Validation of the GENEA Accelerometer

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ABSTRACT

ESLIGER, D. W., A. V. ROWLANDS, T. L. HURST, M. CATT, P. MURRAY, and R. G. ESTON. Validation of the GENEA Accelerometer. *Med. Sci. Sports Exerc.*, Vol. 43, No. 6, pp. 1085–1093, 2011. **Purpose**: The study aims were: 1) to assess the technical reliability and validity of the GENEA using a mechanical shaker; 2) to perform a GENEA value calibration to develop thresholds for sedentary and light-, moderate-, and vigorous-intensity physical activity; and 3) to compare the intensity classification of the GENEA with two widely used accelerometers. **Methods**: A total of 47 GENEA accelerometers were attached to a shaker and vertically accelerated, generating 15 conditions of varying acceleration and/or frequency. Reliability was calculated using SD and intrainstrument and interinstrument coefficients of variation, whereas validity was assessed using Pearson correlation with the shaker acceleration as the criterion. Next, 60 adults wore a GENEA on each wrist and on the waist (alongside an ActiGraph and RT3 accelerometer) while completing 10–12 activity tasks. A portable metabolic gas analyzer provided the criterion measure of physical activity. Analyses involved the use of Pearson correlations to establish criterion and concurrent validity and receiver operating characteristic curves to establish intensity cut points. **Results**: The GENEA demonstrated excellent technical reliability (CV_{intra} = 1.4%, CV_{inter} = 2.1%) and validity (r = 0.98, $P < 0.001$) using the mechanical shaker. The GENEA demonstrated excellent criterion validity using $\dot{V}O_2$ as the criterion (left wrist, r = 0.86; right wrist, r = 0.83; waist, r = 0.87), on par with the waist-worn ActiGraph and RT3. The GENEA demonstrated excellent concurrent validity compared with the ActiGraph (r = 0.92) and the RT3 (r = 0.97). The waist-worn GENEA had the greatest classification accuracy (area under the receiver operating characteristic curve (AUC) = 0.95), followed by the left (AUC = 0.93) and then the right wrist (AUC = 0.90). The accuracy of the waist-worn GENEA was virtually identical with that of the ActiGraph (AUC = 0.94) and RT3 (AUC = 0.95). **Conclusion**: The GENEA is a reliable and valid measurement tool capable of classifying the intensity of physical activity in adults.
Key Words: ACTIVITY MONITOR, MEASUREMENT, ACCELERATION, FREQUENCY, GRAVITY, RELIABILITY

The unequivocal link between physical activity and health has prompted exercise science and public health researchers, their learned societies, and their funders to search for better and more logistically feasible and objective tools to measure physical activity.

This focus has facilitated the development of many objective measurement technologies, such as accelerometers (described in detail elsewhere [17,29]), which provide robust and detailed physical activity information (4).

Although much progress has been made in the assessment of physical activity with accelerometers, there are several limitations that still need to be addressed. An important first step would be to convince manufacturers to abolish the practice of disguising raw acceleration outcomes via proprietary "count" units as it hinders between model comparisons. Second, increased battery life and memory storage would benefit users who require higher-resolution signals. This is especially important for multiaxis accelerometers and seismic-based technologies (26). However, a balance must be struck to ensure that the quest for richer data does not interfere with other more practical issues related to accelerometer size, weight, and functionality. For example, the IDEEA monitor (32) uses an array of wired accelerometers and, as such, is somewhat obtrusive. That said, there are some accelerometers such as the Sensor Wear Armband (7), the activPAL (9), and the DynaPort (26), that seem to have balanced the desire for advanced measurement capabilities, such as activity classification, with feasibility issues (e.g., the desire for high-resolution acceleration data and the need to remain unobtrusive). More recently, another accelerometer, the GENEA, has been developed.

This article functions to introduce the GENEA, a novel acceleration sensor developed by Unilever Discover (Colworth, United Kingdom UK) and manufactured and distributed by Activinsights Limited (Kimbolton, Cambridgeshire, UK). Therefore, the purpose of this study was threefold: 1) to perform a preliminary technical reliability and validity

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assessment of the GENEA using a mechanical shaker table; 2) to perform a value calibration of the GENEA to develop thresholds for sedentary and light-, moderate-, and vigorous-intensity physical activity in adults; and 3) to compare the intensity classification of the GENEA with two widely used accelerometers.

METHODS

Technical Reliability and Validity

Accelerometers. The GENEA is a triaxial, ±6*g* seismic acceleration sensor (LIS3LV02DL; STMicroelectronics, Geneva, Switzerland). The small (36 × 30 × 12 (*L* × *W* × *H*) mm) and lightweight (16 g) splash-proof design of the GENEA allows it to be easily worn at multiple locations on the body (e.g., wrist, waist, ankle). The GENEA has 500 MB of memory to assist with the storage of the raw 80-Hz sampling frequency and can store ~8 d of data in raw mode with 12-bit resolution. Users have the ability to select user-defined sample frequencies ranging from 10 to 80 Hz. Using the GENEA software (version 1.487 update 531), via USB-to-PC connection, 47 GENEA accelerometers were initialized to collect unfiltered, triaxial acceleration data at a sampling rate of 80 Hz.

