 1.92 (658.84)*	88.01 ± 1.94 (672.55)
0.05–0.20	6.73 ± 1.00 (46.39)	6.80 ± 0.87 (47.80)	6.46 ± 1.06 (47.39)	6.94 ± 0.93 (52.78)
0.2–0.4	1.90 ± 0.35 (13.11)*	2.16 ± 0.40 (15.20)††	2.19 ± 0.51 (16.06)*	2.64 ± 0.49 (19.80)
0.4–0.6	0.69 ± 0.16 (4.78)*	0.82 ± 0.18 (5.76)†	0.79 ± 0.24 (5.82)**	1.09 ± 0.29 (8.12)
0.6–0.8	0.32 ± 0.09 (2.18)	0.36 ± 0.10 (2.57)	0.33 ± 0.12 (2.41)**	0.49 ± 0.15 (3.60)
0.8–1.0	0.17 ± 0.06 (1.19)	0.19 ± 0.06 (1.37)	0.17 ± 0.05 (1.26)**	0.25 ± 0.09 (1.87)
1–2	0.30 ± 0.20 (1.86)	0.30 ± 0.20 (2.26)	0.30 ± 0.11 (2.22)*	0.43 ± 0.19 (3.16)
2–3	0.05 ± 0.02 (0.33)	0.06 ± 0.06 (0.45)†	0.07 ± 0.04 (0.53)	0.10 ± 0.07 (0.72)
3–4	0.01 ± 0.01 (0.08)	0.16 ± 0.02 (0.12)†	0.02 ± 0.02 (0.15)	0.03 ± 0.03 (0.21)
4–5	0.00 ± 0.00 (0.03)	0.01 ± 0.01 (0.04)	0.01 ± 0.01 (0.05)	0.01 ± 0.01 (0.07)
5–6	0.00 ± 0.00 (0.01)	0.00 ± 0.00 (0.01)	0.00 ± 0.00 (0.01)	0.00 ± 0.00 (0.02)

Significant difference between sexes in percentage of measurement time in g-force categories $^{*}P < 0.05$, $^{**}P < 0.01$ and between preschool and primary schoolers $^{\dagger}P < 0.05$, $^{\dagger\dagger}P < 0.01$.

Table 2. Percentage of physical activity measurement time (mean ± standard deviation) and accumulated minutes spent per day (mean in parenthesis) in metabolic counts intensity categories

Intensity category	Preschoolers (5–6-year-olds)		Primary schoolers (7–8-year-olds)	
	Girls (*n* = 28)	Boys (*n* = 25)	Girls (*n* = 18)	Boys (*n* = 13)
Sedentary	90.19 ± 2.60 (623.41)**	87.84 ± 3.52 (617.01)††	88.07 ± 3.48 (646.92)**	83.12 ± 4.76 (638.39)
Light	4.65 ± 1.05 (32.01)**	5.73 ± 1.33 (40.13)†	5.18 ± 1.46 (37.87)**	6.84 ± 1.38 (51.66)
Moderate	2.74 ± 0.82 (18.84)*	3.41 ± 1.05 (24.23)††	3.49 ± 1.06 (25.70)**	5.22 ± 1.74 (38.03)
Vigorous	2.44 ± 1.18 (16.92)	3.05 ± 1.93 (21.91)††	3.28 ± 1.45 (24.39)	4.85 ± 2.53 (34.98)

Significant difference between genders in percentage of measurement time in counts intensity categories $^{*}P < 0.05$, $^{**}P < 0.01$ and between preschoolers and primary schoolers $^{\dagger}P < 0.05$, $^{\dagger\dagger}P < 0.01$.

