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Calibration of the GENEA accelerometer for assessment of physical activity intensity in children

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Abstract

Objectives: The purpose of the study was to establish activity intensity cut-points for the GENEA accelerometer via calibration with oxygen consumption ($\dot{V}O_2$).
Design: The study was a lab-based validation and calibration study.
Methods: Forty-four children, aged 8–14 years, completed eight activities (ranging from lying supine to a medium paced run) whilst wearing GENEA accelerometers at three locations (each wrist and at the right hip), an ActiGraph GT1M at the hip and a portable gas analyser. ActiGraph output and $\dot{V}O_2$ were used for assessment of concurrent and criterion validity, respectively. Pearson's r correlations were used to assess validity of the GENEA monitors at each location and location-specific activity intensity cut-points were established via Receiver Operator Characteristic curve analysis.
Results: The GENEA showed good criterion validity at both wrist locations (right: $r = .900$; left: $r = .910$, both $p < 0.01$), although the hip-mounted monitor demonstrated significantly higher criterion validity ($r = .965$, $p < 0.05$). Similar results were shown for concurrent validity (right: $r = .830$; left: $r = .845$; hip: $r = .985$, all $p < 0.01$). GENEAs, irrespective of wear location, accurately discriminated between all activity intensities (sedentary, light, moderate and vigorous) with the hip mounted monitor recording the largest area under the curve for each intensity (area under the curve = 0.94–0.99).
Conclusions: The GENEA can be used to accurately assess children's physical activity intensity when worn at either the wrist or the hip.

Keywords: Activity intensity; Cut-points; Wrist worn; ActiGraph; Physical activity

1. Introduction

The use of accelerometers to assess children's physical activity is by no means novel, and multiple devices have been validated for use within a child population, such as the Actical (Mini Mitter, Bend, OR, USA), the ActiGraph (ActiGraph, Pensacola, FL, USA) and the RT3 (Stayhealthy.com, Monrovia, CA, USA). Previous research has suggested that seven days of activity monitoring is optimal for a reliable estimate of habitual physical activity.[1] However non-compliance resulting in a significant reduction of data is well documented[2–4] and is thought to arise as most accelerometers are attached to a belt worn around the waist making it necessary to remove the monitor when changing clothes, sleeping and participating in some activities, e.g. contact sports, formal occasions.[5] Non-compliance may also arise from children removing the monitor by choice (e.g. for physical comfort or social acceptance) or by necessity for water based activities (e.g. showering or swimming).[3] Some monitors are also unable to record high resolution data for long periods of time, due to limited battery and memory capacity.[6]

In an attempt to combat these problems, the GENEA waveform triaxial accelerometer was developed (Unilever Discover, Colworth, UK; manufactured and distributed by ActivInsights Ltd., Kimbolton, Cambridge, UK). This lightweight (16 g), small (L36 mm × W30 mm × H12 mm) accelerometer collects data in three axes (vertical,

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anteroposterior and mediolateral) at a rate of up to 80 Hz (with the most recent model, the GeneActiv, recording at up to 100 Hz); it is designed to be worn on the wrist and is waterproof. It is hypothesised that the latter two qualities largely negate the need to remove the monitor and thus may lead to greater compliance during assessment of habitual activity in children.

The GENEA has been found to have high intra and inter-instrument reliability (coefficient of variation = 1.8% and 2.4%, respectively), good criterion-referenced validity when compared to a multi-axis shaking table (MAST; Instron Structural Testing Systems, Buckinghamshire, UK) ($r = .97$) and high concurrent validity with the ActiGraph GT1M ($r = .74$).[6] Esliger et al.[6] also found that, irrespective of whether the monitor was worn at the hip or the left wrist, the GENEA could be used to distinguish between sedentary, light, moderate and vigorous intensity activities in adults. This study goes some way to providing support for the GENEA worn at the wrist, however, if this monitor is to be used in child based studies a separate validation and calibration needs to be undertaken within this specific population.

