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Associations of fitness, motor competence, and adiposity with the indicators of physical activity intensity during different physical activities in children

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We investigated the associations of peak oxygen uptake (VO_{2peak}), ventilatory threshold (VT), muscle strength, motor competence (MC), and adiposity with the indicators of PA intensity during different physical activities used to create absolute PA intensity cut-offs among 35 children 7–11-years-of-age. VO_{2peak} was defined as the highest VO_2 achieved in the maximal cardiopulmonary exercise test (CPET) on a cycle ergometer, self-paced running, or running on a treadmill at 8 km/h. VT was defined from the CPET data. Peak isometric knee extensor and flexor strength was assessed by a dynamometer, MC by the Körperkoordination test für Kinder tests, and body composition by the bioelectrical impedance analysis. PA intensity was assessed using VO_2 as a % of $VO_{2reserve}$ or VO_2 at VT, mean amplitude deviation (MAD) measured by accelerometry, metabolic equivalent of task (MET), and muscle activity measured by textile electromyography during walking or running on a treadmill at 4, 6, and 8 km/h, playing hopscotch, walking up and down the stairs, self-paced walking, and self-paced running. Children with lower VO_{2peak} , VO_2 at VT, and MC operated at higher intensity level during given physical task than their peers with higher fitness and MC when PA intensity was expressed using relative PA intensity using VO_2 as a % of $VO_{2reserve}$ or VO_2 at VT ($p < 0.05$). MAD and METs during different tasks were not able to discriminate PA intensity between children with varying levels of physical fitness or MC. Traditionally used absolute measures of PA intensity based on accelerometry or MET underestimated PA intensity in children with lower VO_{2peak} , VO_2 at VT, and MC.

Abbreviations

BF%	Body fat percentage
BMI	Body mass index
BMI-SDS	Body mass index standard deviation score
CHIPASE	Children's physical activity spectrum study
CRF	Cardiorespiratory fitness
EMG	Electromyography
MC	Motor competence
MAD	Mean amplitude deviation
MET	Metabolic equivalent of task
PA	Physical activity
VCO_2	Carbon dioxide production
VO_2	Oxygen uptake
SMM	Skeletal muscle mass
V_E	Minute ventilation
VO_{2peak}	Peak oxygen uptake
VPA	Vigorous intensity physical activity
VT	Ventilatory threshold

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Physical inactivity in childhood has been considered one of the most important public health issues globally¹. Physical activity (PA) has been positively associated with cardiorespiratory fitness (CRF), motor competence (MC), and muscle strength in children and some evidence indicates that vigorous PA has the strongest associations with these outcomes^{2–4}. PA has also been inversely associated with body fat percentage (BF%) in children³. However, to the best of our knowledge, there are no previous studies on the associations of CRF, MC, muscle strength, and adiposity with the indicators of PA intensity in different laboratory tasks, which have been used to create PA intensity cut-offs for the assessment of habitual PA among children^{5,6}. Such information is essential to provide the best evidence to inform PA recommendations and to understand the role of PA in health and wellbeing in children.

Peak oxygen uptake ($\text{VO}_{2\text{peak}}$) refers to the maximal capacity of cardiopulmonary and vascular systems to deliver oxygen to working skeletal muscles and the ability of skeletal muscles to extract oxygen from the blood and use it in aerobic energy metabolism⁷. Therefore, $\text{VO}_{2\text{peak}}$ stands for the highest intensity where energy metabolism can be supported by aerobic energy production and therefore it has been considered the gold standard in the assessment of CRF⁷. However, because children rarely perform activities near their $\text{VO}_{2\text{peak}}$ during their daily lives⁸, VO_2 at ventilatory threshold (VT) has been considered an important submaximal measure of CRF⁹. In exercise physiology, VO_2 at VT has been considered the physiological threshold for vigorous intensity PA (VPA)¹⁰ reflecting the metabolic changes in the skeletal muscle due to elevated lactate concentration during increasing exercise intensity⁹.

$\text{VO}_{2\text{peak}}$ and VO_2 at VT reflects cardiovascular and metabolic capacity to perform daily activities, but several common activities performed by children require sufficient levels of neuromuscular control and capacity, which can be quantified as MC and muscle strength^{11,12}. MC can be defined as the competent and purposeful movement and the ability to flexibly adapt the movement in changing environments¹¹ while muscle strength can be broadly defined as the ability to produce force against an external load¹². Although MC and muscle strength are sometimes considered separate entities, competent performance of various motor tasks requires sufficient levels of muscle strength¹³.

In observational studies PA intensity is often expressed using absolute cut-offs based on metabolic equivalent of tasks (METs) or acceleration magnitude derived from accelerometers¹⁴ and most studies on the associations of PA with CRF, MC, muscle strength, and adiposity have utilised these absolute PA intensity cut-offs^{2–4}. However, these absolute PA intensity cut-offs assess the ability of an individual to reach a certain level of energy expenditure or acceleration without taking into account large interindividual variation in cardiovascular, metabolic, and neuromuscular capacity¹⁴. Furthermore, the absolute cut-offs used in paediatric research has been developed using pre-determined calibration activities, e.g. defining that walking on a treadmill for 6 km/h and walking up and down the stairs reflects moderate intensity PA, without taking individual exercise capacity into account^{5,6}. Therefore, VO_2 as a proportion of $\text{VO}_{2\text{peak}}$ (i.e. $\text{VO}_{2\text{reserve}}$), VO_2 as a % of VO_2 at VT, and muscle activity measured by electromyography (EMG) have been considered recommended methods to express relative PA intensity because they take into account individual variation in exercise capacity^{14–16}.