Table 3. Means, standard deviations, and ranges (in parentheses) of age, height (in cm), weight (in kg), body mass index (BMI), standardized scores on the four items of the KTK, overall gross motor coordination according to the KTK, manipulative skill test raw score (TCB_raw), and standardized score (TCB)

Measures	Preschoolers (5–6-year-olds)		Primary schoolers (7–8-year-olds)	
	Girls (n = 28)	Boys (*n* = 25)	Girls (*n* = 18)	Boys (*n* = 13)
Age (years)	5.95 ± 0.47 (1.91)	5.92 ± 0.45 (1.63)	8.06 ± 0.51 (0.56)	7.93 ± 0.34 (1.04)
Height (cm)	115.41 ± 6.09 (28.10)	117.40 ± 4.97 (17.80)††	128.25 ± 5.85 (25.30)	127.83 ± 4.18 (16.10)
Weight (kg)	20.70 ± 2.72 (10.40)	21.69 ± 2.42 (8.80)††	25.49 ± 4.23 (12.40)	26.70 ± 3.56 (10.20)
BMI	15.49 ± 1.04 (4.29)	15.70 ± 0.89 (3.77)	15.47 ± 2.14 (8.31)	16.28 ± 1.45 (4.61)
WB	91.07 ± 14.27 (64)	86.0 ± 12.77 (48)†	102.22 ± 13.69 (46)**	86.2 ± 14.42 (53)
HH	92.93 ± 16.63 (85)**	108.04 ± 16.87 (55)††	108.56 ± 11.59 (43)	110.67 ± 7.63 (22)
JS	101.00 ± 13.83 (57)*	112.69 ± 18.63 (71)†	109.33 ± 15.95 (59)*	122.92 ± 11.66 (36)
MS	103.25 ± 14.12 (53)	108.81 ± 15.63 (60)†	110.67 ± 11.68 (40)	115.92 ± 15.35 (47)
MC	94.86 ± 13.52 (55)*	104.92 ± 16.69 (57)††	109.72 ± 13.83 (60)	111.42 ± 11.92 (39)
TCB_raw	5.61 ± 2.63 (10)	6.46 ± 3.01 (10)	13.17 ± 3.81 (15)	14.83 ± 4.15 (13)
TCB	0.92 ± 0.43 (1.63)	1.06 ± 0.49 (1.66)	0.95 ± 0.28 (1.09)	1.07 ± 0.30 (0.94)

Significant difference between sexes $^{*}P < 0.05$, $^{**}P < 0.01$ and between preschool and primary schoolers $^{\dagger}P < 0.05$, $^{\dagger\dagger}P < 0.01$.
HH, hopping for height; JS, jumping sideways; KTK, KörperkoordinationsTest für Kinder; MC, overall gross motor coordination according to the KTK; MS, moving sideways; TCB, standardized value of the manipulative skill test score; TCB_raw, throwing and catching a ball manipulative skill test raw score; WB, walking backwards.

school boys were better than girls in JS ($t = 2.45$, $P < 0.05$), although girls outperformed boys in WB ($t = 3.24$, $P < 0.01$).

After controlling for BMI and age, correlations between gross motor skills and PA revealed multifaceted trends (Fig. 1). MC correlated with the time spent sustaining impacts between 0.6 and 1.2 *g* ($0.42 < r < 0.51$, $P < 0.05$) and with the time spent at PA of light ($r = 0.51$, $P < 0.05$) and moderate metabolic intensity ($r = 0.55$, $P < 0.01$), and negatively with sedentary time ($r = -0.52$, $P < 0.05$) in preschool boys. Additionally, mean CPM was associated with MC ($r = 0.45$, $P < 0.05$) in