The purpose of the present study therefore was to develop physical activity intensity cut-points for use with the GENEA when assessing the intensity of children's physical activity. To achieve this, the output was calibrated with a criterion measure of physical activity (indirect calorimetry) allowing accelerometer output cut-points to be established for sedentary, light, moderate and vigorous physical activity for use with children. Additionally, concurrent validity of the GENEA, relative to the ActiGraph, was investigated.

2. Methods

An opportunistic sample of 44 apparently healthy children ($n = 26$ females, $n = 18$ males) aged between 8 and 14 y ($\bar{X} = 10.9 \pm 1.9$) from Devon, UK were recruited for the present study. Children had a mean height of 150.3 cm (±13.0), mass of 41.8 kg (±10.9), body mass index (BMI) of 18.3 kg m^{-2} (±2.8) and waist circumference of 64.0 cm (±8.3). Participants peak $\dot{V}O_2$ ranged from 27.9 ml kg^{-1} min^{-1} to 58.4 ml kg^{-1} min^{-1} ($\bar{X} = 41.6 \pm 7.7$). The Ethics Committee at the University of Exeter granted approval for the study. Prior to data collection, parental informed written consent and the children's assent were obtained.

Participants wore GENEA monitors at three locations; one at each wrist, secured using a watch strap, and one at the right hip (positioned along the mid clavicle line). The GENEA has been described in detail elsewhere.[6,7] An ActiGraph GT1M was also worn adjacent to the hip mounted GENEA. The GENEA and ActiGraph were set to record at 80 Hz and 1 s epochs, respectively. Prior to testing of each participant, all monitors were synchronised with Greenwich Mean Time (GMT). Throughout the testing procedure, $\dot{V}O_2$ and $\dot{V}CO_2$ were measured using the Cosmed K4b2 gas analyser (Rome, Italy). Participants wore a junior face mask, head net and harness. The K4b2 was calibrated with gases of known concentration, prior to commencing testing and on every day of data collection thereafter. The K4b2 has previously been shown to be a valid measure of oxygen uptake.[8] Upon completion of the protocol, each participant's accelerometer and calorimetry data was downloaded and stored on a computer.

Upon arrival at the laboratory, the participant's height (cm), seated height (cm), mass (kg), body fatness assessed using bio-electrical impedance analysis (BIA) (Tanita, TBF-305 scales, Tanita UK Ltd., Middlesex, UK), waist circumference (cm) and handedness were recorded. Participants were then familiarised with the equipment being used throughout the study, specifically the treadmill (PPS 55 MED-I; Woodway, Germany) and the Nintendo Wii (Nintendo, Windsor, UK).

After being briefed about the testing protocol, participants were fitted with the multiple accelerometers, a heart rate monitor (Polar Vantage NV; Polar, Finland) and the gas analyser (Cosmed K4b2; Rome, Italy). Each participant was then asked to perform a series of activities representative of various aspects of children's daily activity. These were, lying supine, seated DVD viewing, active computer games (boxing) using a Nintendo Wii, slow walking, brisk walking, slow running and a medium run. All activities were performed for three minutes followed by a 2-min rest, with the exception of lying supine which took place for 10 min. Using the protocol by Puyau et al.[9] as a guideline, walking and running speeds were set at: 4 km h^{-1} for slow walk, 6 km h^{-1} for brisk walk and between 8 and 12 km h^{-1} for running speeds (adjustable according to age and activity).

Using the GENEA Post Processing software (version 1.2.1), the raw 80 Hz triaxial GENEA data were summarised into a signal magnitude vector (gravity-subtracted) (SVM_{gs}) expressed in 1 s epochs [see equation below],[10] as described by Esliger et al.[6] The resulting *SI* units for this outcome variable are g s.

$$SVM_{gs} = \sum \left| \sqrt{x^2 + y^2 + z^2} - g \right|$$

The correction for gravity was undertaken to focus the outcome variable on dynamic rather than static accelerations.[6] This enabled a comparison with the ActiGraph. Subsequently, criterion and concurrent validity were established and activity intensity cut-points created.