Previous findings in adults suggest that reaching absolute PA intensity cut-offs may be harder for unfit and overweight and obese adults than for higher fit and normal weight adults^{17,18}. However, relative PA intensity cut-offs set individually using either $\text{VO}_{2\text{reserve}}$ or VO_2 at VT reduce the differences in PA volume between adults with varying levels of $\text{VO}_{2\text{peak}}$ and body mass index^{17,18}. While evaluating PA intensity using $\text{VO}_{2\text{reserve}}$ instead of absolute PA intensity cut-offs is preferred, anchoring PA intensity to VT may provide physiologically more appropriate estimate of PA intensity because VT takes individual physiological responses to exercise into account better than $\text{VO}_{2\text{reserve}}$ ¹⁹.

Children with higher $\text{VO}_{2\text{peak}}$, MC, muscle strength, and lower adiposity have been found to accumulate more moderate-to-vigorous PA than other children in observational studies^{6,8,20}. However, there are no previous studies investigating whether $\text{VO}_{2\text{peak}}$, VO_2 at VT, MC, muscle strength, and adiposity are associated with indicators of PA intensity based on $\text{VO}_{2\text{reserve}}$ or VO_2 at VT during different activities commonly used in accelerometry cut-off validation studies^{5,21}. Furthermore, we are not aware of previous studies in children investigating whether PA intensity assessed by accelerometry or METs during those activities can capture differences in physical fitness or adiposity. We have previously observed that VO_2 as a % of $\text{VO}_{2\text{reserve}}$ and VO_2 at VT varies from 30 to 100% of $\text{VO}_{2\text{reserve}}$ and 50–180% of VO_2 at VT running on a treadmill for 6 and 8 km/h, PA intensities considered moderate and vigorous in previous studies, suggesting remarkable interindividual variation in physiological responses during these absolute treadmill speeds²². Therefore, to better understand and interpret the results of observations studies on the associations of the measures of physical fitness, MC, and adiposity and other health outcomes with PA it is essential to investigate the role of physical fitness, MC, and adiposity in different activities utilised to validate commonly used PA intensity cut-offs.

Our first aim was to investigate the associations of $\text{VO}_{2\text{peak}}$ /kg of skeletal muscle mass (SMM), VO_2 at VT/SMM, MC, muscle strength, and BF% with relative PA intensity quantified as $\text{VO}_{2\text{reserve}}$ and VT during different activities. The second aim was to study whether the associations of $\text{VO}_{2\text{peak}}$ /kg of SMM, VO_2 at VT/SMM, MC, muscle strength, and BF% with mean amplitude deviations (MAD) and METs, which are absolute measures of PA intensity agree with the those of relative PA intensity indicators. For completeness, we also report the associations of $\text{VO}_{2\text{peak}}$ /kg of SMM, VO_2 at VT/SMM, MC, muscle strength, and BF% with muscle activity during different activities measured using EMG.

Methods

This study was based on the laboratory phase of the Children's Physical Activity Spectrum (CHIPASE) study²³. A total of 35 children (21 girls; 14 boys) aged 7–11 years were recruited from local schools and volunteered to participate in the study. Children were included if they were apparently healthy and were able to perform the

physical activities at moderate and vigorous intensities. Children with chronic conditions or disabilities were excluded from the study. The study protocol was approved by the Ethics Committee of the University of Jyväskylä (28.8.2017). All children gave their assents and their parents/caregivers gave their written informed consents. The study was conducted in agreement with the Declaration of Helsinki.

Based on the main research question of the CHIPASE Study, a sample size of 30 was estimated to provide sufficient statistical power for differentiating METs between sitting (1.33 ± 0.24) and standing (1.59 ± 0.37) based on the data of Mansoubi et al²⁴ with 80% power and 5% α -error level.

Study protocol. The participants visited laboratory three times as described previously²². At the first visit, research staff explained the research protocol to children and their parents. They were also familiarised to the laboratory environment and measurement equipment. At the second visit, children arrived at the laboratory in the morning after 10–12 h overnight fast for assessment of anthropometrics, body composition, resting VO_2 , and MC and muscle strength. Children consumed a breakfast after the assessment of resting VO_2 before the assessment of MC and muscle strength. At the third visit, children were asked to perform following activities for 4.5 min in a random order interspersed with 1-min rest: sitting quietly, sitting while playing a mobile game, standing quietly, standing while playing a mobile game, playing hopscotch, walking up and down the stairs, and walking or running on a treadmill at 4, 6, and 8 km/h. They were also asked to walk and run around an indoor track at self-chosen speed for 4.5 min. For the self-paced tasks, children were instructed to perform the tasks at their own comfortable pace without rushing or slowing down (e.g. walk at the same speed as you would walk to school; run at a speed that fits for you and you can run a little longer distance). At the end of the third visit, children performed maximal cardiopulmonary exercise test on a bicycle ergometer. During the third visit, children did not consume snack or beverages during the course of the assessment but they were allowed to drink water at will. During the activities, we confirmed that VO_2 returned near to baseline levels during the 1-min rest²². Children also rested approximately 30 min before the maximal bicycle ergometer test after they had completed other activities. Concurrent recording of VO_2 by portable respiratory gas analyser, movement by triaxial accelerometer, and muscle activity by the textile EMG shorts were conducted during the activities. The activities used in this study have been used in previous calibration studies^{5,21,25} and they also mimic normal daily activities performed by children.

