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Technical note

# Concurrent validity and intrasession reliability of the IDEEA accelerometry system for the quantification of spatiotemporal gait parameters☆

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**Abstract**

The aim of this pilot study was to evaluate concurrent validity and intrasession reliability of the IDEEA (Minisun, Fresno, CA) accelerometry system (and associated software) with force plate measurements for spatiotemporal gait variables recorded during normal walking. Ten healthy individuals were asked to walk at a self-selected comfortable speed, over five multicomponent force plates embedded into the walkway floor. For each trial, spatiotemporal gait parameters (single support time, cadence, speed, step and stride length) obtained by the force plates were compared to those recorded by IDEEA. Concurrent (criterion-related) validity between the two systems was analysed with intraclass correlation (ICC) (2,1). Intrasession reliability was quantified by using coefficient of variations (CV) and ICC. For the ensemble of the parameters, ICC (2,1) ranged between 0.998 (cadence) and 0.784 (step length right) ( $p < 0.001$–0.01). However, speed, step length and stride length were significantly lower for IDEEA ( $\sim$7%; $p < 0.001$) compared to force plate data. Intrasession reliability of IDEEA was excellent, with CV lower than 5.7 and ICC higher than 0.961. The present accelerometry system demonstrated strong concurrent validity for the assessment of spatiotemporal gait parameters. However, spatial variables (stride and step length) and walking speed were significantly underestimated compared with analyses using force plates.


*Keywords:* Accelerometers; Stride; Step; Cadence

## 1. Introduction

Clinicians need a simple method for quantifying spatial (e.g., step and stride length) and temporal (e.g., single and double support times, cadence) parameters of gait, which could provide useful information for diagnosis and treatment. Different valid and reliable tools (force plates, 3D kinematic analyses, pressure sensors) are used for the assessment of these gait variables, mainly in laboratory settings [1–3]. In the last few years, due to considerable advances in portable technology, the use of accelerometer-based gait systems has been suggested. For example, single and multiple (triaxial) accelerometers fixed over different parts of the body have been found to be valid and reliable for the analysis of gait parameters [4–6] and lower limb motion [7].

A system composed by five biaxial body-mounted accelerometers (chest, thighs and feet) has recently been introduced (IDEEA, Minisun, Fresno, CA), which according to the manufacturer [8] could provide valid assessment of spatiotemporal parameters of gait. Compared to previously described systems, IDEEA can provide the concurrent quantification of basic gait variables and human daily physical activity, including the accurate estimation of energy expenditure [9]. However, it is unclear whether the proposed

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biaxial accelerometers can accurately take into account the 3D motion of the lower limbs during walking or not.

The aim of this pilot study was to examine concurrent validity and intrasession reliability of the IDEEA accelerometry system (and associated software) with force plate measurements (criterion measure) for spatial and temporal gait variables recorded during normal walking.

## 2. Methods

### 2.1. Subjects

Ten healthy individuals (five males, five females), with no known orthopaedic or neurological problems volunteered to participate in the study (mean age ± S.D.: 34 ± 11 years; height: 1.76 ± 0.12 m; mass: 70.5 ± 11.0 kg). As members of the laboratory staff, they were well accustomed to the experimental procedures. The local ethics committee has approved this study, and subjects provided written informed consent prior to data collection.

### 2.2. Data acquisition

On their arrival at the laboratory, subjects were fitted with IDEEA accelerometers according to manufacturer's recommendations [8,9]. Briefly, five biaxial capacitive accelerometers (size 18 mm × 15 mm × 3 mm; weight ~2 g) were taped over the sternum (4 cm below the jugular notch; Fig. 1A), over each thigh (midway between the patella and anterior superior iliac spine; Fig. 1B) and on the plantar surface of each foot (~2 cm proximal to the head of the fourth metatarsal; Fig. 1C). Chest and thigh sensors were vertically oriented (*z*-axis) while foot sensors were oriented in the anteroposterior direction (*y*-axis). Sensors were connected to a 32 MHz microprocessor (size 70 mm × 44 mm × 18 mm; weight 59 g; capacity 200 MB) with wires, and the microprocessor was fixed to the subject's waist band (Fig. 1B). After the entire setup procedures, each subject was asked to sit in an upright position, with the thighs parallel to the floor and both feet flat on the ground (i.e., 90° at the hip, knee and ankle joints), while the system performed a baseline calibration of each sensor (~10 s). A maximal deviation of 15° in each direction was allowed. Following calibration, subjects walked (barefoot) at self-selected comfortable speed over the force plates (FP).