A series of group (group 1 = 8–10 y; group 2 = 11–12 y; group 3 = 13–14 y) X activity mixed model ANOVAs were undertaken to establish whether there were significant differences between groups for accelerometer output at each location. Where assumptions of sphericity were violated ($p < 0.05$) the Greenhouse–Geisser (GG) correction factor was applied to adjust the degrees of freedom. Post hoc analysis using a modified Tukey's[11] was then undertaken to establish where any differences lay.

To establish criterion referenced validity, correlations between steady state $\dot{V}O_2$, taken from the final minute of

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each activity, and counts for each monitor (3 GENEAs and ActiGraph; taken from 15 s after start of activity until activity completion) were established for each participant. These correlations were then transformed into Fisher's Zr values, a mean taken and transformed back into a Pearson's *r* value. The same method was used to establish concurrent validity, with the individual correlations between each GENEA monitor and the ActiGraph GT1M. To determine whether validity differed across wearing site, correlations were assessed for significant differences.[12]

To establish cut-points for the GENEA monitors, the $\dot{V}O_2$'s for each activity were converted into METs, using age specific values (1 MET = 5.92 ml kg^{-1} min^{-1} (8–12 boys/8–11 girls) and 4.85 ml kg^{-1} min^{-1} (13–15 boys/12–14 girls)[13]). The activities were then coded into one of four intensity categories: sedentary (<1.5 METs), light (1.5–2.99 METs), moderate (3–5.99 METs) and vigorous (≥6). The accelerometer counts for activities were coded into binary indicator variables (0 or 1) based on intensity (sedentary versus >sedentary, less than moderate versus moderate to vigorous, and vigorous versus <vigorous) in order for a Receiver Operator Characteristic (ROC) curve analysis to be carried out as described in Esliger et al.[6] 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). ROC analysis was undertaken using GraphPad Prism 5 software (Graphpad software, San Diego, USA).

3. Results

Table 1 shows the intensity of each activity performed by participants, given in METs, along with the corresponding accelerometer output. Increases in MET values coincided with an increase in accelerometer output, for both the GENEA and the ActiGraph. The exception to this concerns the computer game activity (Nintendo Wii) where the wrist worn GENEA monitors recorded a high number of counts while the MET values remained relatively low. A series of group X activity mixed model ANOVAs revealed no significant differences for GENEA output between groups across activities for the wrist monitors, however there was a significant interaction for the GENEA hip monitor ($F_{GG(5.774,115.488)} = 2.304$, $p = 0.041$). Similarly, a group X activity interaction was observed for

Table 1
Means and SD for accelerometer output and METs for each group by activity.

