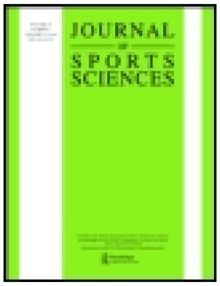

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Technical variability of the Vivago® wrist-worn accelerometer

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Abstract

The aim was to assess the technical variability of a new wrist-worn accelerometer under controlled conditions with a shaker device and during normal daily physical activities (PAs). In the first experiment, 10 wrist-worn accelerometers (Vivago® Wellness, Paris, France) were attached to the shaker device. Variability was tested at five shaking frequencies (1.1, 2.1, 3.1, 4.1, and 10 Hz) for 10 min at each frequency. In the second experiment, 21 participants wore wrist-worn accelerometers and performed six consecutive 10-min periods of activity at increasing levels of intensity from sedentary to vigorous. Results from the first experiment show a modest inter- and intra-instrument reliability at low frequencies and that reliability improved as frequency increased. The inter-instrument coefficient of variation (CV) was 2.6–18.3%. The intra-instrument CV was 4.1–23.2%. Variability was similar in the second experiment with a CV inversely related to PA intensity. The inter- and intra-instrument CV varied from 24.2% and 19.9% for sedentary activities to 3.7% and 4.3% for vigorous PA, respectively. Results suggest that reliability was higher at high intensities, corresponding to moderate and vigorous PA, intensities generally recommended for public health purposes.

Keywords: *accelerometry, physical activity, reliability*

1. Introduction

Physical activity (PA) is widely recognised for its role in prevention and treatment of chronic ailments, such as obesity and cardiovascular diseases. Activity monitors, such as accelerometers, are often used in clinical, epidemiological, or interventional studies to measure PA (Brage et al., 2004; Martinez-Gomez et al., 2012; Metzger et al., 2010; Riddoch et al., 2004; Vanhelst et al., 2011; Vanhelst, Béghin, et al., 2012a). Accelerometers are usually worn around the waist, hip, or lower back with an elastic belt and adjustable buckle. Recently, a manufacturer (http://www.vivagowellness.fr) has developed a new waterproof device, called Vivago® Wellness accelerometer, which is worn on the wrist. Compared with waist-worn monitors, the wrist-worn accelerometer may be more convenient to wear and may result in improved compliance (Evenson & Terry, 2009). Indeed, when a participant wears an accelerometer around the waist with an elastic belt or on a belt clip, the participant is obliged to remove the device for sleeping, changing clothes, doing contact sports, or during activities in water, e.g. bathing, showering, and swimming. These constraints may lead a lower compliance.

This new wrist-worn accelerometer (Vivago®, Paris, France) provides a good assessment of sleep/wake patterns and good agreement when compared with accelerometry (Lötjönen et al., 2003). Vanhelst, Hurdiel, et al. (2012) demonstrated also that this wrist-worn accelerometer was a valid device to assess PA in free living conditions and provided cut-off points to quantify time spent performing sedentary, light, moderate, and vigorous activities. However, the validity of the accelerometer to assess the PA is not sufficient to determine the accuracy of the device. The assessment of the technical variability, i.e. inter- and intra-instrument reliability, is also necessary to appreciate the performance of an accelerometer.

The aim of this study was to assess the technical intra- and inter-instrument variability of this new wrist-worn accelerometer (Vivago®, Paris, France) under controlled conditions with a shaker device and during normal daily PAs.

2. Methods

2.1. Instrument

The accelerometer used is a uniaxial wrist-worn accelerometer (Vivago®, Paris, France). The activity

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signal, which is constructed from measured force changes at the unit's movement sensor, is continuously recorded on average once per minute and can store data recorded at 1-min epochs. The wrist-worn accelerometer reacts to omnidirectional changes in acceleration that generate a voltage via a piezoelectric sensor. The signal is amplified, digitised, and stored in memory as activity counts. The dynamic range of the accelerometer is ±4 g. The sample rate for body motion is 40 samples per second. The accelerometer is sensitive to movements in the 0.5–10-Hz range. Each accelerometer was initialised according to the manufacturer's recommendation according to each participant's body mass, stature, and age. The same computer was used for the initialisation and synchronisation of each accelerometer. Data were downloaded from the monitor to a computer after completion of all activities. Accelerometer data between minutes 3 and 10 were used to represent physiologic steady state. Data were expressed as the mean in *counts* $\cdot$ min^{-1}.

