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ORIGINAL ARTICLE

# Calibration of GENEActiv accelerometer wrist cut-points for the assessment of physical activity intensity of preschool aged children

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**Abstract** This study sought to validate cut-points for use of wrist-worn GENEActiv accelerometer data, to analyse preschool children's (4 to 5 year olds) physical activity (PA) levels via calibration with oxygen consumption values ($VO_2$). This was a laboratory-based calibration study. Twenty-one preschool children, aged 4.7 ± 0.5 years old, completed six activities (ranging from lying supine to running) whilst wearing the GENEActiv accelerometers at two locations (left and right wrist), these being the participants' non-dominant and dominant wrist, and a Cortex face mask for gas analysis. $VO_2$ data was used for the assessment of criterion validity. Location specific activity intensity cut-points were established via receiver operator characteristic curve (ROC) analysis. The GENEActiv accelerometers, irrespective of their location, accurately discriminated between all PA intensities (sedentary, light, and moderate and above), with the dominant wrist monitor providing a slightly more precise discrimination at light PA and the non-dominant at the sedentary behaviour and moderate and above intensity levels (area under the curve (AUC) for non-dominant = 0.749–0.993, compared to AUC dominant = 0.760–0.988).

*Conclusion*: This study establishes wrist-worn physical activity cut-points for the GENEActiv accelerometer in preschoolers.

**What is Known:**
- *GENEActiv accelerometers have been validated as a PA measurement tool in adolescents and adults.*
- *No study to date has validated the GENEActiv accelerometers in preschoolers.*

**What is New:**
- *Cut-points were determined for the wrist-worn GENEActiv accelerometer in preschoolers.*
- *These cut-points can be used in future research to help classify and increase preschoolers' compliance rates with PA.*

**Keywords** Preschoolers · Physical activity · GENEActiv accelerometers · Calibration

## Abbreviations

| | |
|---|---|
| AUC | Area under the curve |
| MET | Metabolic equivalents |
| PA | Physical activity |
| REE | Resting energy expenditure |
| ROC | Receiver operating characteristics |
| Se | Sensitivity |
| Sp | Specificity |
| SPSS | Statistical Package for Social Sciences |
| SVMgs | Signal magnitude vector |
| $VCO_2$ | Carbon dioxide output |
| $VO_2$ | Oxygen consumption |

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## Introduction

Physical activity (PA) during preschool years is critical to child development, health and well-being [1, 7]. However, habitual PA is declining and sedentary behaviour becoming more dominant in the preschool population [11]. Objective monitoring of PA via accelerometry provides a useful means to accurately quantify PA behaviour [26]. However, few studies have used accelerometry in preschoolers; therefore, this topic requires additional scrutiny.

Assessing PA in very young children is problematic [9]. Accelerometers are widely used to measure PA in public health research [24] and have been validated to assess PA and sedentary behaviour with paediatric populations. Therefore, the use of accelerometers with children is not novel, although fewer studies examine accelerometer data in younger children (<5 years old). The GENEActiv waveform triaxial accelerometer (ActivInsights Ltd., Cambridge, UK) is a recently developed accelerometer. It is lightweight (16 g), small (43 mm × 40 mm × 13 mm) and collects data on three axes (vertical, anteroposterior and mediolateral) at a rate of up to 100 Hz.

Although the GENEActiv accelerometer has been validated as a PA measurement tool [8], few studies have examined its utility with paediatric samples and none have calibrated its use in preschoolers. Phillips [16] have validated cut-points for sedentary, light, moderate and vigorous PA using the GENEActiv accelerometers; for 8–14 year olds and recently, Duncan [6] cross-validated these cut-points for 5–8 year olds. Whilst the validity of the GENEActiv accelerometer is unlikely to change in preschoolers, the development of preschool population specific cut-points for the GENEActiv accelerometer is crucial to better quantify PA.