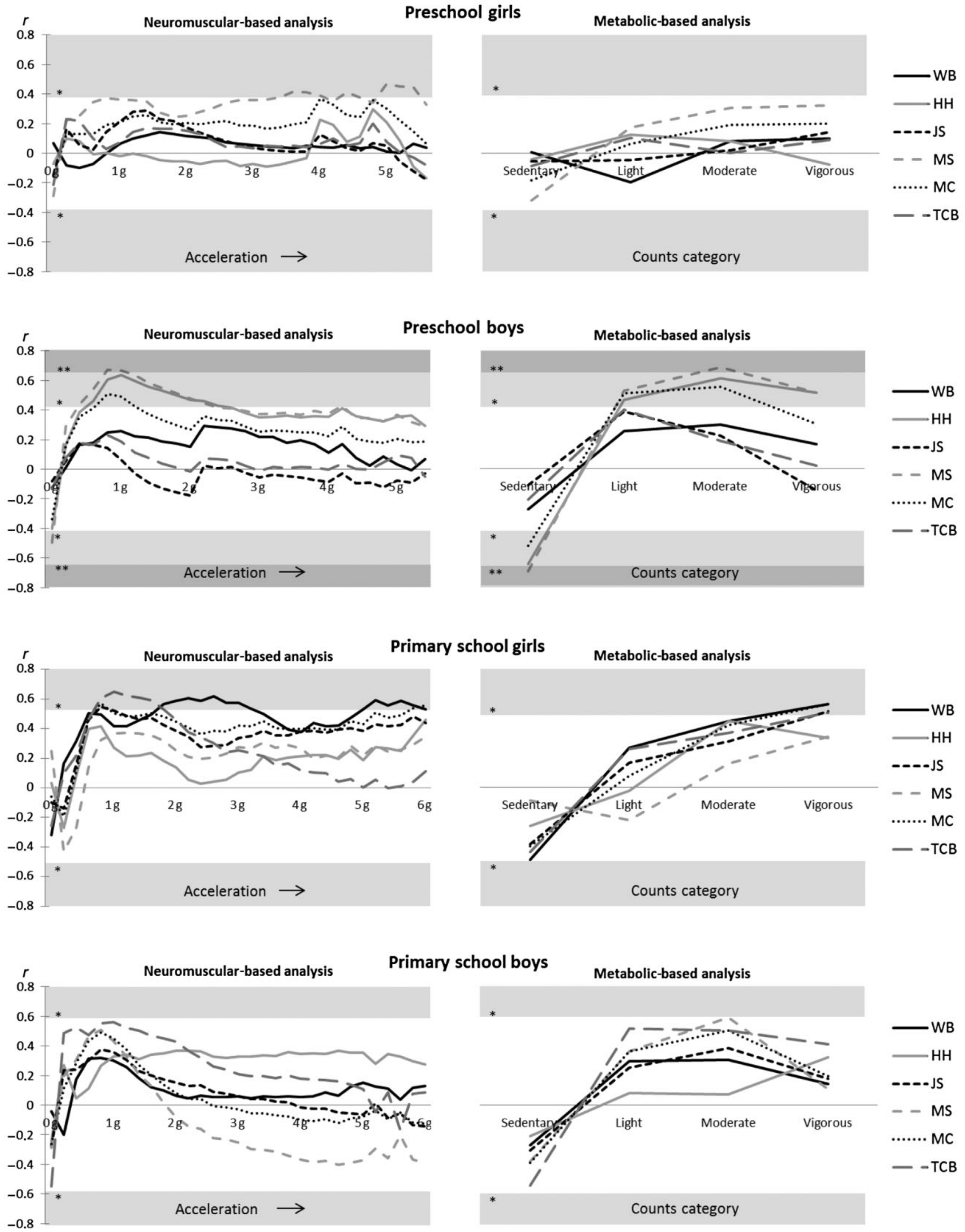

Fig. 1. Display of relations of gross motor skills and the time spent at neuromuscular impact-based g-force categories and metabolic-based counts intensity categories after controlling the effect of body mass index and age. The time spent at g-force categories and counts categories are plotted in the *x*-axis, and Pearson's correlation coefficients (two-tailed) in the *y*-axis. HH, hopping for height; JS, jumping sideways; KTK, Körperkoordinationstest für Kinder; MC, overall gross motor coordination according to the KTK; MS, moving sideways; TCB, throwing and catching a ball; WB, walking backwards. Significant correlation $*P < 0.05$ and $**P < 0.001$.

preschool boys. In primary school girls, MC was in association with the time spent at 0.6–1.0, 1.4–1.6, and 5.6–6.0 g impacts ($0.50 < r < 0.57$, $P < 0.05$) and with the time spent at vigorous intensity ($r = 0.56$, $P < 0.05$).