2.2. Experiment 1: technical variability of the wrist-worn accelerometer in a mechanical set-up

Technical variability was assessed using a shaker device. This device performs movement in the vertical plane. Ten accelerometers (Vivago®, Paris, France) were set up from the computer with the software. All monitors were attached to the shaker device in random order. Various acceleration conditions were applied to the devices by altering the frequency of oscillation. Intra- and inter-instrument comparisons were tested at five shaking frequencies (1.1, 2.1, 3.1, 4.1, and 10 Hz). Each frequency was maintained for 10 min. A detail of the number of repetition is presented in Table I. For statistical analysis, the first and the last minutes of each stage were discarded. The five frequencies level tests were randomised to avoid order effect. Amplitude was identical in the five testing conditions (0.035 m). The choice of the conditions was similar to other studies assessing the technical variability of different accelerometer models (Esliger & Tremblay, 2006; Powell, Jones, & Rowlands, 2003; Santos-Lozano et al., 2012). It is important to use these frequencies because they provide accelerations close to human movement (Freedson, Melanson, & Sirard, 1998; Santos-Lozano et al., 2012). In accordance with previous studies, the shaker device was warmed up for 5 min at each of the five frequencies before the testing period to achieve optimal functioning of the hydraulics and the control electronics (Esliger & Tremblay, 2006; Santos-Lozano et al., 2012).

Table I. Number of repetitions for each frequency.

	Number of repetition per minute
1.1 Hz	66
2.1 Hz	126
3.1 Hz	186
4.1 Hz	246
10 Hz	600

2.3. Experiment 2: technical variability of the wrist-worn accelerometer during normal daily PAs

Twenty-one healthy, active adults (10 females and 11 males), aged 20–34 years, were recruited for the study. The mean for age, body mass, and stature were 29.3 (5.2) years, 80.7 (11.9) kg, and 180.4 (9.2) cm for males, and 59.3 (4.6) years, 59.6 (4.5) kg, and 173.2 (8.6) cm for females, respectively. The purpose and objectives of the study were explained to each participant before the study began and written informed consent was obtained. The study was approved by the Lille University Research Ethics Committee (Comité de Protection des Personnes, Lille, France). All procedures were performed in accordance with ethical standards of the Helsinki Declaration of 1975, as revised in 2008, and Good Clinical Practice (Béghin et al., 2008).

A physical examination was required for all participants to check for exclusion pathologies. Eligibility criteria included body mass index between 19 and 24.4 kg $\cdot$ m^{-2}, 18–35 years of age, and normal clinical examination including normal psychomotor development. Exclusion criteria included obesity, chronic diseases, cardiovascular diseases, or metabolic diseases. Body mass was measured without shoes and heavy outer garments to the nearest 0.1 kg using an electronic scale (Oregon Scientific®, GA 101, Portland, OR, USA). Height was measured without shoes to the nearest 0.1 cm using a standard physician's scale. PA was assessed by accelerometry and oxygen uptake by gas-collection methodology. Intensity of PA varied from sedentary to vigorous. Activities were selected that reflected typical PA in adults under normal living conditions, e.g. walking, running, and sitting in the office or resting. Treadmill speed (mph) was similar to the study of Freedson et al. (1998). Participants wore two accelerometers on the wrist of the dominant arm and performed six consecutive 10-min periods of activity at increasing levels of intensity from sedentary to vigorous. Intensities of activity were defined as sedentary (resting on a bed and reading a book), light (walking slowly at 2.5 mph), moderate (walking at 3.7 mph and running slowly at 5 mph), and vigorous (running at 6.2 mph). All intensities were performed during the same testing session with a rest period between each activity varying between 3 and 10 min according to the participant's fatigue. The criterion chosen to

Table II. Mean of counts ± standard deviation and inter- and intra-instrument coefficient of variation (CV) at each frequency.

	1.1 Hz	2.1 Hz	3.1 Hz	4.1 Hz	10 Hz
Accelerometer (counts · min^{-1})	2.5 ± 4.2	20.4 ± 8.2	52.2 ± 10.9	62.1 ± 5.5	98.2 ± 3.2
CV inter-instrument					
%	18.3	12.4	6.7	4.8	2.6
SEM	2.98	2.23	1.23	1.03	0.58
CV intra-instrument					
%	23.2 ± 12.4	12.6 ± 8.7	8.1 ± 6.2	6.5 ± 4.7	4.1 ± 2.2
SEM	3.92	2.74	1.91	1.52	0.71

Note: SEM: Standard error of measurement.

proceed to the next activity was a return to the participant's respiratory quotient at rest (±10%).

