

Reproducibility of a Triaxial Seismic Accelerometer (DynaPort)

VINCENT T. VAN HEES^{1,2}, SANDER M. SLOOTMAKER^{3,4}, GERT DE GROOT¹, WILLEM VAN MECHELEN^{3,4}, and ROB C. VAN LUMMEL²

¹Faculty of Human Movement Sciences, VU University, Amsterdam, THE NETHERLANDS; ²McRoberts B.V., The Hague, THE NETHERLANDS; ³Department of Public and Occupational Health, EMGO Institute, VU University Medical Centre, Amsterdam, THE NETHERLANDS; and ⁴Research Centre Body@Work TNO VUMC, VU University Medical Centre, Amsterdam, THE NETHERLANDS

ABSTRACT

VAN HEES, V. T., S. M. SLOOTMAKER, G. DE GROOT, W. VAN MECHELEN, and R. C. VAN LUMMEL. Reproducibility of a Triaxial Seismic Accelerometer (DynaPort). *Med. Sci. Sports Exerc.*, Vol. 41, No. 4, pp. 810–817, 2009. **Purpose:** To examine the reproducibility of a triaxial seismic accelerometer under controlled conditions and real-life conditions. **Methods:** Instrumental reproducibility was examined using a shaker device. The accelerometers (DynaPort MiniMod; McRoberts B.V., The Hague, The Netherlands) were shaken at four frequencies (0.8, 2.1, 3.6, and 4.6 Hz) in *x*- and *y*-directions. The magnitude of acceleration ranged from 0 to 1.277g. Additionally, reproducibility under real-life conditions was examined in 55 adolescents (12–17 yr), with the accelerometer attached to the lower back. Each subject walked four short walking trials on level ground at preferred speed. To make this setting meet real-life conditions, we detached and reattached the accelerometer between trials 2 and 3. Detachment of accelerometer between trials 2 and 3 was done by either the same researcher or different researchers (four in total). Intra- and interobserver reproducibility were calculated. **Results:** Intra- and interinstrumental intraclass correlation coefficients (ICC) were 0.99 for both *x*- and *y*-directions. The intrainstrumental coefficients of variance (CoV) were lower than 1.13%. The interinstrumental CoV were lower than 1.37%. Intraobserver ICC was 0.97, and interobserver ICC was 0.88. **Conclusion:** The reproducibility of the accelerometer is high under the controlled conditions of a shaker device and in walking at preferred speed. **Key Words:** GRAVITY, TECHNICAL, ADOLESCENTS, ACCELEROMETRY

The World Health Organization has pointed out that insufficient physical activity in adolescents is becoming an international health hazard. Insufficient physical activity may lead to overweight, obesity (5,13), cardiovascular diseases (10), and type II diabetes (12) in adulthood. Observation of daily physical activity and individual support (coaching) in active adolescents are important tools in the fight against insufficient physical activity. Physical activity can be characterized by four measures: time (duration), frequency (defined as the number of times an activity is executed during a day), intensity (defined as the level at which an activity requires energy), and type.

Accelerometers are used more and more to monitor the characteristics of physical activity. Accelerometers are inexpensive compared with calorimetric methods. Further,

accelerometers are suitable for long-lasting measurements in the daily environment due to their light weight and small size (21,23,24,30). Piezoelectric acceleration sensors are applied in most accelerometers as reviewed by Chen and Bassett (4). Seismic accelerometers are less commonly used when measuring physical activity. Seismic accelerometers have a DC response to the Earth's gravitational field. Seismic accelerometers use a seismic or a proof mass suspended by a spring structure in a case. When the case is accelerated, the proof mass is also accelerated by the force transmitted through the spring structure. Then the displacement of the spring, the displacement of the mass within the case, or the force transmitted by the spring is transduced into an electrical signal proportional to the acceleration. A capacitor or a resistor can be used as transduction element. A seismic sensor requires a permanent power supply for sensing. In a piezoelectric sensor, the electrical signal is produced by the piezoelement itself, and for that, a piezoelectric sensor does not require power supply for sensing. Both types of sensor require power supply for data processing and data storage. Therefore, a piezoelectric sensor will consume less energy to operate compared with a seismic sensor. The lower amount of energy consumption by the sensor results in a longer measurement duration. Further, piezoelectric sensors are useful as they can produce high outputs for small strains over a large dynamic range of motion

Address for correspondence: Rob C. van Lummel, MSc, McRoberts B.V., Raamweg 43, 2596 HN, The Hague, The Netherlands; E-mail: rcvanlummel@mcroberts.nl.