Assessments. *Body size and body composition.* Stature was measured to the nearest 0.1 cm using a wall-mounted stadiometer²². Body mass (BM), SMM, fat mass, fat free mass, and body fat percent were measured by InBody 770 bioelectrical impedance device (Biospace Ltd., Seoul, Korea). A relatively good agreement between SMM assessed by bioelectrical impedance and lean mass assessed by dual-energy X-ray absorptiometry have been reported in children²⁶. Furthermore, we observed a strong correlation between SMM and fat free mass in the present study ($r=0.997$, $p<0.001$). Body mass index (BMI) was calculated by dividing body weight with body height squared and body mass index standard deviation score (BMI-SDS) was computed using the Finnish references²⁷.

Peak oxygen uptake and oxygen uptake at ventilatory threshold. Cardiorespiratory fitness was assessed by a maximal ramp exercise test on an electromagnetically braked Ergoselect 200 K[®] electromagnetic cycle ergometer (Ergoline, Bitz, Germany) as described previously^{22,28}. Shortly, the protocol included 2-min resting period sitting on an ergometer, a 3-min warm-up with a workload of 20 W, and an incremental exercise period with increase of workload either by 1 W/3 s (totalling 20 W/min for children > 150 cm), 1 W/4 s (totalling 15 W/min for children 126–150 cm), or 1 W/6 s (totalling 10 W/min for children ≤ 125 cm) until voluntary exhaustion²⁹. The participants were asked to maintain the cadence at 70–80 during the test. The test was terminated when the participant was unable to keep the cadence of 65 or required to stop. Participants were verbally encouraged to exercise until voluntary exhaustion.

Respiratory gas exchange was assessed directly by breadth-by-breadth method using the metabolic cart from the 2-min resting period sitting on the ergometer until the voluntary exhaustion and were averaged over 15-s periods. We defined peak cardiorespiratory capacity as the highest VO_2 achieved in the exercise test ($\text{VO}_{2\text{peak}}$) averaged over 15 s recorded during the last minute of the exercise test and normalised it for SMM. We normalised $\text{VO}_{2\text{peak}}$ for SMM because it has been suggested that normalising CRF for SMM provides physiologically the most appropriate measure of peak aerobic capacity independent of body size and body composition³⁰. The results remained unchanged when we used fat free mass as a scaling factor. If higher VO_2 was observed during running on a treadmill for 8 km/h or during self-paced running ($N=21$) than during maximal cycle exercise tests ($N=14$), the higher VO_2 value was used as a measure of $\text{VO}_{2\text{peak}}$. Beat-by-beat heart rate (HR) was continuously recorded during the exercise test using Polar H7 HR sensor (Polar Electro, Kempele, Finland).

The cardiopulmonary exercise test was considered maximal if the primary and secondary objective and subjective criteria indicated maximal effort and maximal cardiorespiratory capacity (a plateau of VO_2 regardless of increasing workload, $\text{HR}>85\%$ of predicted, respiratory exchange ratio >1.00 , or flushing and sweating), and the exercise physiologist supervising the exercise test considered the test maximal⁷.

VO_2 at VT was determined individually by two exercise physiologists using modified V-slope method³¹ and any disagreements were solved by these two exercise physiologists²². The VT was identified as a time point the increase in VCO_2 is steeper than the increase in VO_2 during the maximal cardiopulmonary exercise test on a cycle ergometer. In determination of VT, we used data averaged over 15 seconds³¹ normalised for SMM. VO_2 at VT was verified utilising the equivalents for V_E/VCO_2 and V_E/VO_2 . According to equivalent method VO_2 at VT was defined as a rate of VO_2 where V_E/VO_2 begins to increase without an increase in V_E/VCO_2 .

Motor competence and muscle strength. A proxy for MC was assessed by the Körperkoordination test für Kinder³². During the assessment, children were asked to (1) walk backwards on balance beams with decreasing widths of 6.0 cm, 4.5 cm, and 3.0 cm, (2) hop for height on one foot at a time, over a pile of soft mattresses (width 60 cm; depth 20 cm; height 5 cm each) with increasing height after each successful attempt, (3) jump sideways from side to side over a thin wooden lath (60 × 4 × 2 cm) on the jumping base (100 × 60 cm), and (4) move sideways with wooden plates (size 25 × 25 cm; height 5.7 cm) without stepping out as quickly as possible for 20 s. We calculated the MC score from the sample specific z-scores by summing-up these four z-scores. A higher MC indicates better MC.

Peak isometric knee extensor and flexor strength was assessed using knee extensor and knee flexion dynamometers (David ltd, Helsinki, Finland). After three submaximal trials, children were asked to maximally extend or flex their knee during the task. Children had three maximal trials. Muscle strength was defined as a mean of the maximal extension and flexion force in Newtons normalised using log-linear allometry for kg of SMM^{1,77}.

Oxygen uptake, accelerometry, and electromyography during different physical activities. *Oxygen uptake.* Mobile metabolic cart (Oxycon mobile, CareFusion Corp, USA) was calibrated and dead space was adjusted to 78 ml for the petite size of the face mask following the manufacturer's recommendations^{22,23}. VO_2 , carbon dioxide production (VCO_2) and respiratory exchange ratio were collected breath by breath and computed in non-overlapping 1 s epoch lengths. Resting VO_2 was determined as the mean value between the 15th and 25th minute of 30 min of supine rest when the steady state was reached³³. When steady state was not observed between 15 and 25th minute, the steady state was visually selected for further analysis. In physical activities, VO_2 was averaged over 2 min from the 3rd and 4th minutes of each task when plateau in VO_2 and VCO_2 was observed^{23,34}. VO_2 reserve as a percentage of $\text{VO}_{2\text{peak}}$ during different physical activities was calculated as $(\text{VO}_2 \text{ during PA task} / \text{VO}_{2\text{peak}} - \text{VO}_2 \text{ during rest}) \times 100$. Metabolic equivalent of task (MET) values were computed as $\text{VO}_2 \text{ measured during the physical activities} / \text{VO}_2 \text{ during supine rest}$.