Simultaneously, oxygen consumption (VO_2) and carbon dioxide production (VCO_2) were measured every 10 s for 10 min during each activity using a gas analyser (Respironics Novametrix Medical System® Inc, NICO 7300, Wallingford, WA, USA and Datex®, Ohmeda, Fairfield, CT, USA). The gas analyser was calibrated with standard gases before each session. Participants wore an adapted mask that was connected by plastic tubing to the gas analyser. The mask was worn during all experiments. Data captured between minutes 3 and 10 of each activity level were analysed.

2.4. *Statistical analysis*

All data were downloaded and the analysis performed using Statistical Package for the Social Sciences, Windows 11.5 (SPSS, Inc., Chicago, IL, USA), and Excel 2007 (Microsoft, Inc., Redmond, WA). All accelerometer data are expressed in counts per minute. Data are presented as means ± standard deviation (SD). The threshold for statistical significance was set to $P < 0.05$.

2.4.1. Inter-instrument variability. The inter-instrument coefficient of variation (CV) for each intensity was assessed using the formula: CV = standard deviation of the measure × 100/mean of the measure for each intensity. When CV increases, reliability decreases. The Pearson correlation coefficients were also calculated to assess the reproducibility between the accelerometers. In addition, the Bland and Altman method was used to test agreement of data output between the two devices in experiment 2 (Bland & Altman, 1986). The analysis measures bias as estimated from mean differences, the 95% confidence interval for bias, and the limits of agreement, ±2 standard deviations of the difference.

2.4.2. Intra-instrument variability. The intra-instrument CV was calculated for each accelerometer between minutes 3 and 10 of each activity. The intra-instrument CV was also calculated for each accelerometer over different periods of activity. This CV was also calculated with the formula CV = standard deviation of the measure × 100/ mean of the measure for each intensity. Decrease in intra-instrument CV reflects better reliability. In addition, intra-instrument variability was also assessed with intra-class correlation coefficient (ICC). The scale used for interpretation of concordance was previously described (Fleiss, 1986).

3. Results

3.1. *Experiment 1*

3.1.1. Inter-instrument variation. The inter-instrument CV for the wrist-worn accelerometer was 2.6–18.3% throughout different frequencies (Table II), with an average of 8.9%. Inter-instrument CV improved as frequency increased. Pearson correlation coefficients were calculated for all intensities (Table III).

3.1.2. Intra-instrument variation. Intra-instrument CV values using a mechanical set-up are presented in Table II. Intra-instrument CV showed greater variability at low compared with high frequency. The ICC for data accelerometer across all frequencies was 0.89 ($P < 0.001$).

Table III. Pearson's correlation in the two experiments.

	Pearson's correlation coefficients (p)
Experiment 1	
1.1 Hz	0.71 (0.05)
2.1 Hz	0.76 (0.042)
3.1 Hz	0.89 (0.021)
4.1 Hz	0.93 (0.002)
10 Hz	0.96 (0.0001)
Experiment 2	
Sedentary	0.63 (0.0262)
Light	0.85 (0.0151)
Moderate	0.92 (0.0014)
Vigorous	0.96 (0.0001)

Table IV. Mean of counts and oxygen uptake ± standard deviation and inter- and intra-instrument coefficient of variation (CV%) during typical PAs.

	Resting	Reading	Walking 2.5 mph (4 km · h^{-1})	Walking 3.7 mph (6 km · h^{-1})	Running 5 mph (8 km · h^{-1})	Running 6.2 mph (10 km · h^{-1})
Accelerometer (counts · min^{-1})	2.4 ± 1.3	10.6 ± 4.3	18.3 ± 2.8	29.3 ± 5.1	62.5 ± 6.8	95.6 ± 5.3
Oxygen uptake (ml · kg · min^{-1})	4.3 ± 0.8	7.1 ± 1.6	14.2 ± 1.7	18.3 ± 4.9	30.5 ± 5.4	37.1 ± 6.3
CV inter-instrument						
%	13.4	24.2	15.3	8.1	5.4	3.7
SEM	2.58	2.22	1.43	1.03	0.89	0.68
CV intra-instrument						
%	19.9 ± 11.7	13.3 ± 9.6	10.9 ± 7.3	6.3 ± 5.1	5.1 ± 4.7	4.3 ± 3.1
SEM	2.62	2.13	1.65	1.11	1.02	0.71

Note: SEM: Standard error of measurement.