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(4). A major limitation of most piezoelectric accelerometers is that they can only reliably be used to detect dynamic events; this is due to a phenomenon known as “leakage,” which occurs when the initial change in charge in the piezoelectric element dissipates in time (4). The resistor or the capacitor in seismic accelerometers does not show leakage, and for that, seismic accelerometers are able to measure static acceleration. In static situations, the seismic accelerometer signal yields inclination information, whereas in dynamic situations, this information is combined with acceleration information (28). The information about inclination can be used to detect postures (7,28). The ability to measure the type of physical activity may be of use in addressing the role of physical activity patterns in the development of obesity and related health risk (11,15) or in COPD (19).

Recently, a new accelerometer, the DynaPort MiniMod (McRoberts B.V., The Hague, The Netherlands), referred to as DynaPort, has been developed. The DynaPort makes use of a triaxial seismic acceleration sensor (ADXL202; Analog Devices, Norwood, MA). The sensor has a full-scale range of $\pm 2g$; the frequency response of the sensor is 0–6 kHz (3 dB). The sample frequency is set at 100 Hz. An algorithm was developed by its manufacturer to detect the type of physical activity from the acceleration signals. This algorithm takes advantage of the sensor’s sensitivity to the earth’s gravitational field (28).

Little is known about the reproducibility of seismic sensors in measuring daily physical activity. Using such a sensor for individual feedback purposes demands a high reproducibility. A criterion applied to a measurement instrument at individual level is an intraclass correlation coefficient (ICC) greater than or equal to 0.90 (16). Lohr et al. (16) stated that an ICC greater than 0.70 is acceptable when comparing groups. The coefficient of variance (CoV) is another measure of reproducibility. The CoV is calculated by dividing the SD of the measurement values by the average measurement value (17,20,29).

Determining reproducibility of an accelerometer using a mechanical shaker device ensures minimal interference of other parameters (17,20,29). Reproducibility of accelerometers has also been examined with subjects (27). Walking is an important activity in daily life and is often chosen for reproducibility studies (2,6,14). Also, reattachment of an accelerometer between repeated measures is applied in daily practice but is not always applied in research on reproducibility (2,6,14). Furthermore, a change in observer between repeated measures can be a real-life measurement condition. Several studies, however, have used only a single observer (2,6,14). A discrepancy in the way of attachment of the accelerometer to the body will probably influence the measured value. The terms intraobserver and interobserver reproducibility are used when analyzing reproducibility within and, respectively, between observers (26). In this context, the observer is the person who attaches the physical activity monitor and instructs the subject about the experimental protocol.

The purpose of this study was to examine the reproducibility of the DynaPort under controlled conditions of a shaker device and whether the reproducibility is acceptable during walking in adolescents, taking the issues mentioned above into account.

METHODS

Accelerometer

The DynaPort contains three orthogonal positioned acceleration sensors. The resolution is 5.5 mg, the dimensions are $64 \times 62 \times 13$ mm, and the weight is 78 g (batteries included). The measurement duration is limited by energy supply (72 h). Recently, an external battery has been developed. This battery can be connected to the main instrument by a cable and increases measurement duration to 7 d. The dimensions of the external battery are $64 \times 40 \times 5$ mm (weight = 30 g). Data were stored on a commercially available secure digital card.

The sample frequency is set at 100 Hz to allow for appropriate functioning of the activity detection algorithm mentioned in the Introduction. Additionally, 100 Hz is required for gait analysis (3,8). The accelerometer was attached around the waist by using an elastic belt. The precise location of the accelerometer was on the back, near the spine. This position allows for a stable attachment of the accelerometer and allows for the estimation of trunk angles being part of the activity detection algorithm. Another reason for attaching the accelerometer to the lower back is to make the accelerometer equally sensitive to movement of the left and the right half of the body.

Analog signals were low-pass filtered (3 dB filter, cutoff frequency = 30 Hz). A digital high-pass filter can remove the component of gravitation acceleration from the signal only when the frequency of angular displacement is below the cutoff frequency of the high-pass filter. No literature was found about the right choice of cutoff frequency for the specific measurement setup used in this study. A fourth-order Butterworth band-pass filter was used, and cutoff frequencies were set at 0.2 and 8 Hz, similar to other accelerometers (4).

