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Acceleration-based gait test for healthy subjects: Reliability and reference data

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ABSTRACT

Accelerometers enable us to analyse gait outside conventional gait laboratories. Before these devices can be used in large scale studies and in clinical settings a thorough evaluation of their performance in different populations is required. The aim of this study was to present an acceleration-based reference database for healthy gait. The repeatability and inter-observer reliability of acceleration-based gait analysis was investigated. The sensitivity was tested on different age groups and the effect of gender was studied. A comprehensive set of gait parameters (i.e. cadence, speed, asymmetry and irregularity) were studied in 60 women and 60 men. Basic gait parameters showed high repeatability (VC_{cadence} 1.51%, ICC_{cadence} 0.996) and inter-observer reliability (ICC_{cadence} 0.916), while asymmetry and irregularity showed lower repeatability (VC_{asym} 47.88%, ICC_{asym} 0.787) and inter-observer reliability (ICC_{asym} 0.449). The effects of age and gender on gait parameters were found to be consistent with those reported in studies using other methodologies. These findings and the advantages of the device support the application of AGA for routine clinical use and in daily life.

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1. Introduction

As walking is a basic requirement for many daily activities, gait analysis provides important information on the functional capacity of subjects [1]. In clinical practice, gait is analysed visually or using questionnaires, producing subjective and mainly pain-related functional results [2,3]. In research settings, advanced motion analysis systems are used to carry out quantitative gait analysis and evaluate the impact of age, gender and several pathologies on gait characteristics [4].

Several studies have investigated spatio-temporal, kinematic and kinetic data for substantial sample groups under standardised laboratory conditions using 3D-motion analysis systems and/or force plates [5]. Although these methods can provide objective evaluation of gait, they are impractical for routine clinical use. They require technically skilled personnel and the measurements are time-consuming. Furthermore, most of these studies take place in laboratory settings, with smaller and shorter walkways than in daily life, creating unusual walking conditions [5–8]. In addition, single stride analysis limits the determination of gait variability

and symmetry which are considered important parameters for the evaluation of pathological gait.

Recently accelerometer-based gait analysis (AGA) has emerged as a potential alternative for conventional gait analysis because of its reliability in analysing gait parameters and lower limb motion [9,10]. Various clinically relevant gait parameters, such as cadence and walking variability, can simultaneously be derived from acceleration signals using autocorrelations or peak detection algorithms [11–13]. Studies comparing different attachment positions of the accelerometer on the body showed attachment at the sacrum to produce the most reliable accelerometer signals. It has been argued that this is because the sacrum is near the Centre of Mass (CoM) of the body and the trunk provides stable support for the head and neck during walking [14–16]. Accelerometers are wireless, non-obtrusive and easy to use, making them suitable for use outside the laboratory, in clinical settings. A long hospital corridor with normal walkways, normal surroundings, without intimidating equipment etc. provides a more natural environment to measure gait than the usual laboratory setting. To conduct a single gait test, including setup, measurement and analysis, may take as little as 10 min, permitting the examination of several subjects in a relatively short time period. In addition, AGA can be used for quick analysis of multiple steps, which allows us to test fluctuations in gait pattern resulting in the measurement of gait variables such as variability [17].

To apply AGA in clinical practice on patients with functional limitations, a large healthy sample group is needed for reference. Auvinet et al. used a tailor-made biaxial-accelerometer setup to

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collect reference data for common gait parameters like regularity and frequency in 282 healthy subjects [18]. They showed that the portable system easily provides accurate evaluation of walking. Recently, commercial systems have become available, which incorporate sensors and acquisition hardware in small devices and use sampling rates of up to 100 Hz enhancing the capacity for evaluating clinically relevant parameters like asymmetry and irregularity [11]. To make these systems applicable to clinical evaluation a reference database for healthy gait is needed based on these technologies.

The accuracy of AGA depends on several technical factors such as the attachment of the device, the exact measurement of the distance walked, instructions to the subject, the robustness of the algorithm, etc. Since gait is measured by several observers in clinical settings, the repeatability of AGA needs to be investigated.