Accelerometry. Movement was measured by triaxial accelerometer (X6-1a, Gulf Coast Data Concepts Inc., Waveland, USA)²³. We used raw acceleration data in actual g-units with the high range up to 6 g with 16-bit A/D conversion and sampling at 40 Hz. The resultant acceleration of the triaxial accelerometer signal was calculated from $\sqrt{x^2 + y^2 + z^2}$, where x, y and z are the measurement sample of the raw acceleration signal in x-, y-, and z-directions. The X6-1a accelerometer has been shown to produce congruent results with the ActiGraph GT3X accelerometer³⁵. The mean amplitude deviation (MAD) was calculated from the resultant acceleration in non-overlapping 1 s epoch. MAD described as the mean distance of data points about the mean ($\frac{1}{n} \sum_{i=1}^n |r_i - \bar{r}|$ where n is the number of samples in the epoch, r_i is the i th resultant sample within the epoch and \bar{r} is the mean resultant value of the epoch)^{25,35}. The mean of the 1 s MAD values (g) were calculated in the 2 min time epochs for each activity and in 10-min epoch for lying down and are reported as the outcomes corresponding to the steady state intervals of the VO_2 measurements. MAD values derived from the raw acceleration signal have been found to be independent of accelerometer brand and therefore provide an universal method to assess PA intensity across studies and triaxial accelerometry devices²⁵.

Textile electromyography. Textile EMG electrodes embedded into elastic garments were used to assess muscle activity from the quadriceps and the hamstring muscles and has been described in detail previously²³. We have previously showed that day-to-day coefficient variation ranged from 4 to 11% suggesting a good repeatability of textile EMG with a high agreement of textile EMG with a traditional surface EMG³⁶. Four different sizes of EMG shorts (120, 130, 140, and 150 cm) with zippers located at the inner sides of short legs and adhesive elastic band in the hem ensured proper fit in every child. The conductive area of the electrodes over the muscle bellies of the left and the right quadriceps was $9 \times 2 \text{ cm}^2$ (length × width) in all short sizes, while the corresponding sizes for the hamstring muscles were $6 \times 2 \text{ cm}^2$ in sizes of 120, 130, and 140 cm and $6.5 \times 2 \text{ cm}^2$ in size of 150 cm. The conductive area of the reference electrodes was $11 \times 2 \text{ cm}^2$, and they were located longitudinally over the iliotibial band. Water or electrode gel (Parker Laboratories Inc., Fairfield, NJ, USA) was used on the electrode surfaces to minimize the skin–electrode impedance.

In the signal analysis, EMG data were identified from different activities in the certain time windows simultaneously according to the steady state in respiratory gases. Individual EMG activities were normalised channel by channel to EMG amplitude measured during self-paced walking. The normalised EMG data were averaged for quadriceps from right and left side and hamstring muscles from right and left side, then the mean amplitude of the average normalised data was computed as the intensity of muscle activity level for each activity.

Statistical methods. Basic characteristics between girls and boys were compared using Student's t-test for normally distributed continuous variables and Mann–Whitney U-test for skewed continuous variables. We investigated the correlations between $\text{VO}_{2\text{peak}}$, VO_2 at VT, MC, peak isometric strength, and adiposity and VO_2 as a % of VO_2 , VO_2 as a % of VO_2 at VT, MAD, and EMG reserve during different activities using Spearman correlation coefficients. Differences in VO_2 as a % of $\text{VO}_{2\text{reserve}}$, VO_2 as a % of VO_2 at VT, MAD, and EMG among children divided to three equal size groups (thirds) of $\text{VO}_{2\text{peak}}$ normalised for SMM, VO_2 at VT normalised for SMM, MC, peak isometric strength normalised for SMM^{1,77}, and adiposity were investigated using Kruskal–Wallis test. Student's t-test, the Mann–Whitney U-test, and the χ^2 test were performed using the SPSS Statistics, Version 23.0 (IBM Corp., Armonk, NY, USA). The data were visualised and Spearman correlations and Kruskal–Wallis tests were performed by the GraphPad Prism, version 8.0.2 (Graph Pad Software, Inc., San

	All	Girls	Boys	P-value
Age (years) ^a	9.6 (3.0)	9.7 (2.9)	9.6 (2.8)	0.960
Stature (cm)	137.6 (9.2)	135.7 (9.3)	140.4 (8.7)	0.149
Weight (kg)	32.6 (6.9)	30.2 (6.0)	36.2 (6.8)	0.009
BMI (kg/m ²) ^a	16.5 (3.6)	16.1 (2.2)	17.7 (4.8)	0.037
BMI-standard deviation score	- 0.2 (1.2)	- 0.5 (1.1)	0.3 (1.2)	0.052
Fat mass (kg) ^a	4.8 (5.0)	4.2 (4.2)	6.8 (7.5)	0.022
Body fat percentage (%)	16.6 (8.1)	15.7 (7.3)	18.0 (9.3)	0.433
Skeletal muscle mass (kg)	14.0 (2.9)	13.0 (2.5)	15.5 (2.8)	0.009
Resting VO ₂ (mL/min) ^a	153.9 (32.8)	146.4 (26.2)	189.3 (63.9)	0.006
VO _{2peak} (mL/kg of SMM ⁻¹ /min) ^a	103 (17.2)	98.4 (19.8)	103.8 (9.4)	0.576
VO _{2peak} (mL/kg of BM ⁻¹ /min) ^a	44.9 (9.6)	43.8 (11.1)	46.3 (10.2)	0.753
VO ₂ at VT (mL/kg of SMM ⁻¹ /min ⁻¹) on a maximal cycle ergometer exercise test	67.2 (9.8)	69.1 (11.7)	65.8 (5.6)	0.287
Motor competence ^b	0.07 (3.5)	0.38 (3.4)	- 0.37 (3.6)	0.567
Peak isometric knee extensor and flexor strength (Newtons)	78.8 (26.5)	76.5 (25.5)	82.4 (28.8)	0.554
Peak isometric knee extensor and flexor strength (Newtons, sum score)/SMM ^{1.77}	0.7 (0.14)	0.8 (0.1)	0.6 (0.1)	0.009
Peak isometric knee extensor and flexor strength (Newtons, sum score)/kg of body mass	2.4 (0.6)	2.4 (0.6)	2.3 (0.7)	0.586