The values of the x -, y -, and z -signals were summed according to $\sqrt{x^2 + y^2 + z^2}$ (x -axis: posterior–anterior; y -axis: caudal–cranial; z -axis: medial–lateral when the monitor is placed on the waist). This signal will be denoted as the movement intensity (MI). The unit for MI is g ($1 g = 9.81 \text{ m}\cdot\text{s}^{-2}$). This measure is not the integral of the signal as used in some other physical activity monitors (4). The vector magnitude is in the same time resolution as the raw signal. The average MI (g) per test was used for statistical calculations.

Instrumental Reproducibility

Instrumental reproducibility was examined using a shaker device (SM25 B; Edmund Bühler, Deutschland). The

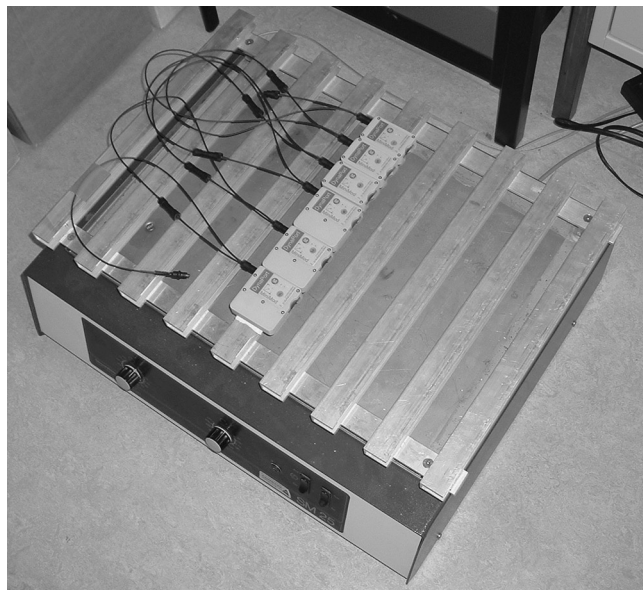


FIGURE 1—Shaker device.

shaker device performs a straight movement in the horizontal plane. The motion of the shaker device is a sine wave (amplitude = 15 mm). Six modules (accelerometers) were attached next to each other (Fig. 1). The intra-instrumental reproducibility was tested at four shaking frequencies (0.8, 2.1, 3.6, and 4.6 Hz) in a sequence from low to high. These frequencies cover the complete range of the shaker device. The most dominant movement frequency of the center of mass in walking at preferred speed is near 2 Hz. Because the accelerometer is attached near the center of mass, the range of frequencies applied by the shaker device (0.8–4.6 Hz) is deemed sufficient to represent the main human movement frequencies. Additionally, a null-frequency trial was performed. The applied MI by the shaker device can be calculated from the displacement and the frequency of shaking. The amplitude of the acceleration can be calculated as $r\omega^2$, where r is the radius of the motion and ω is the angular velocity, given by 2π times the frequency in hertz. Next, the applied MI equals the average of the absolute values of a sine wave having the amplitude just calculated. The characteristics of the applied motion by the shaker device are summarized in Table 1. Per frequency of shaking, six repeated measurements were executed of 5 s (500 samples) each; these six measurements are denoted as tests 1–6. The same data were used to test the interinstrumental reproducibility. The complete measurement session was executed twice. In the first session, the accelerometers were attached

with the x -sensor in the direction of the movement, the x -orientation. In the second session, the accelerometers were attached with the y -sensor in the direction of movement, the y -orientation. The direction of the z -sensor could not be tested due to a lack of space on the shaker device for solid attachment of the accelerometers. A synchronization cable set was used to start the accelerometers synchronously (Fig. 1). The shaker device was placed on a rubber mat and attached with tape to the floor to prevent shifting. The accelerometers were attached to the shaker device immovably using double-sided tape.

Reproducibility in Walking

Subjects. Fifty-seven adolescents (aged 12–17 yr) participated and were conveniently recruited from a secondary school. Subjects were informed about the study orally and on paper. Parents or legal guardians were informed about the study on paper and gave written informed consent. The Medical Ethics Committee of the VU University Medical Center in Amsterdam approved the study. Subjects were randomly divided into two groups: an intragroup for examining the intraobserver reproducibility and an intergroup for examining the interobserver reproducibility. Only adolescents who were able to participate in physical education lessons were admitted. The data of two subjects could not be used for analysis as a result of problems with data storage. The characteristics of the 55 subjects are shown in Table 2, and the weight classification was according to Cole et al. (5).