Of specific gross motor skill test items, MS correlated with the time spent sustaining impacts of 0.6–0.8 g ($r = 0.67$, $P < 0.001$), 0.2–0.6 g, and 0.8–2.4 g ($0.43 < r < 0.67$, $P < 0.05$), 0 g ($r = -0.50$, $P < 0.05$) and with the time spent at light ($r = 0.53$, $P < 0.05$), moderate ($r = 0.69$, $P < 0.001$), vigorous ($r = 0.52$, $P < 0.05$), and inversely with sedentary ($r = -0.69$, $P < 0.001$) categories in preschool boys (Fig. 1). HH correlated with the time spent sustaining impacts between 0.4 and 2.6 g ($0.41 < r < 0.64$, $P < 0.05$) and with the time spent at light ($r = 0.47$, $P < 0.05$), moderate ($r = -0.64$, $P < 0.001$), vigorous ($r = 0.51$, $P < 0.05$), and negatively with sedentary ($r = -0.65$, $P < 0.01$) categories in preschool boys. Both MS and HH were significantly in association with mean CPM ($0.60 < r < 0.66$, $P < 0.01$) in preschool boys.

In preschool girls, MS was associated with the time spent sustaining impacts of 3.4–4.0, 4.2–4.4, and 4.8–5.4 g ($0.39 < r < 0.47$, $P < 0.05$), but not with the time spent at any counts intensity category or with mean CPM. In primary school girls, TCB was associated with the time spent sustaining impacts of 0.8–1 g ($r = 0.65$, $P < 0.01$), WB with 1.6–3.4 and 4.8–6.0 g ($0.50 < r < 61$, $P < 0.05$) and JS with 0.6–1.0 g ($0.52 < r < 0.55$, $P < 0.05$). TCB, WB, and JS correlated with vigorous-intensity category ($0.50 < r < 57$, $P < 0.05$) and WB with mean CPM ($r = 0.52$, $P < 0.05$) in primary school girls. On the whole, in primary school boys, no significant association was found between gross motor skills and the PA analyzed by neuromuscular or metabolic methods, or between gross motor skills and mean CPM.

Discussion

This study indicated that gross motor skills are positively in association with habitual PA and negatively associated with sedentary time in 5–8-year-old children. However, the metabolic and neuromuscular methods, which were used in parallel for analyzing PA, present a novel insight for evaluating this relationship. In primary school girls the MC, referring to the overall gross MC, correlated significantly with moderate-to-high neuromuscular impacts and with PA of vigorous metabolic intensity. On the other hand, in preschool boys, MC correlated positively with the mean level of PA, moderate neuromuscular impacts, PA of light-to-moderate metabolic intensity, and negatively with sedentariness. In addition, there was a weak, but significant association between a gross motor skill and high neuromuscular impacts in preschool girls. These findings suggest that the gross motor skills are in relation to the mean level of PA in boys especially, but to high neuromuscular impacts in girls only.

The novel finding of the present study give support to the assumption that the tendency to perform activities inducing high neuromuscular impacts, i.e., forces, could significantly support the development of gross motor skills, and the limited capacity to perform movements of high neuromuscular impacts could mediate the lack of motor proficiency (Payne & Isaacs, 2007). Moreover, it has been shown that muscular strength could also attenuate the accumulation of subcutaneous adipose tissue during childhood (Lopes et al., 2012a). However, when interpreted the other way round, the limited capacity to perform movements of high neuromuscular impacts and to move vigorously could be caused by the lack of motor proficiency. This assumption is supported by a previous study (Chia et al., 2010) indicating the proficiency of gross motor skills to enable one to move with more easiness and for longer durations at a time because of lower perceived exertion of PA. Nevertheless, because of the cross-sectional design of the present study, the direction of the causality remains unknown.

The present results are in line with previous studies indicating the relationship between gross motor skills and the total amount of PA, MVPA, and sedentariness assessed on metabolic basis (e.g., Fisher et al., 2005; Wrotniak et al., 2006). On the other hand, the present study also revealed weak, but significant correlation between the PA of light metabolic intensity and gross motor skills in preschool boys. In general, the mean CPM of preschoolers at the present sample was substantially lower than previously reported in Dutch preschoolers (Cardon & De Bourdeaudhuij, 2008), and this fact could possibly explain the association between the light PA and gross motor skills. It could be that if the mean level of PA is low, even the increase of light PA could facilitate the development of gross motor skills in preschool-aged children.