Estimating energy expenditure (EE) from PA involves assigning activities an intensity level; metabolic equivalent (MET) values are a way of achieving this [21]. A MET is defined as the EE required when sitting quietly and is equivalent to resting energy expenditure (REE) (3.5 mL $kg^{-1}$ $min^{-1}$) [2]. Indirect calorimetry has been employed to determine MET values and to establish accelerometer cut-points in children [6, 10, 12]. Research has shown that when calculating EE in preschoolers, it is essential to be aware that published adult METs are lower than estimated child METs using breath-by-breath oxygen consumption ($VO_2$) data (bias = −0.03 METs) [18]. Specifically, REE is greater in children than adults [10] to the extent that energy costs may be underestimated by almost 40% when using adult METs; therefore, adult METs should not be used for children [22]. Mackintosh [10] suggested using an estimate of daily resting metabolic rate (RMR), calculating daily EE and an equation to provide a child MET. Saint-Maurice [20] suggested that an adjusted child REE of 1.33 adult-METs should be used (~2 METs) for classifying sedentary activities in children as it improves the classification accuracy of sedentary activities. Reilly [17] also reported that REE was equivalent to 1.9 adult METs for 4–6 year olds. Whilst sedentary activities in children are better characterised by adult-MET values that are greater than 2 [10].

This study sought to calibrate GENEActiv cut-points for the accelerometers when worn at the non-dominant and dominant wrists, of children aged 4–5 years, for assessment of the intensity of preschooler's PA. To achieve this, the output was calibrated with a criterion measure of PA (indirect calorimetry), which allowed for accelerometer cut-points to be determined for sedentary, light and moderate and above PA for preschoolers.

## Methods

### Participants

Twenty-one preschoolers (13 boys and 8 girls) took part following institutional ethics approval, parental informed consent and child assent. Mean ± SD of age was 4.7 ± 0.5 years old, height 1.1 ± 0.1 m, body mass 19.8 ± 2.8 kg and body mass index (BMI) 16.2 ± 2.2 kg $m^{-2}$. A priori power calculation indicated that a sample of 21 participants was needed. Cohen's [4] *d* compares between dependant measures (matched pairs) and a *d* of 0.5 represents a medium effect size, alpha level of 0.05 at 80% power.

### Anthropometric assessment

Height was measured to the nearest millimeters, in bare feet, using a standard portable stadiometer (Leicester height measure, Leicester, UK). Body mass was measured to the nearest 0.1 kg using portable weighing scales (Tanita scales, Tokyo, Japan); the children were lightly dressed and barefoot. BMI was calculated as kilogram per cubic meter.

### Assessment of physical activity

PA was measured using a GENEActiv waveform triaxial accelerometer (ActivInsights Ltd., Cambridge, UK). The accelerometer measured 1 s epochs at a sample frequency of 87.5 Hz, to enable an accurate assessment of the intermittent activities of preschoolers. A GENEActiv accelerometer was attached, using a watch strap positioned over the dorsal aspect of both the left and right wrist (non-dominant and dominant), midway between the radial and ulnar styloid process. Prior to testing of each participant, all monitors were synchronised with Greenwich Mean Time. The participants wore the accelerometers for the entirety of the testing.

Participants wore a paediatric face mask (Hans Rudolph, Kansas, USA), which was attached using a head strap. Breath-by-breath oxygen consumption ($VO_2$), carbon dioxide expenditure ($VCO_2$) and subsequent determination of EE were analysed using the Metamax 3B analyser (Cortex Bio physik, Leipzig, Germany) via established methods [6, 10, 12] and recognised SI units to validate the cut-points. Respiratory volume was calibrated using a 3-L syringe. The Metamax was calibrated with gases of known concentration (15% oxygen and 5% carbon dioxide), prior to commencing testing, and on every day of data collection thereafter. All testing took place between 9 a.m. and 1 p.m.