Design. Subjects walked a straight trajectory on level ground of 15 m, four times. The first two trials served as the test. The third and the fourth trial served as the retest. All trials were executed on the same day. The interval time between all trials was less than 1 min. Two types of subject instruction and instrumentation were applied; the subject was instructed and instrumented by the same observer in both test and retest, or the subject was instructed by two different observers. Four observers (three men and one woman) were involved in a randomized order. Observers were familiar with the accelerometer, ranging from 1 to 5 months. The protocol was instructed in writing and in words. Measurements took place in the school building. Two lines on the floor marked the length of the walking trajectory.

Subjects were asked to walk at their preferred speed from line 1 to line 2 and stop one step behind it. This procedure is assumed to resemble a natural ending of gait in contrast

TABLE 1. Characteristics of the motion applied by the shaker device.

Applied Motion by the Shaker Device				Measured by Accelerometer	
Frequency (Hz)	L (mm)	Acceleration [g / ($m \cdot s^{-2}$)]	MI (g)	MI (g), X-Orientation [Mean (SD)]	MI (g), Y-Orientation [Mean (SD)]
0	0	0 / 0	0	0.0018 (0.0003)	—
0.8	30	0.039 / 0.38	0.025	0.026 (0.0004)	0.024 (0.0003)
2.1	30	0.266 / 2.61	0.169	0.173 (0.0012)	0.174 (0.0011)
3.6	30	0.782 / 7.67	0.487	0.506 (0.0024)	0.516 (0.0030)
4.6	30	1.277 / 12.53	0.812	0.802 (0.0046)	0.810 (0.0070)

L, displacement (twice the radius of the sine wave); MI, movement intensity; —, equal to x -orientation.

TABLE 2. Characteristics of the research population

	Intragroup		Intergroup	
	Boys	Girls	Boys	Girls
N	11	5	17	22
Age (yr)	14.4 ± 1.5	12.6 ± 0.5*	13.7 ± 1.4	13.7 ± 1.1
Height (m)	1.72 ± 0.11	1.57 ± 0.07	1.68 ± 0.10	1.62 ± 0.08
Weight (kg)	62.5 ± 14.8	49.2 ± 7.8	55.9 ± 11.4	50.9 ± 8.9
BMI (kg·m ⁻²)	21.0 ± 3.9	19.9 ± 3.2	19.7 ± 2.8	19.4 ± 2.6
Weight classification	NW: 9 OW: 1 OB: 1	NW: 4 OW: 1 OB: 0	NW: 14 OW: 2 OB: 1	NW: 20 OW: 2 OB: 0

Values are presented as mean ± SD.

* Significantly different from boys $P < 0.05$.

NW, normal weight; OW, overweight; OB, obesity.

to stopping on the line. Subjects were asked to walk the second, the third, and the fourth trajectory at the same constant speed as in the first. The additional walking distance after passing the 15-m line was measured using a measuring tape. In several subjects, a disturbance in gait occurred, mainly due to diversion of attention of the subject. In case of a disturbance in gait, the trial was restarted. The same accelerometer was used in all trials. The accelerometer was attached near the spine on the lower back using an elastic belt around the waist and above the clothes. All observers were instructed to fasten the belt tight. In all subjects, the belt was detached and reattached between test and retest. In the intergroup, the first observer detached the belt and a second observer reattached the belt.

Data analysis. In the measurements executed with the shaker device, the mean MI was calculated per test. Instrumental validity was evaluated by comparing mean measured MI to applied MI. In walking, the mean MI was calculated per walking trajectory. In data analysis, a walking trajectory was defined between the two standing positions, that is, as defined by no alternation of the vertical signal except noise. The beginning and the end of each walking trajectory were manually selected from a graph of the data. The average speed of walking was calculated by dividing the distance walked, as measured with the measuring tape, by the duration of walking. To correct for differences in walking speed, we divided the mean MI per walking trajectory by walking speed. The mean MI / (km·h⁻¹) of trajectories 1 and 2 served as the test value, and the mean MI / (km·h⁻¹) of trajectories 3 and 4 served as the retest value. To evaluate the acceleration components generated during the walking trials, we used the fast Fourier analysis to estimate the most dominant frequency of movement per axis of the accelerometer. Additionally, the range in detected accelerations was evaluated per axis of the accelerometer.