	Lying		Sitting		DVD		Wii		Slow walk		Fast walk		Slow run		Medium run	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
GT1M																
Group 1	0.11	0.21	0.18	0.69	0.07	0.25	7.06	10.17	27.57	11.59	60.28	16.55	92.64	27.4	101.35	26.27
Group 2	0.01	0.04	0.009	0.03	0.005	0.013	2.63	7.65	32.53	6.19	68.27	8.33	123.77	20.32	126.47	16.44
Group 3	0.14	0.38	0.09	0.22	0.02	0.06	0.17	0.25	28.67	7.52	63.96	10.63	125.14	25.77	132.29	26.19
Overall	0.09	0.23	0.1	0.46	0.04	0.16	3.82	8.26	29.54	9.15	63.92	13.01	111.38	28.89	118.02	26.6
GENEA right wrist																
Group 1	2.21	0.94	2.97	1.17	2.15	0.94	50.25	28.74	19.81	13.89	27.67	8.29	67.59	24.74	81.79	22.53
Group 2	2.23	0.85	2.01	0.92	1.45	0.81	49.08	31.76	15.78	9.38	21.98	4.42	61.01	13.44	78.51	15.7
Group 3	1.86	0.7	2.24	1.08	1.69	1.11	35.06	15.34	15.52	12.73	19.39	3.1	63.26	14.95	81.39	20.48
Overall	2.13	0.85	2.46	1.13	1.79	0.97	46.05	27.41	17.36	12.12	23.66	6.94	64.26	19.01	80.55	19.44
GENEA left wrist																
Group 1	2.16	0.94	2.99	1.06	1.98	1.1	48.84	29.65	20.41	11.97	29.18	7.14	68.66	21.53	84.57	18.65
Group 2	1.93	0.66	2.38	0.97	2.85	4.15	38.74	30.17	19.63	21.92	24.62	10.73	58.41	19.79	75.07	22.99
Group 3	1.79	0.73	2.62	0.88	1.73	1.38	31.43	15.11	14.84	11.25	20.89	6.88	67.37	28.13	87.64	36.62
Overall	1.99	0.79	2.69	1	2.22	2.62	40.86	27.26	18.71	15.82	25.47	8.97	64.75	22.75	81.98	25.76
GENEA hip																
Group 1	1.06	0.47	0.99	0.84	0.59	0.57	7.03	4.95	25.75	22.12	35.56	7.7	64.58	9.05	72.81	6.79
Group 2	1.12	0.71	0.57	0.31	0.57	0.61	6.15	5.41	16.37	6.27	31.52	10.19	56.23	12.08	62.24	16.52
Group 3	1.1	0.37	0.75	0.51	0.59	0.62	4.61	2.17	12.08	3.28	24.95	5.22	51.89	12.47	63.16	13.16
Overall	1.09	0.53	0.79	0.64	0.59	0.59	6.13	4.61	19.13	15.57	31.63	9.03	58.56	12.02	66.66	13.24
METs																
Group 1	0.92	0.25	0.95	0.20	0.88	0.19	2.45	0.82	2.74	0.49	3.77	0.64	5.31	1.24	5.19	2.22
Group 2	0.95	0.31	0.98	0.33	0.95	0.36	2.16	1.37	2.53	0.64	3.68	0.90	5.57	1.40	6.62	1.69
Group 3	1.03	0.33	1.16	0.47	1.09	0.26	2.38	0.97	2.77	0.85	4.01	0.71	6.96	1.22	7.99	1.08
Overall	0.96	0.29	1.02	0.34	0.96	0.28	2.34	1.06	2.68	0.64	3.8	0.75	5.81	1.44	6.38	2.1

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Table 2
Criterion and concurrent validity of accelerometer output for each group.

	Criterion validity				Concurrent validity		
Group	Genea right wrist	Genea left wrist	Genea hip	GT1M	Genea right wrist	Genea left wrist	Genea hip
1	0.910**	0.910**	0.970**	0.970**	0.830**	0.860**	0.990**
2	0.890**	0.880**	0.965**	0.965**	0.795**	0.800**	0.985**
3	0.900**	0.925**	0.965**	0.975**	0.845**	0.870**	0.975**

** $p < 0.001$.

MET output ($F_{GG(4.965,101.778)} = 6.0$, $p < 0.001$). Post hoc analysis revealed the youngest group's GENEA hip output was significantly higher than the oldest group's for all walking and running activities and the middle age group for slow walk and both running activities. For MET values, the eldest age group was significantly higher than the youngest group for both running activities. However differences between all groups were observed in the medium running activity, with the eldest group recording the highest values.

Both GENEA wrist monitors demonstrated good criterion validity (right: $r = .900$, $p < 0.01$; left: $r = .910$, $p < 0.01$), while the hip monitor showed excellent validity ($r = .965$, $p < 0.01$), performing to the same standard as the ActiGraph GT1M ($r = .970$, $p < 0.01$). The hip GENEA had the highest concurrent validity, relative to the ActiGraph ($r = .985$, $p < 0.01$), but both wrist monitors also demonstrated good concurrent validity (right: $r = .830$, $p < 0.01$; left: $r = .845$, $p < 0.01$). Overall the hip GENEA demonstrated significantly higher criterion and concurrent validity than the wrist-worn monitors ($p < 0.05$).