On arrival at the laboratory, the participant's height, mass and handedness were recorded. Participants were then familiarised with the equipment that they were to use, specifically the treadmill (Woodway, Wisconsin, USA). Children have inefficient and sporadic gaits, therefore walking at a constant speed, on a treadmill with an indirect calorimeter strapped to them, is not indicative of their normal movement; hence, considerable time was spent familiarising them. The children did not wear a harness; therefore, there was no extra carriage in terms of locomotion. This in-depth familiarisation process, followed similar protocols employed with paediatric samples [6, 10, 12]. After briefing about the testing protocol, participants were fitted with the GENEActiv accelerometers and the face mask. Each participant was then asked to perform activities representative of various aspects of preschoolers' daily life. To complete calibration analysis on 4–5 year olds, it was important to start with locomotor activities as they form the predominant activity in an individual's day [25]. The following activities were performed in this study: sedentary activity (lying supine for 5 min); sedentary activity (playing with Lego® for 5 min); light activity (slow walking at 2.5 kph), moderate activity (medium paced walking at 3.4 kph, fast walking at 4.3 kph and running 5.4 kph) on the treadmill, for 4 min at each speed, based on prior validation of walking speeds in 4–5-year-olds [19]. These activities were performed in order as per prior work [16]; at the end of each activity, participants moved straight to the next activity. Similar designs have been used with 8–14 year olds [16] and 10–13 year olds [5]; however, in the present study, pilot data collection identified that walking/running speeds used by Phillips [16] and Crouter [5] were inappropriate for use with 4–5 year olds; therefore, speeds indicated for children were used [16]. REE was calculated from the supine condition by removing the first 2.5 min of data and averaging the remaining data. For each activity, the absolute $VO_2$ (L min$^{-1}$), relative $VO_2$ (mL kg min$^{-1}$) and EE (kcal min$^{-1}$) were calculated by removing the first 2.5 min of data and averaging the remaining data. This was because Mackintosh [12] reported that children's EE had reached a steady state after 2.5 min, as was indicated by a plateau in $VO_2$ and $VCO_2$, where values varied less than 15%. $VO_2$ was then converted to EE using the values of 1 L $O_2$ = 4.9 kcal [13]. An estimate of RMR was calculated for each participant using the sex-, age- and mass-specific Schofield-(WH) equation for basal metabolic rate (BMR) (kcal/day) in children for 3–10 years [23]. Child metabolic equivalents (Child METs) were then calculated by dividing the activity EE by the predicted RMR. This approach ensured that the MET values for each activity were at the required intensity. Using the GENEActiv Post Processing software (version 3.1), the raw 80 (87.5) Hz triaxial data were summarised into a signal magnitude vector (gravity-subtracted) (SVMgs), expressed in 1 s epochs [8].

### Statistical analysis

To examine any differences in GENEActiv values at the non-dominant and dominant wrist, a series of paired *t* tests were used for each activity. To establish cut-points for the GENEActiv accelerometers, the $VO_2$'s for each activity were converted into child-specific METs as previously mentioned. METs and $VO_2$ (L min$^{-1}$) were all normally distributed apart from the medium walk. When two outliers were removed all $VO_2$ (L min$^{-1}$) were normally distributed according to the Shapiro-Wilk and Kolmogorov-Smirnov tests. The activities were then coded into one of the three intensity categories: sedentary (<2 METs), light (2–2.99 METs) and moderate (3–5.99 METs) as employed by Phillips [16] and Saint-Maurice [20]. On examination, playing with Lego® was equivalent to sedentary activity, walking at a slow speed was equivalent to light activity and walking at medium and fast speeds and running were equivalent to moderate activity. It was not possible for the preschoolers in the current study to run at a speed, for a 4-min period, that was fast enough to be classed as a vigorous (≥6 METs) activity.