Statistics. The intrainstrumental ICC (3,1) for consistency was calculated per x - and y -orientations for all frequencies of shaking and for all modules using two repeated measures per module (test 1 compared with test 2 and test 3 compared with test 4). The interinstrumental ICC (3,1) for consistency was calculated per x - and y -orientations for all frequencies of shaking. All 15 possible pairwise combinations of modules were included (1–2, 1–3,

1–4, 1–5, 1–6, 2–3, 2–4, 2–5, 2–6, 3–4, 3–5, 3–6, 4–5, 4–6, and 5–6), and no measurement value was included twice. The CoV values were calculated for each measurement configuration and each test (interinstrumental or module (intrainstrumental)). When a difference between repeated measures of 5% is set to be acceptable, the CoV should not exceed $5\% / 1.96 = 2.55\%$ ($P < 0.05$).

The intrainstrumental CoV was calculated over the six tests together for every combination of module, frequency of shaking, and orientation. The interinstrumental CoV was calculated for the six modules together for every combination of test, frequency of shaking, and orientation. The x - and y -orientations were compared using a one-sample t -test.

To examine intra- and interobserver reproducibility, we calculated the ICC (3,1) for consistency between repeated walking tests. The walking speed was compared between test and retest for the intragroup and the intergroup using a one-sample t -test. To assess the basic relation between walking speed and accelerometer output, we calculated Pearson's correlation coefficient between average walking speed and average MI per trial over all subjects. Statistical Package for the Social Sciences (version 12.0.1; SPSS Inc., Chicago, IL) was used to calculate ICC. MI and CoV were calculated using Matlab 6.5 (The MathWorks Inc., Natick, MA). A significance of $P < 0.05$ indicates a significant difference.

RESULTS

Instrumental reproducibility. The repeated measurements on the shaker device with the six accelerometers were executed as planned. The ICC for intra- and interinstrumental reproducibility was 0.99 in both x - and y -orientations. CoV values were small for 2.1, 3.6, and 4.6 Hz (<1%). The CoV values tended to be higher at 0 and 0.8 Hz. The intrainstrumental CoV reached a maximum of 1.13% at 0.8 Hz, and the interinstrumental CoV reached a maximum of 1.37% at 0.8 Hz (see Table 3). No significant difference was found in CoV values (0.8–4.6 Hz) between x - and y -orientations. The interinstrumental CoV value for 0 Hz was higher compared with the intrainstrumental CoV value for 0 Hz. For other frequencies of shaking, no obvious differences were found between intra- and interinstrumental CoV values. The SD in MI per module over six tests was

TABLE 3. CoV values (%) for all experimental conditions (mean and range).

Frequency (Hz)	Intrainstrumental		Interinstrumental	
	X-Orientat	Y-Orientat	X-Orientat	Y-Orientat
0*	9.75 (6.16–16.02)	–	18.8 (14.93–26.05)	–
0.8	0.72 (0.60–1.13)	0.91 (0.45–1.13)	1.20 (1.03–1.37)	0.78 (0.62–0.96)
2.1	0.53 (0.49–0.56)	0.67 (0.60–0.73)	0.53 (0.49–0.57)	0.20 (0.12–0.32)
3.6	0.40 (0.37–0.42)	0.36 (0.28–0.42)	0.49 (0.43–0.57)	0.54 (0.38–0.68)
4.6	0.38 (0.35–0.41)	0.19 (0.14–0.21)	0.62 (0.43–0.78)	0.92 (0.84–0.98)

–, equal to x-orientation; *, no movement; for details, see Table 1.

<3.3 mg. The SD in MI per test over several modules was <7.9 mg (Fig. 2). Additional to the assessment of instrumental reproducibility, the instrumental validity was evaluated. Differences between applied MI and average measured MI were low (<2.5%) for both x- and y-orientations (Table 1).