Table 1. Characteristics of participants. The data are mean (SD) or ^amedian (IQR). VO_{2peak} was defined as the highest VO_{2peak} during running on a treadmill for 8 km/h, self-paced running, or on a maximal cycle ergometer exercise test; VO₂ = oxygen uptake; SMM = skeletal muscle mass. P values refer to statistical significance for differences between girls and boys with statistically significant differences bolded. ^bMotor competence score was computed using the sample specific KTK result z-scores.

	VO _{2peak} /kg of SMM/min	VO ₂ at VT/kg of SMM	Motor competence	Peak isometric strength (N)/SMM ^{1.77}
VO ₂ at VT/kg of SMM	0.370*	-		
Motor competence	0.030	0.140	-	
Peak isometric strength (N)/SMM ^{1.77}	0.340	0.165	0.386*	-
Body fat percentage	- 0.136	0.202	- 0.424*	- 0.040

Table 2. Spearman correlation coefficients between the measures of cardiorespiratory fitness, motor competence, muscle strength, and adiposity. VO_{2peak}/kg of SMM/min = peak oxygen uptake scaled by skeletal muscle mass (SMM); VO₂ at VT/kg of SMM = oxygen uptake at ventilatory threshold scaled by skeletal muscle mass; N = Newtons. **p* < 0.05. Statistically significant associations are given in bold.

Diego, CA, USA). Because of some missing data due to the poor data quality or device malfunction, the sample size in different tasks varied from 29 to 35 participants. Analyses were performed using the maximum number of participants with valid data. Because of the large number of statistical analyses, we utilised Bonferroni correction for multiple testing in the correlation analyses. Correction for multiple testing was performed for each activity intensity indicator. Bonferroni-corrected *p*-values were computed by dividing the *p*-value of 0.05 by the number of variables used in each analysis resulting in the corrected critical value of 0.01.

Ethics approval. The study protocol was approved by the Ethics Committee of the University of Jyväskylä.

Consent to participate. All children gave their assents and their parents/caregivers gave their written informed consents. The study was conducted in agreement with the Declaration of Helsinki.

Results

Basic characteristics and correlations between VO_{2peak}, VT, motor competence, peak isometric strength, and adiposity. Girls were lighter, had lower BMI, and had less fat mass and SMM than boys (Table 1). Girls also had lower resting VO₂ and higher peak isometric strength than boys (Table 1). VO_{2peak} correlated positively to VO₂ at VT. MC correlated negatively to BF% and positively to peak isometric strength (Table 2).

	Treadmill			Climbing up and down the stairs	Playing hopscotch	Indoor track	
	4 km/h	6 km/h	8 km/h			Self-paced walking	Self-paced running
Intensity relative VO₂reserve							
VO _{2peak} /kg of SMM/min	-0.339	-0.480**a	-0.562**a	-0.517**a	-0.655***a	-0.274	0.179
VO ₂ at VT/kg of SMM	-0.121	-0.122	-0.093	-0.508**a	-0.203	-0.125	-0.186
Motor competence	-0.165	-0.269	-0.238	-0.313	-0.088	0.060	-0.052
Peak isometric strength (N)/SMM ^{1.77}	0.009	-0.097	-0.167	-0.317	-0.040	-0.234	-0.234
Body fat percentage	0.228	0.240	0.349	0.489**a	0.211	-0.223	0.106
Intensity relative to ventilatory threshold (VO₂ as % of VO₂ at ventilator threshold)							
VO _{2peak} /kg of SMM/min	-0.140	-0.231	-0.157	-0.325	-0.307	-0.003	0.247
VO ₂ at VT/kg of SMM	-0.508**a	-0.482**a	-0.590**a	-0.699***a	-0.592**a	-0.536**a	-0.688***a
Motor competence	-0.408*	-0.572**a	-0.567**a	-0.406*	-0.341	-0.134	-0.356
Peak isometric strength (N)/SMM ^{1.77}	-0.099	-0.188	-0.157	-0.351	-0.070	0.029	-0.075
Body fat percentage	0.003	0.050	0.149	0.358*	0.124	-0.219	-0.024
Intensity assessed by mean amplitude deviation							
VO _{2peak} /kg of SMM/min	0.157	-0.031	0.115	-0.004	0.078	0.500**a	0.282
VO ₂ at VT/kg of SMM	-0.075	-0.026	0.065	-0.449*	0.116	0.001	0.004
Motor competence	-0.700***	-0.382*	0.577**	-0.117	0.608**	-0.010	0.684***
Peak isometric strength (N)/SMM ^{1.77}	-0.316	-0.105	0.208	-0.281	0.496**	0.235	0.094
Body fat percentage	0.260	0.100	-0.269	-0.032	-0.051	-0.171	-0.409*
Intensity based on metabolic equivalent of tasks							
VO _{2peak} /kg of SMM/min	-0.034	-0.155	0.036	-0.239	-0.203	0.116	0.545**
VO ₂ at VT/kg of SMM	0.023	0.158	0.132	-0.230	0.086	0.067	0.138
Motor competence	-0.265	0.351	-0.085	-0.158	-0.064	0.068	0.163
Peak isometric strength (N)/SMM ^{1.77}	0.087	-0.019	0.225	-0.171	0.144	0.151	0.311
Body fat percentage	0.166	0.107	0.196	0.350*	0.144	-0.239	-0.061
Intensity relative to EMG normalised for EMG measured during self-paced walking							
VO _{2peak} /kg of SMM/min	-0.127	-0.010	-0.168	0.096	0.021	-	0.008
VO ₂ at VT/kg of SMM	-0.203	-0.231	-0.331	-0.376*	-0.234	-	0.127
Motor competence	-0.545**	-0.388*	-0.258	-0.025	0.305	-	0.489*
Peak isometric strength (N)/SMM ^{1.77}	-0.342	-0.264	-0.275	-0.159	0.070	-	0.159
Body fat percentage	0.461**	0.274	0.284	0.102	0.131	-	-0.018