Multi-Axis Shaking Table. All technical reliability and validity testing was completed using a Multi-Axis Shaking Table (MAST) manufactured by Instron Structural Testing Systems (Buckinghamshire, United Kingdom, UK) with an industrial Labtronic 8800 Digital Controller (Darmstadt, Germany). The MAST has been described in detail by Gizatullin and Edge (8). The MAST is designed to recreate spatial motion of the platform in three dimensions; however, only the vertical motion was used in this preliminary technical reliability and validity study. Using a combination of command file and individually entered position command signals, the MAST was programmed to accurately and reliably oscillate the platform at the various testing conditions using a sinusoidal oscillation procedure. The testing conditions were restricted by the MAST stroke limits of approximately ±75 mm. The range of possible conditions of acceleration and the frequency of oscillation are described by he equation: acceleration ($m \cdot s^{-2}$) = (amplitude (m) × frequency^2 ($rad \cdot s^{-1}$)). Fifteen different conditions were selected to produce a range of physiologically relevant accelerations from light to moderate to vigorous within the limitations of the MAST.

The GENEA accelerometers were secured/enclosed in a custom test jig (Fig. 1, right inset) lined with high-density foam to avoid potential vibration transference and bolted to the surface of the shaker table (Fig. 1, left inset). Care was taken to ensure that the monitors were secured firmly so the vertical movement was along the *y* axis of the GENEA. Next, the first test condition was programmed, and the condition was executed, accelerating all accelerometers simultaneously in the vertical plane for the 60-s test duration. All 15 conditions were completed in this fashion, and when complete, the accelerometers were removed from the shaker plate and test jig.

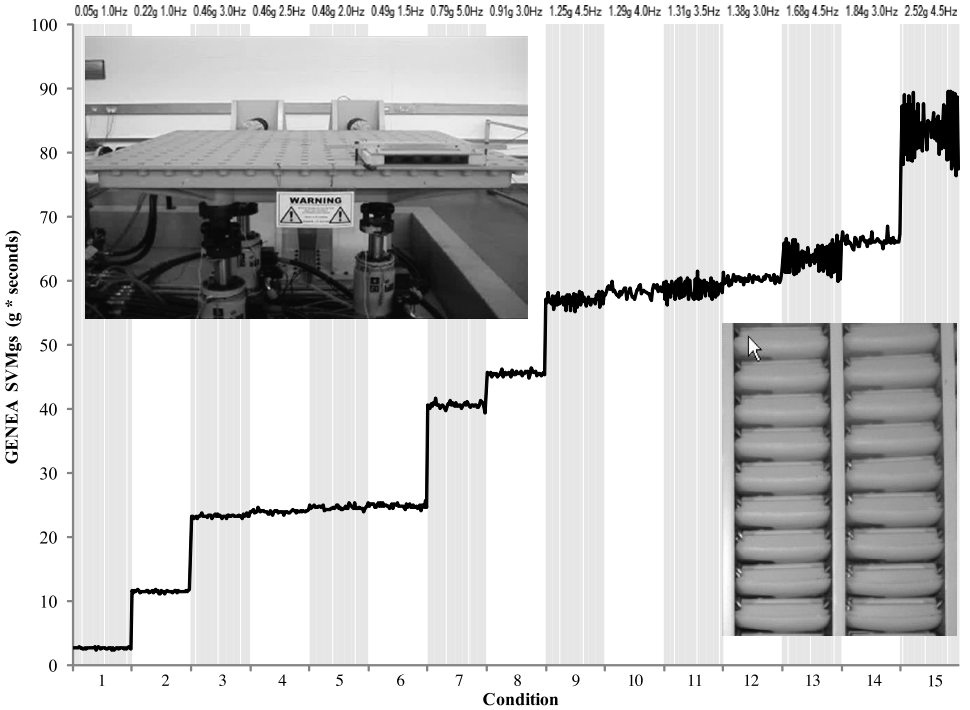

FIGURE 1—*Right inset*, Overhead view of GENEA accelerometers positioned in the test jig. *Left inset*, MAST complete with the test jig secured in place. *Main figure*, Comparison of a typical output trace from one GENEA accelerometer across the 15 test conditions. Note: i) The trace represents the middle 50 s of each of the 15 conditions.