Accelerometer counts for the activities were coded into binary indicator variables (0 or 1), as multiple separate analyses were completed, based on the intensity (sedentary versus > sedentary, less than moderate versus moderate) allowing receiver operator characteristic (ROC) curve analysis to be performed and the calculation of sensitivity (Se) and specificity (Sp) as described by Esliger [8]. Therefore, the cut-points are indicative of moderate intensity and above. The cut-points were selected to maximise both sensitivity (correctly identifying at or above the intensity threshold) and specificity (correctly excluding activities below the threshold for intensity). These ROC curves allow for the determination of cut-point scores [15]. ROC analysis was undertaken using the Statistical Package for Social Sciences (SPSS) (version 22, SPSS Inc., Chicago, Ill, USA).

## Results

Table 1 shows the mean and SD of the accelerometer data for each activity. The increases in accelerometer output corresponded with an increase in the intensity of the activity for the GENEActiv on both the non-dominant and dominant

**Table 1** Accelerometer output and METs for the preschoolers by activity. Data represent mean and SD

| Lying | | Lego ® | | Slow walk (2.5 kph) | | Moderate walk (3.4 kph) | | Fast walk (4.3 kph) | | Running (5.4 kph) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| GENEA non-dominant hand | | | | | | | | | | | |
| 2.15 | 1.02 | 4.86 | 1.49 | 11.13 | 6.44 | 12.24 | 7.02 | 16.13 | 8.49 | 26.89 | 13.55 |
| GENEA dominant hand | | | | | | | | | | | |
| 2.04 | 0.93 | 5.25 | 1.33 | 10.84 | 6.35 | 12.33 | 6.61 | 15.31 | 8.15 | 23.53 | 13.48 |
| METs | | | | | | | | | | | |
| 1.61 | 0.29 | 1.96 | 0.33 | 2.70 | 0.50 | 3.12 | 0.46 | 3.71 | 0.50 | 4.57 | 0.56 |

wrist. There were no significant differences between the non-dominant and dominant wrist GENEActiv data ($P > 0.05$).

Activity intensity cut-points were established via the ROC curve analysis, for the GENEActiv accelerometers worn at both the non-dominant and dominant wrist; the area under the curve (AUC) and the 95% confidence intervals are also included (Table 2). Cut-points for the preschoolers are presented as gram per second in Table 2. ROC curve analysis showed that GENEActiv accelerometers at both locations could discriminate between the different intensity levels. However, the non-dominant wrist monitors gave a marginally more precise discrimination at the sedentary behaviour and moderate and above PA and the dominant wrist monitors at the light PA levels (AUC for non-dominant = 0.749–0.993; AUC dominant = 0.760–0.988). With regard to the different intensities, AUC was the largest for sedentary behaviour, irrespective of location, making it easier to classify (0.993 non-dominant and 0.988 dominant). Analyses in the present study indicated that there was improved accuracy in the classification of sedentary behaviour at both the non-dominant and dominant wrists (non-dominant: Se = 90%, Sp = 90%, dominant = Se 100%, Sp = 10%). This shows, for this sample, that 90% of the data points for the non-dominant wrist fell into the classification of sedentary and 100% for the non-dominant wrist; this indicated a high number of true positives for both wrist monitors. This was not the same for the non-dominant wrist in light PA or the dominant wrist for light, and moderate and above PA. The energy costs of the activities are shown in Table 3.

## Discussion

This study is the first to calibrate PA cut-points for the GENEActiv, wrist-worn accelerometer in preschoolers. This study contributes to the literature and provides important information that can be used to better classify sedentary behaviour, light and moderate PA in preschoolers. Unfortunately, the preschoolers in this study were unable to exercise at a vigorous intensity on the treadmill equivalent to that established by Phillips [16], highlighting the demands of exercise testing in this population. However, the classification of moderate and above intensity PA is appropriate for this population in respect to assessing whether preschoolers meet the recommended 180 min PA guidelines per day [3].

The research design assumed that playing with Lego® would be classed as a sedentary activity. The term "sedentary" is typically defined by both low EE (resting metabolic rate) and a sitting or reclining posture [14]. Lego® in this study was classed as sedentary, with a MET value of 1.9 ± 0.3; however, it was at the top end of the sedentary category. There is evidence that suggests predominantly sedentary activities such as seated play and crafts can be light intensity in preschoolers, but would be sedentary in older children and adults [24]. This data demonstrates that playing with Lego® was classified as sedentary behaviour, yet very close to being light activity for these preschoolers as stated by Vale [24].