3.2. Experiment 2

Accelerometer counts and oxygen consumption from accelerometry and indirect calorimetry are shown for each intensity in Table IV. PAs represented a wide range in oxygen uptake, 2.7–37.1 ml · kg · min^{-1}, with a correspondingly wide range in accelerometer counts, 6.5–95.6 counts · min^{-1}. Table III shows that data output from the accelerometer and indirect calorimetry increased with greater exercise intensity.

3.2.1. Inter-instrument variation. Inter-instrument CV for the wrist-worn accelerometer was 3.7–24.2% across all activities (Table IV). PA intensity was inversely related to inter-instrument CV. The CV varied from 13.4 to –24.2% for sedentary activities and from 5.4 to 8.1% for moderate PAs. The CV was 15.3% for light PA and 3.7% for vigorous PA. The average of the CV was 11.7%. Pearson correlation coefficients were calculated for all intensities (Table III).

Agreement was assessed at different intensities. Mean differences were within the limits of agreement and most data points were within the limits of agreement of bias (Figures 1–4).

3.2.2. Intra-instrument variation. Intra-instrument CV values during typical PAs are presented in Table IV. Intra-instrument CV showed greater variability during sedentary and light activity compared with moderate and vigorous activity. The ICC for data accelerometer across all intensities was 0.90 ($P < 0.001$).

4. Discussion

This study assessed the inter- and intra-instrument variability of the wrist-worn accelerometer under controlled conditions with a shaker device and during normal daily PAs. The principal findings showed high variability of accelerometer data for sedentary and light intensity and low variability for moderate and vigorous intensities.

Results from the present study show that the wrist-worn accelerometer has a poor inter- and intra-instrument reliability during low movement frequencies and that reliability improved at increased frequencies. Intra-instrument variability and inter-instrument variability of different accelerometers have been studied in laboratory settings (Brage, Brage, Wedderkopp, & Froberg, 2003; Esliger & Tremblay, 2006; Krasnoff et al., 2008; Metcalf,

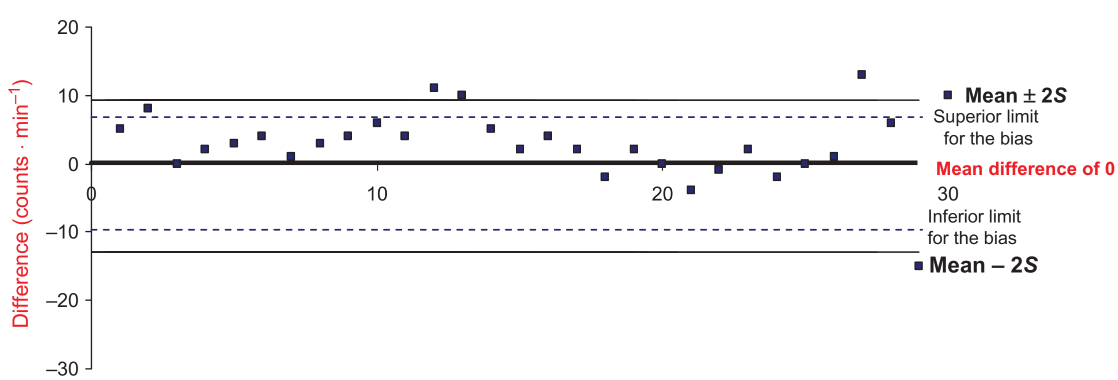

Figure 1. Difference in accelerometer counts between the two devices in sedentary intensity.

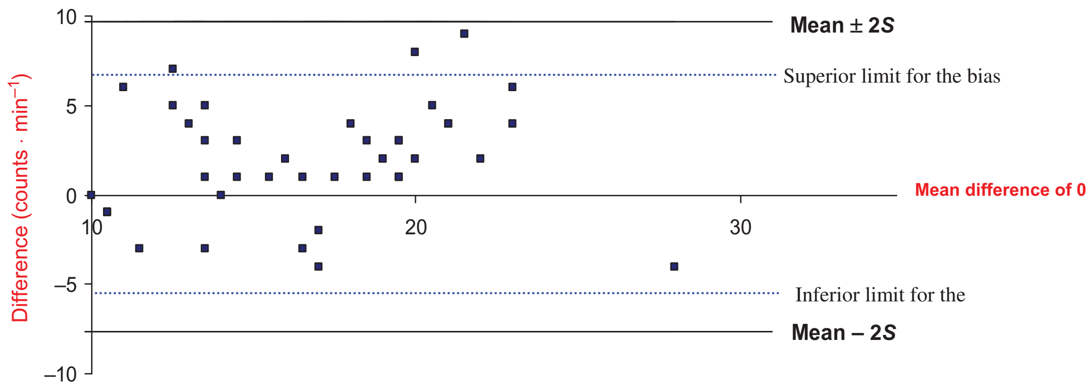

Figure 2. Difference in accelerometer counts between the two devices in light intensity.