Data reduction. All 47 GENEA accelerometers were downloaded to the initialization PC, resulting in the creation of 47 raw, 80-Hz data files containing unfiltered, time and date–stamped x, y, and z axes acceleration data (in gravitational units (g) complete with negative sign indicating directionality). These data were downloaded in comma-separated values file format (.csv extension); however, the user may also (or instead) choose a binary format (.bin extension). Although both files contain the same data, the binary format is much more efficient at nearly eight times the smaller file size. Using the GENEA postprocessing software (version 1.2.1), the raw 80-Hz triaxial GENEA data were summarized into a signal magnitude vector (gravity-subtracted) (SVM_{gs}) using 1-s epochs (equation 1) (11). The resulting SI unit for this outcome variable is g-seconds (g·s):

$$SVM_{gs} = \sum|\sqrt{x^2 + y^2 + z^2} - g| \quad [1]$$

where the correction for gravity was undertaken to focus the outcome variable on dynamic rather than static accelerations

Although not the focus of the present study, the postprocessing software does allow the user to summarize the raw triaxial signal using units of acceleration. This is achieved by using the mean signal magnitude vector over the user-defined epoch (equation 2) rather than the integral measure of the SVM as outlined above (26):

$$SVM\,\overline{r} = \sqrt{x^2 + y^2 + z^2} \quad [2]$$

Because this is a mean rather than an cumulative sum, it retains its gravity-based acceleration units (g), where $1g = 9.81\ m{\cdot}s^{-2}$

Next, data were imported into a customized spreadsheet application using the common epoch-by-epoch time stamp to align/synchronize the data across units and models (verified by cross-correlation analyses). The recorded condition start and end times were identified and the middle 50 s of each condition were extracted for further analysis.

Statistical analyses. For all test conditions, the mean output (50 replicate seconds) of each accelerometer for each condition was calculated. Intrainstrument and interinstrument reliabilities were calculated using SD and coefficient of variation (CV_{intra} and CV_{inter}). Pearson product–moment correlation was used to determine the criterion validity of the GENEA versus the MAST acceleration. All analyses were performed using SPSS version 15.0 for Windows (SPSS, Chicago, IL).

Value Calibration

Participants. Participant recruitment was initiated in February 2008 in an effort to obtain a convenience sample of 60 male and female volunteers aged 40–65 yr. Two recruitment methods were used: an e-mail to employees of the University of Exeter, Devon, UK, and an advertisement in a local newspaper. A health and fitness report and a £20 gift card were offered as incentive and honorarium, respectively, for participating in the study. Data collection was undertaken in March and April 2008, after which time 60 adults (62% female) aged 40–63 yr completed the study protocol. All participants were free from diagnosed disease and musculoskeletal injury and had no affirmative answers to the Physical Activity Readiness Questionnaire. Written informed consent was obtained from each participant. The study was approved by the Ethics committee of the School of Sport and Health Sciences, University of Exeter.

Data collection procedures. Participants arrived at the laboratory having refrained from consuming nicotine, caffeine, or a large meal for at least 2 h before and exercise at least 6 h before the appointment. As part of a larger battery of anthropometry and health-related fitness tests (peripheral to the present study), participants had their height (to the nearest 0.1 cm) and body mass (to the nearest 0.1 kg) measured using a Holtain stadiometer (Holtain; Crymych, Dyfedd, UK) and a Tanita TBF-305 scale (Tanita UK Ltd., Middlesex, United Kingdom, UK), respectively. Whole-body bioelectrical impedance analysis (BodyStat 1500; BodyStat, Onchan, Isle of Man, United Kingdom, UK) was also performed to determine percent body fat. Next, each participant was asked to complete an ordered series of 10–12 semistructured activities in the laboratory and free-living environment. The lying activity was performed for 10 min, whereas all other activities were performed for 4.5 min. In between each activity, the participants were given at least 2 min of rest to allow them to prepare for the next activity and for their metabolic rate (oxygen uptake) to recover to preactivity levels. Throughout testing $\dot{V}O_2$, $\dot{V}CO_2$, and HR were measured by the Cosmed K4b2 (Rome, Italy) portable metabolic gas analysis system with an HR receiver. Before each testing session, the K4b2 was calibrated with gases of known concentration, and the flow sensor calibration and environmental conditions were updated. Lastly, the K4b2 and the computer running the software were time synchronized with the GMT server. The K4b2 has been shown to provide valid measurements of oxygen uptake across a range of exercise intensities (13). After each testing session, the relative $\dot{V}O_2$ data were downloaded and stored on a PC for further analysis.

Accelerometer. Throughout testing, three GENEA accelerometers were worn, one on each of the left and right wrists (using simple watch straps, accelerometers were positioned over the dorsal aspect of the wrists midway between the radial and ulnar styloid processes) and one on the waist (using a elasticized belt, an accelerometer was positioned over the right side of the hip, midclavicular line landmarked by the supraspinale). The same three GENEA accelerometers were used by all 60 participants and were always positioned at the same sites for each. On the same belt, adjacent to the waist-worn GENEA, participants wore two peer accelerometers, a uniaxial ActiGraph GT1M accelerometer with firmware version 3.0.0 (ActiGraph, Pensacola, FL) and a triaxial RT3 accelerometer (Stayhealthy.com, Monrovia, CA). At the start of each testing session, the accelerometers

were time synchronized with the GMT server and initialized to record acceleration data. The epoch length was set at 80 Hz, 1 s, and 1-min three axes for the GENEA accelerometers, ActiGraph, and RT3, respectively; however, only the vector magnitude data from the RT3 were analyzed. After each testing session, the accelerometer data were downloaded and stored on a PC for further analysis.