Reproducibility in walking. An example of the MI over time for one walking trial is shown in Figure 3. The maximal observed average value for MI per trial was 0.33g. Fast Fourier analysis of the frequency content of acceleration signal in walking adolescents reveals that the most dominant frequency was 1.95 ± 0.13 Hz for the x-axis, 2.06 ± 0.71 Hz for the y-axis, and 4.14 ± 2.35 Hz for the z-axis. On average, the x-axis ranges from $-0.91g$ to $0.44g$, the y-axis ranges from $0.42g$ to $1.80g$, and the z-axis ranges from $-0.86g$ to $0.72g$. If adolescents were instructed by one observer, the reproducibility of the MI value between two pairs of walking trails was 0.97 (95% confidence intervals = 0.91–0.99). If different observers were involved, the ICC of the MI value was 0.88 (95% confidence intervals = 0.79–0.94). In the intragroup, the MI value corrected for walking speed was $0.001g / (km \cdot h^{-1})$ higher in the retest ($P < 0.05$); no significant difference was found for the intergroup (Fig. 4). No significant difference in walking speed was found between test and retest for the intragroup (test = $3.98 \pm 0.48 km \cdot h^{-1}$; retest =

$4.08 \pm 0.50 km \cdot h^{-1}$) or the intergroup (test = $3.97 \pm 0.43 km \cdot h^{-1}$; retest = $3.98 \pm 0.42 km \cdot h^{-1}$). The average MI per trial was 0.22 ± 0.05 , 0.24 ± 0.05 , 0.23 ± 0.05 , and 0.24 ± 0.05 for trials 1, 2, 3, and 4, respectively. The correlation coefficient (r) between average walking speed and average MI per trial was 0.81, 0.86, 0.81, and 0.83 for trials 1, 2, 3, and 4, respectively ($P < 0.0001$ for each).

DISCUSSION

This is the first study to examine the reproducibility of a triaxial seismic accelerometer by shaking and during walking in own pace. Instrumental reproducibility was examined for six accelerometers in two directions of movement by using a shaker device. The MI as measured in repeated mechanical movement had a high reproducibility. The ICC were 0.99 for both orientations of the accelerometer. This high value could be explained by the large distribution in the frequencies of shaking. The CoV values were small (<1.37%) for all measurement configurations involving shaker movement. The intrainstrumental CoV values at 0 Hz were smaller compared with interinstrumental. For the other frequencies, no remarkable differences were observed between intrainstrumental and interinstrumental or between x-orientation and y-orientation. Powell et al. (20) found a significant difference between y

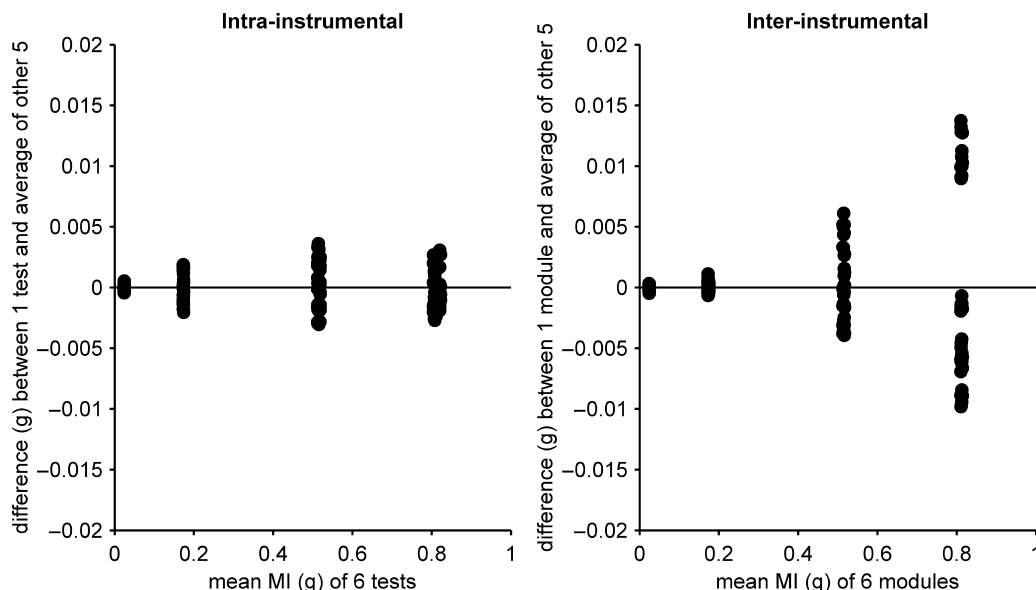


FIGURE 2—Bland Altman plots for intra- and interinstrumental agreement.