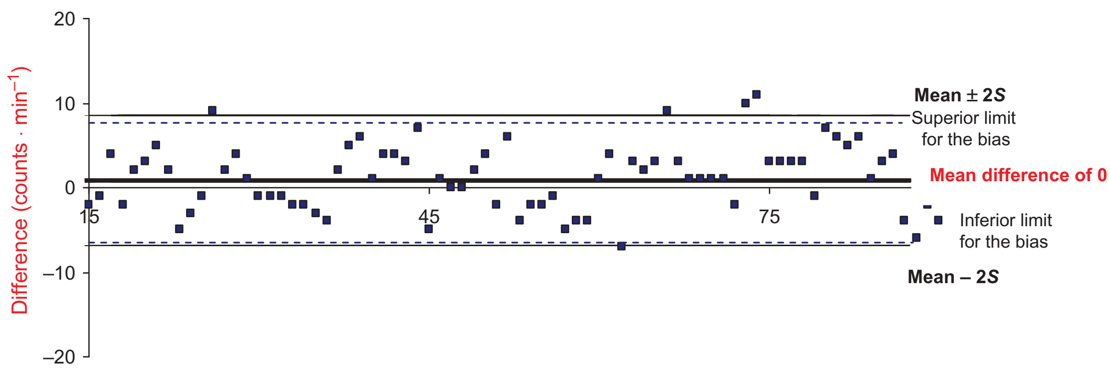

Figure 3. Difference in accelerometer counts between the two devices in moderate intensity.

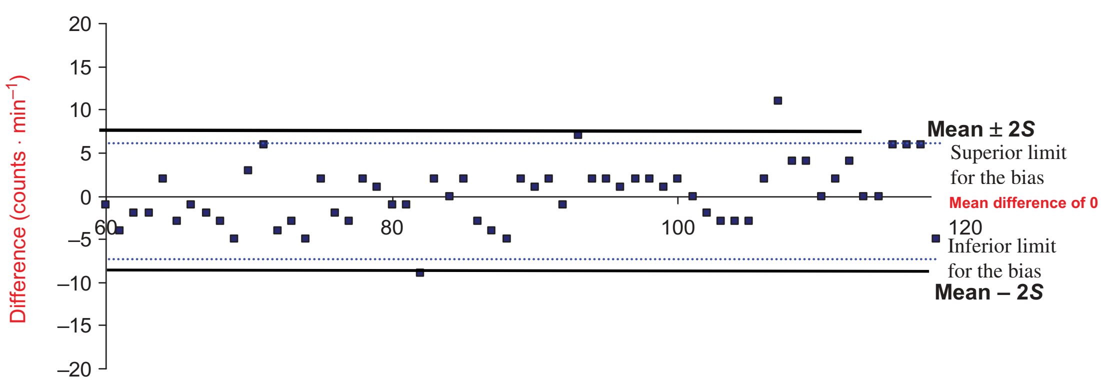

Figure 4. Difference in accelerometer counts between the two devices in vigorous intensity.

Curnow, Evans, Voss, & Wilkin, 2002; Santos-Lozano et al., 2012). These studies assessed technical variability of accelerometers using a motorised vibration table at various frequencies level. Our results are in agreement with other studies, either intra- or inter-instrument (Brage, Brage, et al., 2003; Esliger & Tremblay, 2006; Krasnoff et al., 2008; Metcalf et al., 2002; Santos-Lozano et al., 2012). Previous studies demonstrated that intra- and inter-instrument CV decreased with increased frequency of table vibration. The variability of the wrist-worn accelerometer is more closely related to the RT3® accelerometer than other accelerometers used in health research. Powell et al. (2003) found an inter-instrument CV of 21.9–26.7% at 2.1 Hz, 6.3–9.0% at 5.1 Hz, and 4.2–7.2% at 10.2 Hz, and an intra-instrument CV of 2.1–56.2%, 0.3–2.5%, and 0.2–2.9% at 2.1, 5.1, and 10.2 Hz, respectively. Similar to the wrist-worn accelerometer, these data show a low intra- and inter-instrument reliability of the RT3 during low frequency and that reliability improved as frequency increased.