Table 3. Spearman correlations coefficients of cardiorespiratory fitness, motor competence, muscle strength, and adiposity to physical activity intensity in different tasks. VO_{2peak}/kg of SMM/min = peak oxygen uptake scaled by skeletal muscle mass (SMM); VO₂ at VT/kg of SMM = oxygen uptake at ventilatory threshold scaled by skeletal muscle mass; N = Newtons. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Table includes both non-corrected and corrected significances. Statistically significant non-corrected associations are given in bold. ^aStatistically significant after the Bonferroni correction.

Correlations of VO_{2peak}/VT, motor competence, peak isometric strength, and adiposity with the indicators of physical activity intensity in different tasks. *Peak oxygen uptake.* VO_{2peak} correlated negatively with VO₂ as % of VO_{2reserve} during walking or running on treadmill for 6 and 8 km/h, climbing up and down the stairs and during playing hopscotch (Table 3). Higher VO_{2peak} was associated with higher MAD during self-paced walking and METs during self-paced running. The effect of correction for multiple testing using the Bonferroni correction is demonstrated in Table 3.

VO₂ at ventilatory threshold. VO₂ at VT was inversely associated with VO₂ as % of VO_{2reserve} during climbing up and down the stairs (Table 3). Higher VO₂ at VT was associated with lower VO₂ as % of VO₂ at VT during all PAs and lower MAD and EMG during climbing up and down the stairs. The effect of correction for multiple testing using the Bonferroni correction is demonstrated in Table 3.

Motor competence. MC was inversely associated with VO₂ as % of VO₂ at VT during walking or running on treadmill for 4, 6 and 8 km/h, and climbing up and down the stairs (Table 3). Better MC was associated with lower MAD during walking or running on treadmill for 4 and 6 km/h and with higher MAD during running on a treadmill for 8 km/h, playing hopscotch and self-paced running. MC was also inversely associated with EMG during walking or running on treadmill for 4 and 6 km/h and positively associated with EMG during self-paced

running (Table 3). The effect of correction for multiple testing using the Bonferroni correction is demonstrated in Table 3.

Muscle strength. Peak isometric strength was positively associated with MAD during playing hopscotch (Table 3). Peak isometric strength was not associated with any other indicator of PA intensity. The effect of correction for multiple testing using the Bonferroni correction is demonstrated in Table 3.

Body fat percentage. BF% was positively associated with $\text{VO}_2\%$ of $\text{VO}_{2\text{reserve}}$ and VO_2 as % of VO_2 at VT during climbing up and down the stairs (Table 3). BF% was inversely associated with MAD during self-paced running. BF% was also positively correlated to METs during climbing up and down the stairs and to EMG during walking treadmill for 4 km/h. The effect of correction for multiple testing using the Bonferroni correction is demonstrated in Table 3.

Differences in physical activity intensity between thirds. Children in the lowest third of $\text{VO}_{2\text{peak}}$ had higher VO_2 as % of $\text{VO}_{2\text{reserve}}$ during walking or running on a treadmill for 6 km/h ($p=0.024$ for the main effect) and 8 km/h ($p=0.020$ for the main effect), playing hopscotch ($p=0.005$ for the main effect), and climbing up and down the stairs ($p=0.029$ for the main effect) than those in the highest third of $\text{VO}_{2\text{peak}}$ (Fig. 1). The main effect for MET during self-paced running was also significant ($p=0.036$), but post-hoc tests did not reveal statistically significant differences in METs between the thirds of $\text{VO}_{2\text{peak}}$ ($p=0.07$ for difference).

Children in the lowest third of VO_2 at VT operated at higher level relative to their VT during walking or running on treadmill for 4 km/h ($p=0.032$ for the main effect), 6 km/h ($p=0.012$ for the main effect), and 8 km/h ($p=0.007$ for the main effect), playing hopscotch ($p=0.011$ for the main effect), walking up and down the stairs ($p<0.001$ for the main effect), self-paced walking ($p=0.013$ for the main effect), and self-paced running ($p=0.002$ for the main effect) than those in the highest third of VO_2 at VT. Furthermore, children in the middle third of VT operated at higher level relative to their VT than those in the highest third during climbing up and down the stairs.

Children in the lowest third of MC operated at higher level relative to their VT than children in the highest third of MC during walking or running on a treadmill for 6 km/h ($p=0.039$ for the main effect). Moreover, children in the middle third of MC operated at higher level relative to their VT during playing hopscotch than those in the highest third ($p=0.022$ for the main effect). The main effect of MC for VT was significant ($p=0.048$ for the main effect) for 8 km/h, but post-hoc tests showed no statistically significant differences between thirds ($p=0.054$ for difference). Children in the lowest third of MC had higher MAD during walking on a treadmill for 4 km/h ($p=0.001$ for the main effect) and lower MAD during running on a treadmill for 8 km/h ($p=0.015$ for the main effect), playing hopscotch ($p=0.001$ for the main effect), and self-paced running ($p=0.005$ for the main effect). Children in the lowest third of MC had also higher MAD during playing hopscotch than those in the middle third of MC.