We used five 40 cm × 60 cm multicomponent FP (type 9281B, Kistler Instrumente AG, Winterthur, Switzerland) based on piezoelectric sensors. Force plates were embedded in the walkway, and they were entirely separated mechanically from the surrounding floor. The global coordinate system was set in the centre of the third FP. Subjects walked three to four steps before the first and after the last FP, to reach a steady state of ambulation. A series of three to five familiarization trials always preceded the experimental measurements (minimum 10 trials). For each walking trial, spatiotemporal gait parameters were simultaneously measured by IDEEA (sampling frequency 32 Hz) and FP (sampling frequency 2000 Hz).

### 2.3. Data analysis

For individual trials, only the walking steps performed over the FP (four to five steps in the central part of the walkway) were

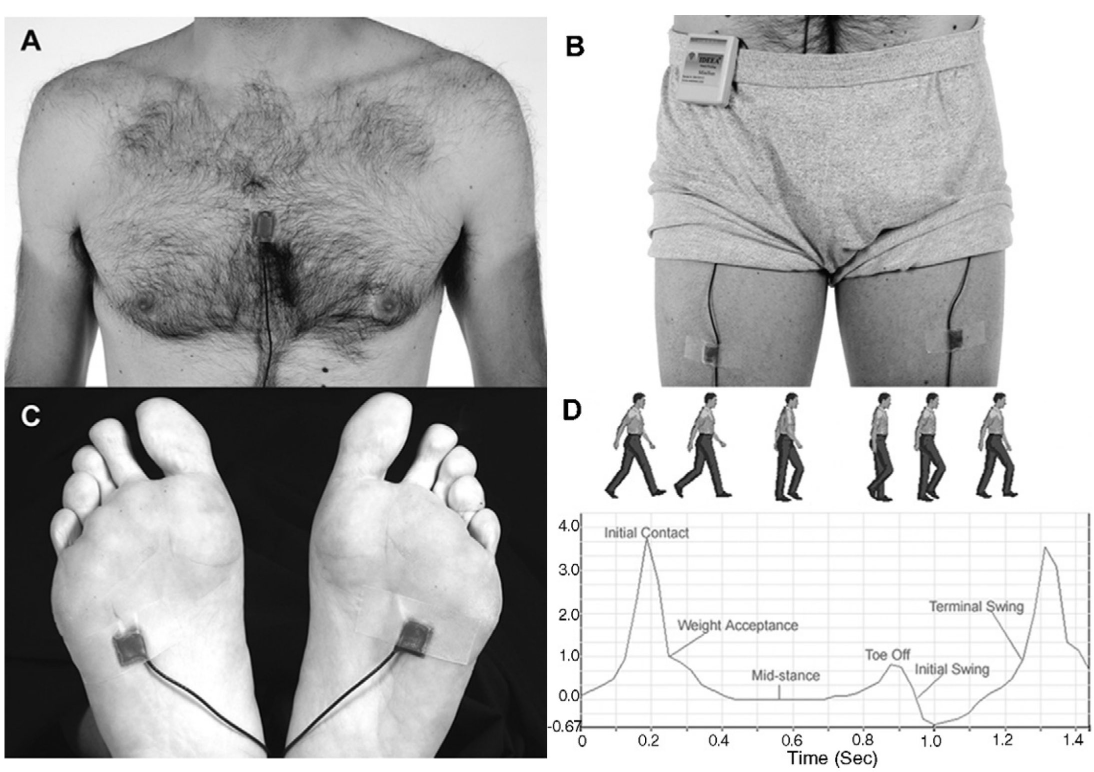


Fig. 1. IDEEA (biaxial) accelerometers were taped over the sternum (A), over each thigh (B) and on the plantar surface of each foot (C). Note that chest and thigh sensors were vertically oriented (*z*-axis) while foot sensors were oriented in the anteroposterior direction (*y*-axis). The microprocessor was fixed to the subject's waist band (B). (D) Anteroposterior acceleration signal recorded by the right foot sensor during a single stride, together with the events detected by the software according to manufacturer's specifications.