Due to the large age range of the children, criterion and concurrent validity of the GENEA monitors were also assessed separately across three age ranges. Table 2 shows the validity values for each monitor in each age group. It can be seen that criterion validity fluctuates slightly across position and age range, with the GENEA positioned at the hip consistently reporting higher validity across the groups, however the hip location was only significantly higher than the wrist for groups one and three ($p < 0.05$). Similar results were also found for the concurrent validity, with small differences being shown between groups and across monitor position. The hip mounted GENEA reported significantly higher concurrent validity across all age groups ($p < 0.05$).

A series of hierarchical regression analyses were undertaken to assess whether height or age accounted for any variance in the METs over and above that reported for each GENEA monitor. Results showed that no additional variance was accounted for ($p > 0.05$) at any wear location; supporting the creation of GENEA cut-points for the whole sample rather than age- or height-specific cut-points.

Table 3 shows activity intensity cut-points, established via the ROC curve analysis, for the GENEA monitors worn at the right wrist, left wrist and hip, along with sensitivity and specificity values and area under the curve (AUC). Cut-points are presented as g s.

ROC analyses showed that GENEA monitors at each location were able to successfully discriminate between all intensity levels. However, the hip monitor gave a slightly more precise discrimination at each intensity levels than the wrist monitors (AUC = 0.94–0.99, compared with AUC = 0.92–0.97). With regard to the different intensities, sedentary behaviour was the easiest to classify, showing the largest area under the curve for each monitor location (0.97–0.99). The wrist GENEAs had lower sensitivity and specificity values for moderate intensity than the other intensities. However, this pattern was less evident in the hip GENEA monitor.

4. Discussion

The aim of the present study was to establish validity for the GENEA waveform triaxial accelerometer, and calibrate the output against energy expenditure to determine activity intensity cut-points for sedentary, light, moderate and vigorous physical activity in a child population.

The expected pattern of increasing MET values corresponding with increasing accelerometer counts was observed, with only one exception in this protocol: the interactive computer games (boxing on Nintendo Wii). This was due to the relatively fast paced movement of the wrists with little torso movement. Similarly, the differences recorded for the different groups with the hip monitor and the MET output can be explained by the use of the same walking speeds for each age category, and later, the self-selected running speeds.

Although GENEAs at each body location demonstrated excellent criterion validity scores, there was a significant difference between the validity values for wrists and hip mounted monitors, with the hip monitor performing to the same standard as the ActiGraph, and better than the wrist worn monitors. The potential for increased feasibility and compliance that may be associated with wrist-worn monitors, may compensate for the slightly lower validity scores observed. Interestingly, these results differ slightly from those found within the adult population; Esliger et al.[6] found that criterion reference validity was similar across all wear locations. However the correlations reported for criterion validity ($r = .83$–$.87$) in the adult population were lower than those recorded in the present study. The lower concurrent validity of the wrist-worn GENEA compared with the GENEA worn

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Table 3
Sensitivity, specificity and area under the curve and resultant cut-points for each GENEA monitor.

Intensity	Sensitivity %	Specificity %	Area under the ROC curve (95% CI)	Cut-points (g s)
Right wrist				
Sedentary	94.85	97.71	0.97(0.95–0.99)	<6
Light	N/A	N/A	N/A	6–21
Moderate	82.43	83.25	0.92(0.89–0.94)	22–56
Vigorous	89.36	85.48	0.93(0.91–0.96)	>56
Left wrist				
Sedentary	94.74	96.67	0.97(0.96–0.99)	<7
Light	N/A	N/A	N/A	7–19
Moderate	88.11	84	0.93(0.90–0.95)	20–60
Vigorous	91.30	89.23	0.94(0.92–0.97)	>60
Hip				
Sedentary	96	96.09	0.99(0.97–0.99)	<3
Light	N/A	N/A	N/A	3–16
Moderate	88.54	88	0.95(0.93–0.97)	17–51
Vigorous	92	88.86	0.94(0.91–0.96)	>51