Data analyses. Using the K4b2 software, the breath-by-breath $\dot{V}O_2$ data were filtered using 1-min averaging. Using the GENEA Post Processing software (version 1.2.1), the raw 80-Hz triaxial GENEA data were summarized into SVM_{gs} using 1-min epoch intervals. The ActiGraph data were also integrated to 1-min epochs for further analysis. Custom spreadsheet applications were developed to temporally synchronize the minute-by-minute data from the K4b2 with the data from the three accelerometer models. The combined data set was then plotted to facilitate the selection of the minutes of accelerometer data that coincided with steady-state $\dot{V}O_2$ for each of the activities performed. Ideally, and in most cases, this was the fourth minute of each activity; however, in a minority of cases, the third minute was selected because it better represented steady-state because of occasional time synchronization issues (the 10th or 9th minute for the lying activity). The relative $\dot{V}O_2$ and accelerometer data corresponding to the selected minute were exported to SPSS version 15.0 for Windows (SPSS) for further analysis. Pearson correlations were calculated between each accelerometer output and $\dot{V}O_2$.

The $\dot{V}O_2$ data were converted to METs using the standard conversion of 1 MET = 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ and then coded into one of four absolute-intensity categories: sedentary (<1.5 METs), light (1.5–3.99 METs), moderate (4.00–6.99 METs), or vigorous (7+ METs) activity. The impetus for using 4- and 7- rather than 3- and 6-MET thresholds to mark moderate- and vigorous-intensity physical activity follows the rationale described in a review by Shephard (23). Citing work by Porcari et al. (19), Shephard noted that those deriving health benefits from lifestyle activities tended to be sedentary, obese, and elderly people, those for whom a given absolute intensity of effort such as brisk walking develops a substantial relative intensity of effort. Simply put, because the present sample were sedentary/unfit, their physical activity energy expenditure for a given absolute-intensity effort such as a brisk walk is likely to be higher than for fitter individuals. Therefore, developing cut points on an unfit sample using 3- and 6-MET thresholds would result in an increased chance of erroneously categorizing fitter individuals as active rather than inactive. As this was the case in the present study, the higher absolute-intensity cut points of 4 and 7 METs were chosen.

Next, the accelerometer data were recoded to create binary indicator variables (0 or 1) to facilitate the receiver operating characteristic (ROC) curve analyses. For sedentary, this corresponded to sedentary activities versus more than sedentary activities. For moderate intensity, this corresponded to less than moderate activities versus moderate to vigorous activities. For vigorous intensity, this corresponded to vigorous activities versus less than vigorous activities. Next, the binary-coded accelerometer data were exported to GraphPad Prism 4.00 for Windows (GraphPad Software, San Diego, CA) to undergo the ROC curve analyses.

An ROC curve is a graphical technique for describing and comparing the accuracy of diagnostic tests. In the present application, ROC analysis is used to examine the potential of using thresholds within the GENEA, ActiGraph, and RT3 data to discriminate between four activity intensity categories. As Jago et al. (10) described, ROC analysis is a means to evaluate and visualize the sensitivity [true positives/(true positives + false negatives)] and specificity [true negatives/(true negatives + false positives)] of tests. The ROC curve is simply a plot of the sensitivity of a test on the *y* axis versus its 1 − specificity (i.e., false positive fraction on the *x* axis). Each possible threshold value corresponds to a point on the ROC curve. The upper left corner [the point (0, 1)] represents perfect classification, and the diagonal line represents the strategy of randomly guessing. Sensitivity is maximized by correctly identifying at or above the threshold for intensity, whereas specificity is maximized by correctly excluding activities below the threshold for intensity. Similar to the methods of Evenson et al. (6), the cut points at

TABLE 1. Reliability results for the GENEA for all 15 test conditions.