considered for analysis. The number of correct trials included in the analyses ranged between 9 and 12 for individual subjects. For each walking trial, spatiotemporal gait parameters were calculated from FP measurements according to the methodology proposed by Stacoff et al. [10]. Briefly, vertical ground reaction force signal was detected during foot–ground contact at a threshold of 2% body weight. Stance time was thus defined as the time elapsed between touchdown and takeoff of the same foot. The following spatiotemporal variables were then quantified (average of one walking trial):

(i) Single support time (ms) for the right and the left foot, i.e., the time elapsed between the last contact of the current footfall to the first contact of the next footfall of the same foot.
(ii) Cadence (steps/min).
(iii) Speed (m/s), i.e., the average velocity over two consecutive strides.
(iv) Step and stride length (m) for both sides, i.e., the difference of the *y*-coordinate (direction of walking) of the centre of pressure at the instant of touchdown between the left and right (or right and left) foot (defined as one step), and between two consecutive contacts of the same foot (defined as a stride).

Spatiotemporal parameters obtained from FP measurements were compared to those calculated by IDEEA manufacturer's proprietary software (GaitView 2.2, Minisun, Fresno, CA), after individual data transfer from the microprocessor to a PC via a 12-bit ac/dc converter. According to Saremi et al. [8], the two independent sensing axes (anteroposterior and vertical) of each accelerometer use a proprietary algorithm that depends especially on subject height and thigh and foot acceleration during the swing phase to calculate spatiotemporal gait variables. The anteroposterior acceleration recorded by one foot sensor (right) during a single stride, as well as the gait events detected by the IDEEA software – according to manufacturer's specifications (see http://www.portablegaitlab.com) – are presented in Fig. 1D.

### 2.4. Statistical analysis

Concurrent (criterion-related) validity between the two systems was analysed with intraclass correlations (ICC) (2,1) (absolute agreement). In addition, paired sample *t*-tests were used to determine if the gait values obtained from FP and IDEEA were significantly different. Intrasession reliability was quantified by using the coefficient of variation (CV), i.e., absolute reliability, and the ICC (3,1) (consistency), i.e., relative reliability. As a general rule, we considered ICC over 0.75 as strong, or excellent. Statistical significance was set at $p < 0.05$.

## 3. Results

### 3.1. Validity

For the ensemble of the parameters, ICC (2,1) ranged between 0.784 and 0.998, indicating strong concurrent validity ($p < 0.01$ in some parameters and $p < 0.001$ in others; Table 1). The highest ICC was observed for temporal parameters (single support time and cadence), and the lowest for spatial parameters. In addition, speed, step length and stride length (for both sides) were significantly lower ($p < 0.001$) for IDEEA compared to FP. The average difference between the two systems was 7.2% for walking speed, 7.5% for step length, and 7.2% for stride length.

Table 1
Concurrent validity of the IDEEA accelerometry system with force plates for spatiotemporal gait parameters ($n = 10$)

| | Force plates | IDEEA | ICC (2,1) |
|---|---|---|---|
| Single support L (ms) | 418.0 ± 38.3 | 420.3 ± 28.7 | 0.940† |
| Single support R (ms) | 422.3 ± 40.4 | 419.5 ± 22.7 | 0.870‡ |
| Cadence (steps/min) | 116.2 ± 9.3 | 116.6 ± 9.8 | 0.998† |
| Speed (m/s) | 1.492 ± 0.152 | 1.383 ± 0.140* | 0.836† |
| Step length L (m) | 0.764 ± 0.060 | 0.715 ± 0.068* | 0.821† |
| Step length R (m) | 0.779 ± 0.073 | 0.714 ± 0.083* | 0.784† |
| Stride length L (m) | 1.549 ± 0.132 | 1.441 ± 0.133* | 0.823† |
| Stride length R (m) | 1.538 ± 0.132 | 1.427 ± 0.149* | 0.799† |

Mean values ± S.D. *Abbreviations*: ICC, intraclass correlation; L, left; R, right.
* IDEEA lower than force plates, $p < 0.001$.
† $p < 0.001$.
‡ $p < 0.01$.