The EE (kcal min$^{-1}$) and EE (Child MET) values increased with increasing activity intensity and GENEActiv accelerometer counts. The MET values for the moderate walk (3.1 ± 0.5 METs), fast walk (3.7 ± 0.5 METs) and run (4.6 ± 0.6 METs) were all in the moderate and above intensity classification, suggesting that these activities were expending similar energy. The MET costs of activities, playing Lego® through to running, were all calculated using child MET values in this study. This was appropriate as MET costs are influenced by age [18] and the MET values reported in this study increased as the intensity of the exercise increased, suggesting that the MET values used in this study were suitable to identify levels of PA.

ROC curve analysis showed that the GENEActiv accelerometer at both the non-dominant and dominant wrist can distinguish between sedentary behaviour, light, and moderate PA, similar, to research performed on 8–14 year olds [16]. The cut-points determined in this study are location specific for the non-dominant and dominant wrists. Although comparable, they were lower than those previously reported at the wrist, for 8–14 year olds for sedentary behaviour, light and moderate and above PA intensities [16]. This difference, supports the relevance of, and need to, calculate specific cut-points for different age categories.

In this present study, a fixed order of activities was followed which went from sedentary to running. This may have been

**Table 2** Sensitivity, specificity, area under the curve and resultant cut-points for activities undertaken by preschool children assessed via GENEA accelerometer

| Intensity | Sensitivity (%) | Specificity (%) | Area under the ROC curve (95% CI) | Cut-points (gram per second) |
|---|---|---|---|---|
| Non-dominant | | | | |
| Sedentary | 90 | 90 | 0.993 (0.98–1.0) | *<5.3* |
| Light | 40 | 20 | 0.749 (0.65–0.85) | *5.3–8.6* |
| Moderate and above | 86 | 40 | 0.917 (0.86–0.98) | *>8.6+* |
| Dominant | | | | |
| Sedentary | 100 | 10 | 0.988 (0.97–1.0) | *<8.1* |
| Light | 10 | 85 | 0.760 (0.66–0.86) | *8.1–9.3* |
| Moderate and above | 76 | 40 | 0.898 (0.83–0.96) | *>9.3* |

a limitation due to the more sporadic nature of preschoolers' daily movement patterns. Children are reported as having a higher oxygen cost during weight-bearing activities, which is possibly a result of their 'wasteful' gait during walking and running [23], due to their higher stride frequency as they have shorter limbs. Therefore, assessing different activities, for example weight-bearing and free-living activities may produce varied results. Additionally, there may have been the possibility, although unlikely, of an order effect where fatigue from earlier activities could have influenced later activities [6]. Finally, as the preschoolers moved from one station to another, it may be appropriate to readdress the 'transition' time for future research to prevent any carry-over effect in the oxygen uptake between activities. However, as this present study measured $VO_2$ by removing the first 2.5 min of data and averaging the remaining data of an activity [12], it is likely that the measurements of EE reflected steady-state conditions in the various activities involved.

The results of the present study showed relatively poorer performance for the light cut-points than any other PA intensity when referring to the AUC (non-dominant = 749; dominant = 760). This may be because there is reported to be greater 'noise' in light PA intensity levels for younger children, making it more difficult to differentiate from sedentary activities [24]. As children spend a large percentage of their time in light PA, there is the need to better classify this intensity using the GENEActiv accelerometers to avoid any misreporting of PA intensities; this is supported by Duncan [6].