N.B. Light activity was not assessed individually, as the upper and lower boundaries for sedentary and moderate, respectively, were employed to form the light intensity threshold.

at the hip is not surprising as the ActiGraph was also worn at the hip and monitor output differs by body location.[14]

When validity was assessed at various age groups, it was expected that each monitor would perform to a similar standard, as output for groups across activities were not significantly different. All monitors performed consistently across groups, with the output from the hip-mounted monitor showing comparable validity to the ActiGraph GT1M counts in all groups. It is therefore sufficient to say that the GENEA demonstrates good criterion referenced and concurrent validity at all locations and across each age category, with the slightly lower validity of the wrist monitors a small compromise if an increase in compliance is evident.

Further analysis via ROC curve showed that the GENEA monitors at all three locations were able to successfully distinguish and classify sedentary, light, moderate and vigorous activity. The hip-mounted GENEA provided the most precise discrimination of each intensity level, consistently reporting the highest sensitivity, specificity and AUC. It is important to note that the cut-points are location specific; this is highlighted by the difference between cut-points for wrist and hip locations. It was noted that the child population cut-points are much higher than those reported with an adult population. Previous research differs on whether age-specific cut-points are required in a child population.[15,16] This premise was examined in the present study. There were no significant differences in accelerometer output across age groups for the wrist GENEAs, although some differences were observed for walking and running with the hip-mounted GENEA. To investigate this further, regressions analysis were carried out. These indicated that height or age did not add significantly to the variance explained in METs by accelerometer output. Therefore, from the data presented, it appears that the cut-points established for the GENEA can be used for the entire age range covered in the present study.

The present study has some limitations that should be addressed. It is possible the skew of the data towards right handed participants may have influenced the validity and cut-points slightly, although none of the activities used the dominant hand more than the non-dominant hand, some activities may have been influenced by this bias. For example, the Nintendo Wii condition involved boxing, with both hands being used; however it was not noted if the participant favoured the use of one hand more than the other. Secondly, although age and sex-specific resting $\dot{V}O_2$ values were used to calculate METs, individual resting $\dot{V}O_2$ values may have provided a more accurate view of each activity's intensity. However, due to the constraints of time and collecting data with this age range, gaining a true resting metabolic rate would have been difficult.

The present study was lab-based, thus future research should attempt to cross-validate the GENEA monitors within an independent sample of children by looking at a wide range of activities in a semi-structured or free-living environment. Furthermore, future studies should consider whether handedness impacts upon the validity of the GENEA output as a measure of habitual physical activity. The high frequency of data capture possible with the GENEA facilitates the use of pattern recognition approaches to classify activity type, potentially overcoming some of the well-documented limitations associated with the use of cut-points to classify activity intensity. However, the development of cut-points that can be used with epoch data to determine activity intensity will allow the use of the GENEA wrist-worn accelerometer while more sophisticated pattern recognition methods are being developed. When using the most recent model, the GeneActiv, it is possible to select frequencies of data collection up to 100 Hz. Measurements from different recording frequencies and epoch lengths can be compared with suitable scaling as the number of measures included in the SVM_{gs} is equal to the recording frequency multiplied by the epoch length.

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5. Conclusion

The GENEA has demonstrated high criterion and concurrent validity, irrespective of whether it is worn on either wrist or the hip, and has been established as peer to the ActiGraph. Cut-points for use with the GENEA when worn at the wrist or hip are presented to enable the classification of sedentary, light, moderate and vigorous intensity activity. It therefore has the potential to be used in future child related studies and may facilitate increased compliance rates.

Practical implications

- The GENEA accelerometer is a valid measure of children's activity intensities whether worn at the wrist or the hip.
- GENEA output and ActiGraph counts showed similar criterion validity as measures of children's physical activity.
- Cut-points are now available to use with the GENEA to determine the intensity of children's physical activity.

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