Acceleration				GENEA SVM_{gs} (*g*·s)		GENEA	
g	($m \cdot s^{-2}$)	Frequency (Hz)	Amplitude (m)	Mean	SD	CV_{intra} (%)	CV_{inter} (%)
0.05	0.49	1.0	0.0124	3	0.1	3.9	5.3
0.22	2.16	1.0	0.0547	11	0.2	1.7	2.0
0.46	4.51	3.0	0.0127	23	0.2	0.8	1.4
0.46	4.51	2.5	0.0183	24	0.2	0.9	1.4
0.48	4.71	2.0	0.0298	25	0.3	1.0	1.4
0.49	4.81	1.5	0.0541	25	0.3	1.1	1.6
0.79	7.75	5.0	0.0079	41	0.4	1.0	1.5
0.91	8.93	3.0	0.0251	46	0.4	0.8	1.3
1.25	12.26	4.5	0.0153	57	0.8	1.5	2.1
1.29	12.65	4.0	0.0200	58	0.8	1.3	2.0
1.31	12.85	3.5	0.0266	59	1.2	2.1	2.6
1.38	13.54	3.0	0.0381	60	0.6	1.0	1.8
1.68	16.48	4.5	0.0206	64	2.2	3.4	3.7
1.84	18.05	3.0	0.0508	66	0.9	1.3	2.2
2.52	24.72	4.5	0.0309	84	4.3	5.1	5.3
Average variability across all 15 test conditions						1.8	2.4

TABLE 2. Descriptive characteristics of the study participants.

Gender	Sample Size[a]	Age	Left-Handed	Right-Handed	Height (cm)	Weight (kg)	Body Mass Index (kg·m^{-2})	Body Fat (%)
Male	23	48.9 (6.8)	1	22	176.2 (6.2)	80.6 (11.6)	25.9 (2.7)	20.7 (3.4)
Female	37	49.6 (6.4)	4	33	162.8 (5.4)	62.9 (8.4)	23.8 (3.5)	32.8 (6.6)
Overall	60	49.4 (6.5)	5	55	167.9 (8.7)	69.7 (13.0)	24.6 (3.4)	28.2 (8.1)

[a] For the measurement of body fat, there were two fewer participants (one male and one female).

which sensitivity and specificity were both maximized were identified.

RESULTS

Technical Reliability and Validity

All 47 GENEA accelerometers successfully initialized, collected, and downloaded data. The mean SMV_{gs} (g·s) for the GENEA accelerometers displayed a linear trajectory across all 15 testing conditions when organized from low to high acceleration values (Fig. 1, main). The average intra-instrument and interinstrument reliability of the 47 GENEA accelerometers across the 15 conditions was CV_{intra} = 1.8% and CV_{inter} = 2.4%, respectively (Table 1). The criterion validity for the GENEA versus the MAST acceleration for all 15 test conditions was excellent (r = 0.97, P < 0.001).

Value Calibration

Descriptive characteristics of the participants are shown in Table 2. The body mass index data are a testament to the fact that this is a convenience sample because the participants are leaner than the general population. In fact, the prevalence of obesity among the group was 4% for men and 5% for women, much lower than the 23% and 25% found in the general population (21). However, the number of left-handed participants in this study (12%) matched well the 11% prevalence of left-handedness in the UK population (14).

Table 3 compares the mean METs and the position-specific GENEA results. As expected, the activities in the posture grouping were the lowest intensity, whereas the optional running activities were the highest, which was reflected in the $\dot{V}O_2$ and the accelerometer output. The fact that the slow treadmill walking, an activity intended to be light intensity, resulted in an average 3.88 METs response helps justify the decision to use the higher absolute-intensity cut points of 4 and 7 METs to distinguish moderate- and vigorous-intensity activity in this sample. Comparing the different wear positions of the GENEA showed that data for the left and right wrists were similar, whereas the mean GENEA data collected at the waist were lower as were the SD. Comparative data from the waist-worn ActiGraph and RT3 are also displayed in Table 3.

TABLE 3. Average intensity (METs); average left-, right-, and waist-positioned GENEA output; average ActiGraph counts; and average RT3 counts by activity.

			GENEA (SVM_{gs} (g·min)								ActiGraph (Counts per Minute)		RT3 (VM Counts per Minute)	
			METs		Left Wrist		Right Wrist		Waist		Waist		Waist	
Activity	Grouping	n[a]	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Lateral recumbent (lying on side)	Posture (all)	53	0.94	0.23	63	55	143	53	34	17	0	0	4	11
Seated computer work		55	1.22	0.29	185	86	242	67	48	33	1	3	9	21
Standing		55	1.13	0.25	100	66	103	177	48	15	0	0	3	9
Window washing	Lifestyle (2 of 4)[b]	31	3.37	1.06	469	693	1808	708	185	61	138	177	463	344
Washing dishes		24	2.35	0.45	634	177	768	239	132	164	51	80	160	74
Shelf stacking		30	4.19	0.98	884	224	940	202	214	72	2620	1933	421	297
Sweeping		23	3.39	0.67	878	264	976	289	187	48	465	355	356	96
Slow treadmill walk (4 km·h^{-1})	Ambulatory (all)	54	3.88	0.69	864	195	847	232	856	221	2323	643	1267	318
Medium treadmill walk (5 km·h^{-1})		55	4.59	0.79	1177	299	1204	357	1264	214	3745	656	1659	331
Brisk treadmill walk (6 km·h^{-1})		55	5.88	0.98	1506	400	1513	350	1815	272	4917	940	2228	450
Stair ascent/descent (80 steps per minute)	Stairs (all)	55	6.19	1.10	836	620	794	597	697	127	2427	780	811	208
Slow treadmill run (8 km·h^{-1})	Ambulatory (1 of 3)[c]	18	11.13	1.38	3858	588	4087	798	3553	593	8936	1794	4578	799
Medium treadmill run (10 km·h^{-1})		14	12.00	1.24	5345	1073	4915	787	4043	325	8904	1826	5419	423
Fast treadmill run (12 km·h^{-1})		5	13.61	0.60	5096	2339	5358	2460	4066	299	6982	3233	6093	674
Brisk free-living walk (6 km·h^{-1})	Ambulatory (all)	40	5.76	0.94	1433	171	1474	216	1769	227	4912	748	2434	559
Medium free-living run (10 km·h^{-1})	Ambulatory (optional)	5	12.62	1.17	5151	1113	4844	1232	3756	631	8825	1592	5525	787