The previous studies have reported stronger positive correlations among boys (Williams et al., 2008; Cliff et al., 2009) or no sex difference (Fisher et al., 2005; Wrotniak et al., 2006) when examining the relationship between gross motor skills and PA. Comparison between studies is difficult because of heterogeneity in methodologies used for assessing PA and gross motor abilities. The relationship is presumably also affected by multiple individual and environmental factors and therefore causing inconsistency between studies. For instance, perceived motor competence may play an important role when it comes to the relation between actual motor competence and PA (Barnett et al., 2008a; Stodden et al., 2008). In the present study, the varied correlations between gross motor skills and PA in girls could be an indication of more complex relationship between these factors. The finding gives support to the assumption that ongoing interaction between gross motor development and ability to perform greater force allows children to take part to physical activities typical to their developmental level (Haywood & Getchell, 2009). It is worth specifying in this connection that even though the motor performance has interrelationship with biological growth and maturation rate (Payne & Isaacs, 2007), it has been shown that the KTK, primarily used for assessing the gross motor proficiency at the present study, is not related to biological maturity (Vandendriessche et al., 2012).

When examining the relationship between gross motor skills and habitual PA in children, there are some potential advantages with the use of real-time acceleration forces for analyzing PA. The results revealed a weak, but significant relationship between the time spent at high g-forces and MS in preschool girls. The reason why only PA analyzed by neuromuscular-based method was associated with gross motor skills in some cases of this study may be the fact that real–time-based method is able to distinguish intermittent and short-term PA typical to children (Baquet et al., 2007). Moreover, although the relationship between gross motor skills and vigorous PA in primary school girls was revealed by the metabolic-based counts method, the significance of PA of high impacts in this relation was reinforced by neuromuscular method. Further, the selection of cutoff points and epoch time for analyzing accelerometer-derived PA may significantly affect the outcome of PA (Bornstein et al., 2011) and especially the amount of MVPA (Cliff & Okely, 2007), and thereby also the relationship between gross motor skills and PA. In contrast, the neuromuscular-based method as used in the present study examines the raw data in real time in a simple histogram style. Together, the two analysis methods can provide comprehensive interpretation of the amount and quality of objectively measured PA.

In this study, PA measurements were administered at different times of the year and seasonal differences in Finland may affect the total amount of PA (Sääkslahti, 2005), although the methodological comparisons presented remain unaffected. While the gross motor skills measured in this study encompass only a part of the spectrum of coordinative capabilities, both KTK and TCB have been used extensively for assessing gross motor skills in children (Iivonen et al., 2011; Vandorpe et al., 2011). Also, the sample used in the present study was limited. However, the purpose of the research was to examine the relations between habitual PA and gross motor skills in children from a neuromuscular perspective parallel to metabolic perspective, and further research is needed for generalizing the results found by this novel approach.

In conclusion, our study indicates that gross motor skills and accelerometer-derived PA are related in 5–8-year-old children. The result is in line with previous studies examining this relationship based on valid and reliable gross motor assessment and objective PA monitoring (Fisher et al., 2005; Wrotniak et al., 2006; Williams et al., 2008; Burgi et al., 2011). The novel neuromuscular-based accelerometer signal analysis method found significant relations between high neuromuscular impacts and gross motor skills in preschool and primary school girls. The results of the present study suggest that in addition to the mean level of PA, even short activities inducing high loads may be important for enhancing gross motor proficiency in children, and in girls especially.

Perspectives

The decline of habitual PA from childhood to adolescence requires understanding of factors attenuating this trend. Motor skills in children have been shown to play an important role in encouraging and enabling maintenance of PA (Barnett et al., 2009; Lopes et al., 2011) and health-related fitness level later in life (Barnett et al., 2008b). Adequate motor skills are needed for participating in age-related physical activities, and thereby forming a positive circle to healthy lifestyle (Stodden et al., 2008; Hands et al., 2009). The present data support the evidence of association between gross motor skills and habitual PA in children, and also give a novel insight of this relationship. In the light of gross motor development, girls could especially benefit from PA including high neuromuscular impacts, even if they were transitory in nature. The neuromuscular perspective of gross motor development should be considered when PA recommendations for children are given. By taking the features of motor development comprehensively into account, practitioners and educators can have more concrete foundation to support growth and maturation through physical education.

Key words: physical activity, motor abilities, motor skill assessment, young children, elementary school children, accelerometry.

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