In the second experiment (i.e. during normal daily PAs), the number of devices used was limited to two accelerometers, because they were attached around the wrist. It was not possible to add a third wrist-worn accelerometer on the same wrist. In fact, the position of the monitors around the wrist, i.e. closer or farther from the hand, might influence recorded values. The accelerometer attached closest to the hand might not detect the same amplitude of movements as the one placed farther from the hand. Because of the limited number of devices used in this second experiment, interpretation of inter-instrument CV must be taken with caution. Results may be compared with data obtained from experiment 1 because the average of accelerometer data output between the two experiments was similar. The mean of accelerometer data output in sedentary, light, moderate, and vigorous was 6.5, 18.3, 45.9, and 95.6 counts · min^{-1}, respectively, compared with 2.5, 20.4, 52.2, 62.1, and 98.2 counts · min^{-1} for 1.1, 2.1, 3.1, 4.1, and 10 Hz. A 1.1 Hz corresponds to sedentary activities, 2.1 Hz corresponds to light activities, 3.1 and 4.1 Hz correspond to the moderate activities, and 10 Hz corresponds to vigorous activities. Reliability assessed in normal daily PAs is in agreement with reliability assessed by the motorised vibration table. Data show modest intra- and inter-instrument reliability of the wrist-worn accelerometer during sedentary and light activity and that reliability improved with increasing PA. Results confirm data obtained in the first experiment using a motorised vibration table. Previous studies performed with other accelerometers, simulating activity patterns with a treadmill or in free living conditions, found that PA intensity was inversely related to intra- and inter-instrument CV with better CV for moderate and vigorous PA (Brage, Wedderkopp, Franks, Andersen, & Froberg, 2003; Powell & Rowlands, 2004; Reneman & Helmus, 2010; Vanhelst, Theunynck, Gottrand, & Béghin, 2010; Welk, Schaben, & Morrow, 2004). The possible explanation for this poor reliability of the Vivago® wrist-worn accelerometer in sedentary and light activity is the sensitivity of this device. The sensitivity has a direct effect on the reliability of the device. The Vivago® wrist-worn accelerometer has a wide frequency range (0.5–10.0 Hz). The wide frequency range allows smaller movements to be detected with a wider range of variation. The variation might lead to significant error in assessing PA level in sedentary and light activities in free living conditions.

Some limitations and considerations when transferring our findings to free living conditions about this wrist-worn accelerometer should be addressed. One limitation relates to the use of a uniaxial accelerometer. The triaxial accelerometer can measure movement in the three dimensions of space (Bouten, Koekkoek, Verduin, Kodde, & Janssen, 1997; Westerterp, 1999). The triaxial accelerometer measures PA during walking with more precision than the uniaxial accelerometer (Eston, Rowlands, & Ingledew, 1998; Levine, Baukol, & Westerterp, 2001). Plasqui and colleagues (Plasqui, Joosen, Kester, Goris, & Westerterp, 2005) concluded also that the triaxial accelerometer is better than a uniaxial accelerometer for measuring energy expenditure under free living conditions. However, two recent studies showed that the new uniaxial accelerometers do not differ in the measurement of PA in free living conditions than triaxial accelerometers (Adolph et al., 2012; Vanhelst, Béghin, et al., 2012). A second limitation is the wrist-worn device to assess PA. Although wrist-worn monitors improve feasibility and compliance in the assessment of PA in free living conditions, many studies showed a lower concurrent validity of the wrist-worn accelerometer compared with the accelerometer worn on the hip (Phillips, Parfitt, & Rowlands, 2013; Rosenberger et al., 2013; Routen, Upton, Edwards, & Peters, 2012). Therefore, further investigations should include the comparison of the PA intensity assessment between hip and wrist placements and a comparison of data obtained from the Vivago® wrist-worn accelerometer with an accelerometer widely used in the literature, such as the ActiGraph (ActiGraph™, Pensacola, CA, USA) accelerometer. Finally, the design of the experiment 2 was performed with young adult range. We cannot exclude the possibility that results would have been different had we used other age ranges.

5. Conclusions

In summary, the study demonstrated a high variability of accelerometer data for sedentary and light intensity and low variability for moderate and vigorous intensities. The wrist-worn accelerometer (Vivago®, Paris, France) appears to have an acceptable reliability compared with other accelerometers and can therefore be used for assessing PA in health and PA research.

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