Discussion

We found that children with lower $\text{VO}_{2\text{peak}}$ and VO_2 at VT operated at higher intensity level during given physical activity than their peers with higher fitness. We also observed that children with better MC operated at lower intensity level relative to their VT. Despite the significant differences in the indicators of relative PA intensity between children with lower and higher $\text{VO}_{2\text{peak}}$, VO_2 at VT, and MC, the associations of $\text{VO}_{2\text{peak}}$, VO_2 at VT, and MC with MAD and METs during different tasks were weak and inconsistent. Therefore, these results suggest that absolute MAD and METs were not able to discriminate physiological strain between children with lower and higher fitness and MC. These results are in line with previous findings in adults showing that higher fit individuals can reach absolute PA intensity cut-offs more easily than lower fit individuals^{17,20}.

We found that children with higher $\text{VO}_{2\text{peak}}$ and VO_2 at VT operated at lower level relative to their maximal physiological capacity, than those with lower $\text{VO}_{2\text{peak}}$ and VO_2 at VT during most PA tasks. Nevertheless, we found no statistically significant differences in MAD and METs measured during different PA tasks between children in the thirds of $\text{VO}_{2\text{peak}}$ and VO_2 at VT. Furthermore, previous studies have shown large differences in moderate-to-vigorous PA between lower and higher fit adults when PA intensity was based on absolute cut-offs^{17,18}. Nevertheless, those differences reduced remarkably when PA intensity was related to individual exercise capacity^{17,18}. Furthermore, most studies providing the absolute acceleration magnitude cut-offs for PA intensity in children have used pre-determined calibration tasks to define PA intensity. In those studies walking on a treadmill for 4 km/h has been considered light PA, running on treadmill for 6 km/h, walking up and down the stairs playing hopscotch, and walking around an indoor track on self-chosen speed as moderate PA, and running on a treadmill for 8 km/h and running around an indoor track on self-chosen speed as vigorous PA^{5,6}. Therefore, these results together suggest that absolute acceleration magnitude cut-offs penalise children with lower fitness level and may cause bias on the association of PA with $\text{VO}_{2\text{peak}}$ and VO_2 at VT.

Children with higher $\text{VO}_{2\text{peak}}$ achieved higher MET values during self-paced running although there were no differences in proportion of $\text{VO}_{2\text{reserve}}$ during self-paced running between children in the thirds of $\text{VO}_{2\text{peak}}$. Similarly, $\text{VO}_{2\text{peak}}$ was positively associated with MAD during self-paced walking whereas we observed no differences in % of $\text{VO}_{2\text{reserve}}$ during self-paced walking between children with varying levels of $\text{VO}_{2\text{peak}}$. These results suggest that children with higher $\text{VO}_{2\text{peak}}$ walk and run faster at self-chosen speed, causing higher MAD and MET values. Furthermore, we did not observe other statistically significant associations of measures of physical fitness with METs in any other tasks indicating that absolute PA intensity increases at similar manner in lower and higher fit children. We also found that while higher fit children operated at lower level relative to their cardiovascular and metabolic capacity in several activities commonly used in accelerometry cut-off calibration