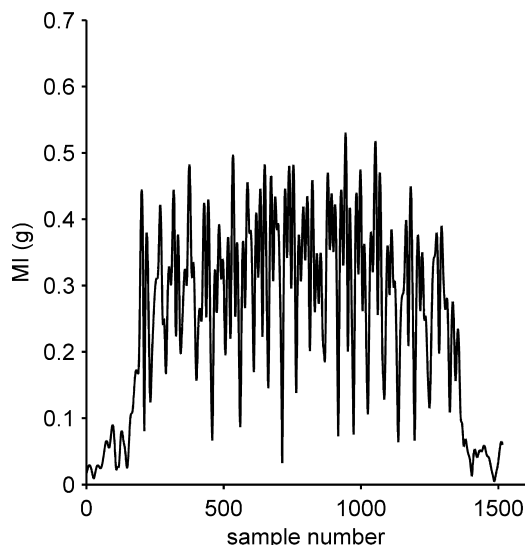


FIGURE 3—Example of MI (g) over time for one subject in one trial.

and x/z -axes of the RT3 accelerometer at 5.1 and 10.2 Hz. The differences found in CoV value between x -orientation and y -orientation in the current study are very small (0.1–0.3%) and not consistent over the frequencies. By that, it may be concluded that the reproducibility of the x -axis in the DynaPort is comparable to the reproducibility of its y -axis.

The sensitivity of the sensor may be the limitation for instrumental reproducibility. The smallest detectable change of the sensor (sensor sensitivity) is 5.5 mg. The SD in MI per module over six tests on the shaker device was <3.3 mg. The SD in MI per test over several modules was <7.9 mg. These figures indicate that most of the variation within and between modules is beyond the sensitivity of the sensor. The CoV values at frequency 0 and 0.8 Hz tended to be higher compared with 2.1, 3.6, and 4.6 Hz. This may be the result of a constant absolute error at all measurement configurations. A constant error will mathematically result

in higher CoV values when MI values are low. This constant error could be the finite sensitivity of the acceleration sensor. Besides the current study, only two other studies have assessed the technical reproducibility of an accelerometer for low accelerations ($<0.5g$) (1,20). Brage et al. (1) showed that CoV rapidly increases when acceleration approaches zero. A similar pattern was recognized in the current study and may be explained by the constant measurement error resulting from a limited sensitivity of the sensor as discussed before. The sensitivity of the accelerometer investigated by Brage et al. (1) had a sensitivity three times lower compared with the accelerometer used in the current study (16.6 vs 5.5 mg). This may explain the difference in CoV values for low acceleration between both studies. The intrainstrumental CoV values found in the current study at higher levels of acceleration (0.5–1.3g) are comparable to the results found for the Actical by Esliger et al. (9) and to the results found for the Actigraph by Metcalf et al. (17). The interinstrumental CoV values found in the current study are the lowest reported so far (1,9,17,20,24). An explanation for the good interinstrumental CoV might be the procedure used for sensor calibration. Seismic sensors can be calibrated in a static situation with gravitational acceleration as a reference. Piezoelectric sensors require a calibration device that applies a known dynamic acceleration to the sensor. The reproducibility of the calibration procedure will affect the interinstrumental reproducibility of the sensor.

Instrumental validity was assessed by comparing applied MI to mean measured MI. The difference was smaller than 2.5%, indicating high technical validity. The measured MI value at 0 Hz (0.0018g) represents white noise within the frequency range (0.2–8 Hz). This type of noise cannot be removed by filters because then acceleration related to movement by the shaker device or the human movement will be removed too.