1 MET = 3.5 mL·kg^{-1}·min^{-1}.
[a] Listwise sample size.
[b] Participants were randomly allocated two of the four activities in this grouping.
[c] Participants had the option to run (select one of the three activities in this grouping) if they so chose.

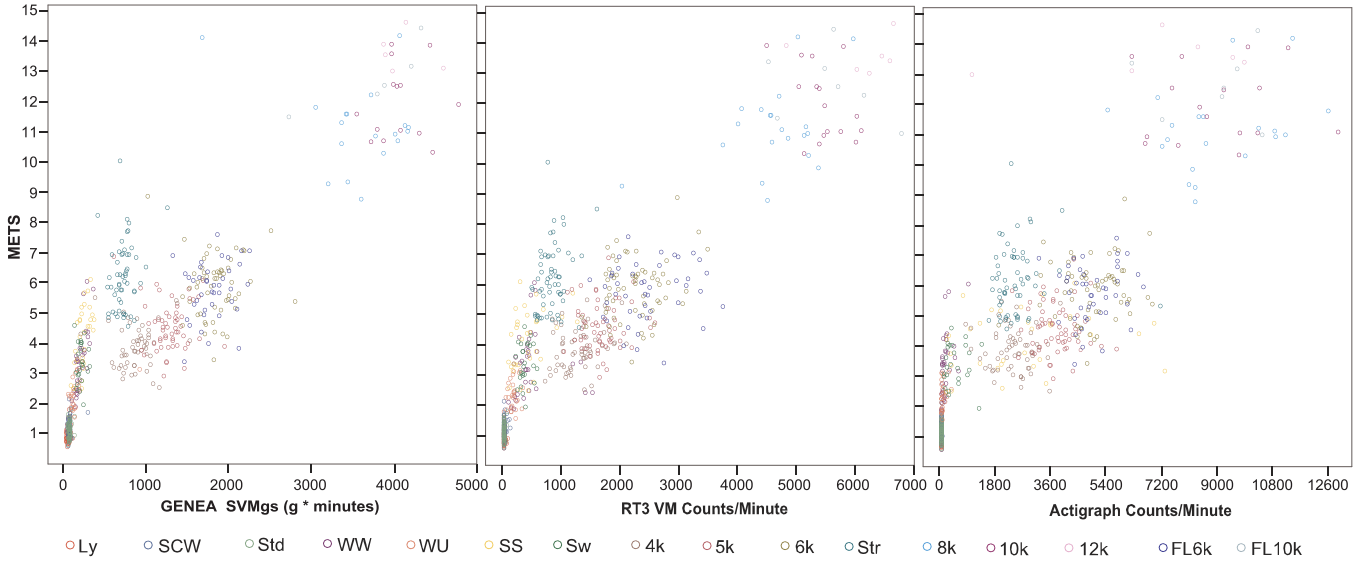

FIGURE 2—Relationship between physical activity intensity (METs) and the outputs from the waist-worn GENEA SVM_{gs} (g·min), RT3 (counts per minute), and ActiGraph (counts per minute) accelerometers across the 16 activity conditions.

Using relative $\dot{V}O_2$ as the criterion, the GENEA demonstrated excellent criterion validity across all activities (left wrist, $r = 0.86$; right wrist, $r = 0.83$; waist, $r = 0.87$), performing as well at the waist as the ActiGraph GT1M ($r = 0.86$) and RT3 ($r = 0.88$). The GENEA also demonstrated excellent concurrent validity compared with the ActiGraph GT1M ($r = 0.92$) and the RT3 (0.97) accelerometers. Device-specific scatter plots in Figure 2 provide a graphical comparison of criterion validity (i.e., METs versus each accelerometer's output) across the varying activity conditions.