The present study successfully used accelerometry to create a new way of objectively distilling PA counts into meaningful units for preschoolers; however, some limitations should be considered. Recruiting 4–5-year-old children, and subsequently using indirect calorimetry whilst exercising, was challenging and more time-consuming than if older children or adults were the population. This resulted in a relatively small sample size for the calibration of the new cut-points. Secondly, the data did not show a greater skew towards either the non-dominant or dominant hand, as the non-dominant was more accurate in determining sedentary and moderate and above PA and the dominant light PA. In this current study, none of the activities required the use of one hand more than the other; however, it was not noted if the children did favour one hand more than the other in the activities.

It would be beneficial for future research to cross validate the cut-points reported here, with an independent sample and evaluate their efficacy in a free-living environment than the laboratory based, predominantly ambulatory activities used in this study.

**Table 3** Energy expenditure of sedentary and active behaviours

| | $O_2$ uptake (L min$^{-1}$) | | O2 uptake (mL kg$^{-1}$ min$^{-1}$) | | EE (kcal min$^{-1}$) | | EE (child METs) | |
|---|---|---|---|---|---|---|---|---|
| | Mean ± SD | Min–max | Mean ± SD | Min–max | Mean ± SD | Min–max | Mean ± SD | Min–max |
| Rest | 0.22 ± 0.04 | 0.16–0.28 | 11.2 ± 2.1 | 7.5–14.1 | 1.09 ± 0.2 | 0.77–1.38 | 1.6 ± 0.3 | 1.3–2.1 |
| Lego | 0.27 ± 0.05 | 0.20–0.38 | 13.6 ± 2.2 | 9.1–18.5 | 1.32 ± 0.24 | 0.98–1.88 | 1.9 ± 0.3 | 1.5–2.7 |
| Slow walk | 0.37 ± 0.09 | 0.25–0.57 | 18.7 ± 3.5 | 13.1–23.6 | 1.83 ± 0.42 | 1.21–2.82 | 2.7 ± 0.5 | 2.0–3.7 |
| Medium walk | 0.43 ± 0.08 | 0.34–0.66 | 21.7 ± 3.2 | 18–28.1 | 2.11 ± 0.40 | 1.68–3.25 | 3.1 ± 0.5 | 2.7–4.2 |
| Fast walk | 0.51 ± 0.08 | 0.38–0.63 | 25.8 ± 3.9 | 19–34.1 | 2.51 ± 0.41 | 1.88–3.43 | 3.7 ± 0.5 | 2.9–4.4 |
| Run | 0.63 ± 0.09 | 0.44–0.75 | 32.0 ± 4.4 | 24.2–41.3 | 3.07 ± 0.43 | 2.19–3.61 | 4.6 ± 0.6 | 3.5–5.6 |

## Conclusions

The current study developed cut-points for the wrist-worn GENEActiv accelerometer in preschoolers aged 4–5 years. The newly developed cut-points were lower than but broadly comparable to the cut-points previously validated in 8–14 year olds [16]. To conclude, the cut-point for GENEActiv accelerometers when worn at the non-dominant and dominant wrist for preschoolers (4–5 year olds) are as follows: sedentary (non-dominant <5.3 gram per second, dominant <8.1 gram per second), light (non-dominant 5.3–8.6 gram per second, dominant 8.1–9.3 gram per second) and moderate and above (non-dominant >8.6 gram per second, dominant >9.3 gram per second). Therefore, these cut-points can be used in future research to help classify PA; they will help researchers to determine activity levels of preschoolers wearing wrist-based GENEActiv accelerometers. However, any future study using children of different age or ethnicity should estimate new cut-points for their own study population.

**Authors' contributions** Clare Roscoe—conception and design of the study, data acquisition (patients' measurements), analysis of the data, preparation of the tables, preparation of the manuscript, finding relevant references and final approval of the manuscript.

Michael Duncan—conception and design of the study, analysis of the data, preparation of the tables, preparation of the manuscript, finding relevant references and final approval of the manuscript.

Rob James—analysis of the data, preparation of tables and charts, preparation of the manuscript, finding relevant references and final approval of the manuscript.

**Compliance with ethical standards**

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**Ethical approval** All procedures performed in the studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Conflict of interest** The authors declare that they have no conflict of interest.

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