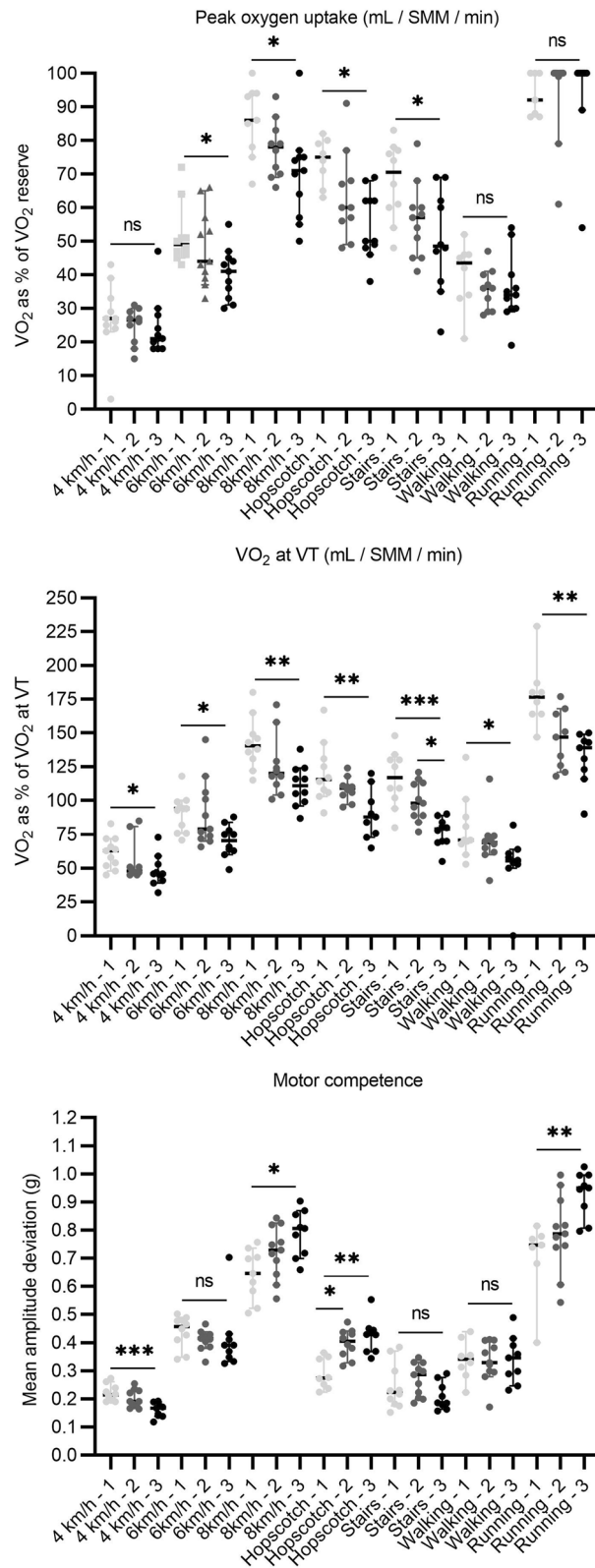


Figure 1. Differences in the different measures of physical activity intensity indices among the thirds of measures physical fitness and motor competence. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, ns = statistically insignificant. VO₂ = oxygen uptake, VT = ventilatory threshold.

studies, METs were not able to differentiate these differences between children. Therefore, our results together with others^{17,18,20}, suggest that absolute MAD and MET values may underestimate PA in lower fit children because reaching absolute cut-offs requires more effort from them than from higher fit children.

MC was inversely associated with VO_2 at VT during walking and running tasks, but similar associations were not found when PA intensity was assessed by MAD and METs. In contrast, children with better MC achieved higher MAD values during running on a treadmill for 8 km/h, playing hopscotch, and self-paced running than those with lower MC although MC was inversely associated with VO_2 relative to VO_2 at VT. These results suggest that children with higher MC can operate lower relative intensity level at a certain task than those with lower MC. In addition, accelerometry may underestimate PA intensity in children with lower MC especially in tasks considered vigorous. Finally, we found negative association patterns between MC and PA intensity defined by proportion of EMG normalised for self-paced walking at lower gait speeds suggesting that relative muscle activity is lower in children with better MC than their less competent peers. Similar association pattern was found between MC and MAD. Because we observed that MC was not associated with $\text{VO}_{2\text{peak}}$ or VO_2 at VT, the lower PA intensity at a certain task in children with better MC compared to those with lower MC could not be solely explained by their fitness level. Therefore, more efficient movement patterns and step frequency in children with better MC may explain these findings.

Partly in contrast with previous studies in adults^{17,20}, we found few and weak associations between adiposity and the measures PA intensity in different physical activities. Nevertheless, children with higher BF% operated at higher intensity level assessed by VO_2 as % of $\text{VO}_{2\text{reserve}}$, VO_2 as % of VO_2 , and MAD during climbing up and down the stairs. One reason for these partly contrasting findings may be that our sample was relatively lean. It is possible that inert load caused by excess fat mass would have caused different responses in a sample with more overweight and obese children. Furthermore, climbing up and down the stairs may be demanding activity for those with higher adiposity because the need to carry inert fat mass. However, these findings need to be confirmed in other populations.

Most observational studies using accelerometry providing evidence on the associations of PA with CRF, MC, muscle strength, and adiposity have used absolute intensity cut-offs and therefore estimated an ability of an individual to operate at certain absolute intensity level¹⁴. Our results suggest that absolute MAD and MET are not able to differentiate true physiological strain, which could cause remarkable misclassification of PA intensity. Therefore, the use of absolute PA intensity cut-offs in previous studies showing positive associations between PA, CRF, and MC may have clouded our understanding on the role of CRF and MC in PA and vice versa. Therefore, it seems that these previous results are partly due to the fact that higher fit and motorically more competent children reach absolute cut-offs more easily than other children. These results are supported by few studies in adults^{17,18}.

The strengths of the present study include a valid and simultaneous assessment of VO_2 , accelerometry, and EMG during physical activities. We also assessed of $\text{VO}_{2\text{peak}}$ and VT, muscle strength, MC, and adiposity using valid methodology. However, $\text{VO}_{2\text{peak}}$ and VT were assessed during a maximal cycle ergometer test and $\text{VO}_{2\text{peak}}$ was adjusted using the data from treadmill running or self-paced running if higher VO_2 was observed during those tasks. Therefore, it is possible that we have underestimated true $\text{VO}_{2\text{max}}$ in some participants and this may have had a minor effect on $\text{VO}_{2\text{reserve}}$ estimation. We also determined VT in the maximal cardiopulmonary exercise test on a cycle ergometer. VT assessed during cycling may not be directly comparable that of measured during running, but the evidence is still equivocal³⁷. Furthermore, relatively small sample size precluded further analyses to investigate whether the observed associations would be similar in different age or maturation groups. However, because it is common in large scales studies to utilise a single absolute accelerometry cut-off in a sample of children and adolescents with large age-range^{38–42}, our results can be used to inform further analyses and interpretation of the results of such studies. Finally, the relatively large number of analyses increases the possibility of false positive findings.

In conclusions, we found that MADs and METs as measures of PA intensity underestimated PA intensity in children with lower $\text{VO}_{2\text{peak}}$, VO_2 at VT, and MC. More research is warranted to develop better methods to assess PA and to take into account these individual characteristics.

Data availability

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

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Author contributions

E.H., Y.G., and T.F. conceived and designed the experiments. Y.G. performed the experiments. E.A.H., Y.G., and T.R. analysed the data. E.A.H. wrote the first draft of the manuscript. Y.G., J.H., T.R., and T.F. revised it critically for important content. All authors approved the final draft of the manuscript submitted for review and publication.

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Competing interests

The authors declare no competing interests.

Additional information

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