Table 4 outlines the results of the ROC curve analysis for the GENEA. Across all three wear positions, discrimination of sedentary behavior was almost perfect, with the area under the ROC curve ranging from 0.97 to 0.98. On account of reduced specificity, the discrimination of moderate activity was slightly less precise, ranging from 0.84 to 0.93. Meanwhile, it was the reduced sensitivity of vigorous-intensity cut points that compromised the discrimination of vigorous activity, which ranged from 0.89 to 0.92. Overall, the waist-worn GENEA had the greatest classification accuracy (0.95), followed by the left (0.93) and then the right wrist (0.90). Interestingly, the GENEA on the right wrist was unable to discriminate between light- and moderate-intensity categories. The overall ability to discriminate between sedentary and light-, moderate-, and vigorous-intensity physical activity of the waist-worn GENEA was virtually identical with that of the ActiGraph GT1M (0.94) and the RT3 (0.95) (data not shown).

TABLE 4. Sensitivity, specificity, area under the ROC curve, and GENEA SVM_{gs} (*g*·min) cut points that maximized sensitivity and specificity at three wear positions.

Intensity[a]	Sensitivity	Specificity	Area Under ROC Curve (95% CI)	GENEA Cut Points SVM_{gs} (*g*·min)
Left wrist				
Sedentary	97	95	0.98 (0.98–0.99)	<217
Light	NA	NA	NA	217–644
Moderate	95	72	0.91 (0.88–0.93)	645–1810
Vigorous	78	98	0.91 (0.86–0.95)	>1810
Right wrist				
Sedentary	99	96	0.98 (0.97–0.99)	<386
Light	NA	NA	NA	386–439
Moderate	100	56	0.84 (0.81–0.87)	440–2098
Vigorous	78	97	0.89 (0.84–0.94)	>2098
Waist				
Sedentary	99	96	0.97 (0.96–0.98)	<77
Light	NA	NA	NA	77–219
Moderate	96	80	0.93 (0.91–0.95)	220–2056
Vigorous	73	99	0.92 (0.88–0.96)	>2056

[a] Sedentary (<1.5 METs), light (1.5–3.99 METs), moderate (4.00–6.99 METs), and vigorous (7+ METs).
NA, not applicable as the sedentary and moderate cut points provide the boundaries for the light-intensity category.

DISCUSSION

Technical Reliability and Validity

Researchers have used various mechanical apparatuses to oscillate accelerometers in various axes in an effort to assess reliability. These apparatuses allow the researcher to control the magnitude of the acceleration being imparted as well as the frequency of the oscillation, two key variables that contribute to the accelerometer's output. Mechanical setups, by virtue of the precise control of the experimental conditions, are able to determine the variability attributed solely to the accelerometer. Examples include turntables (15), rotating wheel setups (2,16), vibration tables (20), and various types of mechanical shakers (5,12,22,24,26). This type of testing is important because if the measurement error intrinsic to the accelerometer is found to be small, then focus can shift to other sources of variation (e.g., position worn on the body, variation over time (e.g., day-to-day, week-to-week, season-to-season)) (15).

This is the first study to evaluate the technical reliability and validity of the newly introduced GENEA accelerometer.

Using 15 testing conditions across a range of accelerations and frequencies, the GENEA was found to be highly reliable with mean intrainstrument and interinstrument coefficients of variation of 1.8% and 2.4%, respectively. Likewise, the GENEA was found to have excellent criterion validity when compared with the MAST acceleration (r = 0.97). Two-thirds of the above-mentioned technical reliability studies focus on ActiGraph model accelerometers, and as such, it is a logical comparator for the GENEA. Of six studies, the current GENEA results demonstrate the highest technical reliability with the next best performer coming in a recent study on the ActiGraph GT1M (CV_{intra} = 2.9% and CV_{inter} = 3.5%) (24). In terms of criterion validity with the MAST, the only relevant comparison comes from a study on the ActiGraph 7164 (2) where the validity coefficient was identical with the present study.

Value Calibration

This is the first study to develop accelerometer cut points for both wrist and waist-worn GENEA accelerometers that reflect sedentary and light-, moderate-, and vigorous-intensity physical activity in adults. The delineation of intensity of physical activity from accelerometer data aids in the understanding of the relationship between health-related physical activity and potential predictor variables such as adiposity, age, health status, and ethnicity (10). The process used to convert raw accelerometer data into more meaningful and interpretable units is generally called "value calibration" (30). Although raw accelerometer data provide an indicator of overall movement, a fundamental research challenge has been to determine how to equate it to more meaningful indicators, such as energy expenditure or time spent at given activity intensity. Being able to identify the amount of time spent in a range of intensity categories is useful given the fact that numerous international physical activity guidelines recommend various amounts of time be spent in specific intensity categories (27).