Table 2
Intrasession reliability of force plates and IDEEA accelerometry system for spatiotemporal gait parameters ($n = 10$)

| | Relative reliability, ICC (3,1) | | Absolute reliability, CV | |
|---|---|---|---|---|
| | Force plates | IDEEA | Force plates | IDEEA |
| Single support L | 0.993 | 0.974 | 2.24 | 2.96 |
| Single support R | 0.990 | 0.961 | 2.56 | 3.61 |
| Cadence | 0.994 | 0.981 | 1.86 | 2.73 |
| Speed | 0.991 | 0.985 | 2.58 | 4.13 |
| Step length L | 0.994 | 0.965 | 1.75 | 5.72* |
| Step length R | 0.988 | 0.987 | 2.24 | 4.96* |
| Stride length L | 0.992 | 0.977 | 1.65 | 4.02 |
| Stride length R | 0.992 | 0.981 | 1.67 | 5.30** |

*Abbreviations*: ICC, intraclass correlation; CV, coefficient of variation; L, left; R, right.
* IDEEA higher than force plates, $p < 0.05$.
** IDEEA higher than force plates, $p < 0.01$.

### 3.2. Reliability

Intraclass correlations (3,1) showed excellent relative reliability of the IDEEA system, with values ranging between 0.961 (single support right) and 0.987 (step length right). In respect to the FP data, all ICC values were even higher compared to IDEEA (range 0.988–0.994) (Table 2). In the same way, CV for IDEEA (range 2.7–5.7) was higher compared to FP (range 1.6–2.6). These differences were significant for step length (both sides) and for stride length (right) ($p < 0.05$). With IDEEA, the lowest CV (~3) was observed for temporal parameters and the highest CV (~5) for spatial parameters, while CV calculated on FP data was similar (~2) whatever the variable considered.

## 4. Discussion and conclusions

The results of this pilot study provided experimental evidence that, despite the IDEEA accelerometry system demonstrated excellent validity and reliability, walking speed and spatial parameters of gait (step and stride length) were significantly underestimated compared to force plate data. Considering that the processes (e.g., algorithm(s) and filter(s) characteristics) performed by the IDEEA software have not been specified, several factors may have contributed to this error. For example, it is unclear if the gravitational component of the foot and thigh acceleration [5] or if any soft-tissue vibrations and any drift occurring during double integration of the acceleration signal were adequately taken into account by the IDEEA proprietary algorithm.

Despite the lack of information on the calculation of spatiotemporal data by the commercial system, it is interesting to note that temporal parameters were found to be valid and extremely similar to vertical (1D) ground reaction force measurements recorded by FP. On the other hand, spatial variables and speed calculated by IDEEA (based on acceleration measurements on anteroposterior and vertical axes) demonstrated lower validity and were significantly underestimated compared with FP findings, based on centre of pressure measurements on mediolateral and anteroposterior axes. The major problem for the quantification of spatial gait parameters using IDEEA is that mediolateral acceleration is not measured and therefore movements in the horizontal plane (e.g., toeing-in and -out) cannot be taken into account. As an example, more toeing-out would produce large deviations in step length.

Despite the above discussed limitations, the IDEEA system is potentially useful for the assessment of walking performance in real-life conditions, it can provide data over a long period of time, it is easy-to-use and relatively inexpensive. However, it should be noted that steady state of ambulation – which is necessary for the validity of gait data – cannot be easily obtained outside the laboratory. Intrasession reliability has been found to be excellent, and therefore the system is probably sensitive to relative changes. The validity and reliability of the IDEEA system in patients with gait abnormalities require further investigation in the future. These individuals may indeed produce unexpected accelerations including movements out of the sagittal plane which could potentially increase the $\sim$7% error observed in the current investigation.

The manufacturer of this accelerometry system should provide more technical information on gait data acquisition and analysis and possibly improve the accelerometer technology. Triaxial sensors – perhaps with additional gyroscopes – represent a possible evolution of this body-mounted device.

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