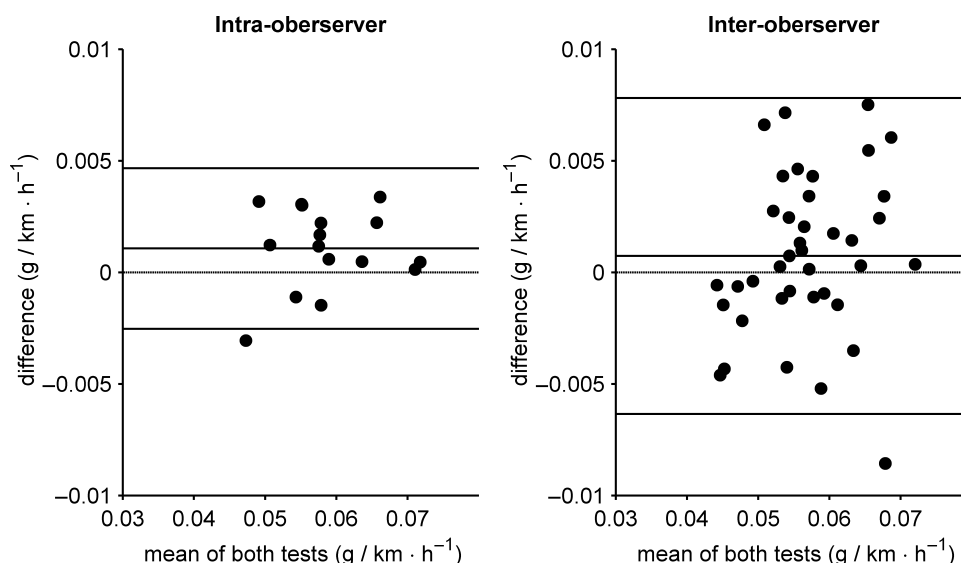


FIGURE 4—Bland Altman plots for intra- and interobserver agreement.

Unfortunately, the instrumental reproducibility of the z -axis could not be tested. However, the small differences in CoV values between x - and y -orientations indicate the sensor axis not to play an important role in reproducibility. Six modules were tested on the shaker device. In the study by Esliger et al. (9), the CoV value for the Actical decreased from 15.5% in 5 monitors to 5.4% in 39 monitors. Further, the CoV value for the Actigraph increased from 3.2% in 5 monitors to 4.9% in 48 monitors (9). Such changes may theoretically apply to the DynaPort too. However, results will still remain good compared with other accelerometers, even if the interinstrumental CoV values increases threefold.

The MI values for walking are within the range of the MI applied by the shaker device. The accelerations detected by the x -axis and the z -axis for the walking trials are also within the range of the shaker device. The accelerations in walking detected by the y -axis were not, which limits the generalizability of the experiment on the shaker device. In a previous study, fast Fourier analysis of the frequency content of daily activities reveals that the major energy band of human movements lies within the interval of 0.3 to 3.5 Hz (25). These figures indicate that the frequencies generated during the walking trials for x - and y -axes were within the range of daily physical activity. However, the frequencies generated in sideward direction (z -axis) were outside the range just mentioned, probably because sideward accelerations are less dominant in daily life.

The reproducibility of the DynaPort was estimated in 55 adolescents. The intraobserver reproducibility ICC was high (0.97). According to the criteria of Lohr et al. (16) (>0.90), this allows for the application of the DynaPort by one observer in walking adolescents. The interobserver reproducibility (ICC = 0.88) was lower compared with the intraobserver reproducibility.

The time between detachment and reapplication was short, less than 1 min. This possibly increased the ability of the observer to reattach the belt in the same way and may

have affected the intraobserver reproducibility in a positive way. The lower reproducibility in adolescents compared with the shaker device can be explained by three aspects. (i) The variability of the subject's movement and the correction for walking speed may not be sufficient to correct for all differences in body movement. (ii) The freedom of movement of the accelerometer relative to the body, which depends on the way in which the elastic belt was fastened. Despite the general instructions given to the observers, the method of fastening could have differed between them and thus have affected the signal. A higher degree of freedom could further have originated from the attachment of the accelerometer above the clothes. Recently, a new belt was developed, made of neoprene. In the future, this belt can be worn direct on the skin. (iii) Finally, the exact position of attachment could also have affected the signal. In mechanics, the acceleration of a mass is related to the distance between its center of mass and the axis of rotation. The exact position of the attachment relative to the axis of rotation was not verified by measuring it. The preferred walking speed on level ground in the current study ($1.1 \text{ m}\cdot\text{s}^{-1}$) corresponds well to values found in literature; $0.98 \text{ m}\cdot\text{s}^{-1}$ in younger adolescents ($9.4 \pm 1.4 \text{ yr}$) (18), $1.32 \text{ m}\cdot\text{s}^{-1}$ in young adults (18–35 yr) (22), and also $1.32 \text{ m}\cdot\text{s}^{-1}$ in older adults (65–85 yr) (22).

The current study is restricted to walking at preferred speed and of very short duration. Future research will have to examine other intensity levels, other types of physical activity (e.g., sit to stand transfers or running), and physical activity of longer duration. However, it seems fair to conclude that the reproducibility of the DynaPort is such that it can be used in adolescents when walking at preferred speed.

The authors V.T. van Hees and R.C. van Lummel are employed by the McRoberts B.V., who sponsored this investigation. This company is manufacturer of the DynaPort. The results of the present study do not constitute endorsement by the ACSM.

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