In the present study, the GENEA demonstrated high levels of criterion validity (with an average correlation with METs across wear positions of r = 0.85) across 10–12 static and dynamic physical activities. In fact, the criterion validity of the GENEA was virtually identical with that of the ActiGraph and RT3. Similarly, high levels of criterion validity were shown by Bouten et al. (1) during the development of their novel triaxial accelerometer. The GENEA also demonstrated high levels of concurrent validity compared with the ActiGraph GT1M and the RT3, with the highest correlations between the triaxial devices. These data illustrate that the GENEA is comparable to peer accelerometers, a result that is confirmed in the graphical representation of the data in Figure 2. However, a closer look suggests that the GENEA data are less variable than the RT3 and ActiGraph across the intensity spectrum. Although speculative, the tighter clustering of data within activities may provide greater success for the GENEA when pursuing alternative analytical approaches. For example, the tighter clustering of data within activities in the GENEA should allow for more optimal activity classification (i.e., the determination of the mode of physical activity).

The GENEA SVM_{gs} (g·min) cut points established in this study demonstrated excellent accuracy for classifying physical activity intensity across the intensity spectrum. Because this is the first article to report cut points for the GENEA, it is not possible to compare these values with other studies. Although the accuracy of the GENEA was greatest at the waist, it also performed well at the wrist, with the left wrist being more accurate than the right. The diminished accuracy experienced on the right wrist was likely due to differences in participant handedness; that is, extraneous movements recorded during the activity conditions were more likely to occur on the right wrist (e.g., scratching, adjusting clothing/glasses, hand gestures). However, given the small number of left-handed participants (n = 5), testing of the hypothesis was untenable. Future research should specifically address this issue so that users, especially left-handed users, may know if wearing the GENEA on the right hand is possible. The small size of the GENEA and the fact that it can be positioned at the wrist, a location intuitively less obtrusive than the waist, may help rectify issues related to participant compliance in future studies and may allow for studies with extended physical activity monitoring periods (28).

Strengths and limitations. Several strengths are noteworthy in the present study. The first strength was the use of a mechanical shaker to perform a preliminary technical reliability and validity assessment on the GENEA. The use of this well-controlled experimental setup allowed for a robust assessment of this new technology. Next, the GENEA output was collected, analyzed, and presented in a nonproprietary SI unit and, as such, can be compared with other devices that retain/use classic physics-based measurements. Next, ROC curve analysis was chosen to determine the physical activity intensity cut points, which is known to be superior over previous accelerometer calibration methods that used linear regression approaches (see Jago et al. (10) for a more thorough discussion on this topic). To date, only four studies have used ROC curve analysis to generate cut points, and these were done on children (3,6,10,31). A further strength of the ROC curve analyses was that the cut points were chosen to optimize the balance between sensitivity and specificity (i.e., point nearest 0,1 on the ROC curve), which, in all analyses, also coincided with the Youden index, ensuring the optimality of the cut points. The intuitive interpretation of the Youden index is that it is the point on the curve farthest from chance (18). Finally, the comparison to two widely used peer technologies also strengthens the study as does the fact that energy expenditure ($mL \cdot kg^{-1} \cdot min^{-1}$) rather than direct observation was used to provide a continuous, objective, and physiologically meaningful dependent variable with which to compare the GENEA data (25).

Several limitations of this study should be acknowledged. First, the preliminary technical reliability and validity assessment was only performed on one axis, the vertical,

leaving the performance of the other two axes uncharacterized. Next, the comparison of the GENEA would have been more appropriate with the triaxial ActiGraph GT3X rather than the GT1M accelerometer; however, at the time of this study, the newer ActiGraphs were not part of our accelerometer inventory. Next, although our sample includes men and women of differing ages and body size, our population may not be representative. Larger and more variable samples (e.g., more left-handed, more overweight and obese participants) are needed to determine whether these factors might modify our findings. The use of standard METs as opposed to individualized METs may be considered a limitation. However, the measured $\dot{V}O_2$ during lying was not significantly different from the standard 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$. In addition, the activity conditions selected in this study may not represent the full complement of activities undertaken by a population; therefore, caution must be used when generalizing these results to other groups. Finally, cross-validation of the GENEA physical activity intensity cut points by other research groups in different adult populations is warranted.

CONCLUSIONS

The GENEA demonstrated excellent technical reliability and validity and excellent criterion validity compared with $\dot{V}O_2$. The GENEA cut points established in this study can be used to estimate the time spent in sedentary and light-, moderate-, and vigorous-intensity physical activity in adults. As a result, the GENEA has established itself as an objective and feasible measurement tool, comparable to other peer accelerometers, such as the ActiGraph GT1M and RT3, with the potential of offering advanced measurement features in the future. Additional work is warranted to further refine the adult cut points and to develop cut points for other age groups in an effort to calibrate the GENEA across the life span. Given that the high-resolution sampling of the GENEA allows for advanced data mining (e.g., extraction of frequency domain features), future research should strive to classify/recognize activities of daily living.

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