This study aims to create a reference gait database for healthy subjects based on AGA including step length, cadence, speed, vertical displacement of the CoM, asymmetry (difference in successive step times) and irregularity (variability in subsequent steps of the same leg). The repeatability and inter-observer reliability of AGA was tested by repeating the measurement with the same subject, firstly on the same day with the same observer, and secondly on a second day with another observer. The resulting gait parameters were compared with previous published gait data.

2. Methods

2.1. Subjects

Based on a self defined questionnaire assessing state of health, subjects were included who showed no neuromuscular, musculoskeletal or cardiovascular pathologies affecting their motion pattern. Only healthy subjects were chosen to ensure that the gait measured represented a healthy walking pattern. All subjects were able to walk without walking aids. Eight men and 16 women, ranging in age from 21 to 60 years, participated in the first study to establish the inter-observer reliability of AGA. For the main study, 120 volunteers (60 males, 60 females) ranging from 20 to 86 years of age were recruited for measurement. For each of the six age categories (20–30, 30–40, 40–50, 50–60, 60–70 and ≥ 70) 10 female and 10 male participants were included. The study was approved by the local ethical committee; all participants gave their informed consent. Anthropometric measurements were collected (Table 1).

2.2. Equipment

Trunk accelerations were measured using a three-dimensional accelerometer (62 mm $\times$ 41 mm $\times$ 18 mm, 53 g, $f = 100$ Hz, range: ± 2 g, McRoberts BV, The Hague, The Netherlands [11]). To avoid extraneous movement, this accelerometer was attached

tightly to the skin at the level of the sacrum using adhesive tape. Data was stored on a local memory card (256 MB). The unit was powered by two AAA1.5 V batteries.

2.3. Protocol

Subjects walked a 20 m straight distance at preferred speed while wearing the accelerometer. Their last step had to take them beyond the 20 m mark. The additional distance was measured by a ruler to obtain the exact distance walked. After 20 m subjects turned around and walked back. This procedure was carried out three times. Repeatability of AGA was measured within these six walks ensuring that all factors such as attachment of the device and shoe wear were kept constant. All subjects walked across linoleum flooring in the hospital and they wore their own, flat shoes without high heels.

For the first study, the complete exercise was repeated with the same individual on a second day with another observer to investigate the inter-observer reliability. For the main study, the gait test was carried out on one occasion, with the same observer.

2.4. Data analysis

Raw data was downloaded to a PC using specific software (Mira 1.9 Beta, McRoberts BV, The Hague, The Netherlands [11]) and uploaded to a web-based analysis application. Gait parameters were calculated by proprietary, non-disclosed algorithms of the manufacturer based on the algorithms by Brandes et al. [11]. Only the most relevant gait parameters demonstrated in a previous study were used [19]. The basic gait parameters considered were step length, cadence, speed, and step time. Other parameters were vertical displacement of CoM and left–right asymmetry, which was calculated as the difference between the left and right step time divided by the bilateral average. Gait irregularity was determined by the variability in successive steps of the same leg. There are different methods for calculating this variability [20,21]. In this study the standard deviations of the left and right step time were used. Averages of the parameters over the six walks were used for analysis. To minimise the inter-subject variation in gait data, the step length, cadence, speed and vertical displacement were scaled for leg length (estimated from body height) according to Hof [22]. Five asymmetry values out of the 120 were removed as outliers due to miscalculations. The other values for these subjects were not outliers.

2.5. Statistical analysis

The repeatability of AGA, measured over the first and second walk of six successive walks, was tested using intra-class correlation coefficients (ICC). Variation coefficients (VC%) were determined over the six successive trials to express the percentage variation in a subjects' gait between successive trials. The inter-observer reliability was evaluated using ICCs to show the effect on gait output of taking measurements on a second day with another observer. ICCs > 0.75 , between 0.40–0.75, and < 0.40 were interpreted respectively as excellent, fair-to-good and poor inter-observer reliability [23]. In addition, paired *t*-tests were performed to test for any systematic differences between the two measurement sessions. The Kolmogorov–Smirnov test was used to check the normality of the variables. Depending on the nature of the distribution, parametric and non-parametric tests were performed to test for differences between genders. All statistics was performed using SPSS version 15.0 and differences were considered significant if *p*-values were less than 0.05.

Table 1
Demographics of subjects categorized by decade of age and sex.

Age	Men/women	Weight (kg)	<i>p</i> -value	Height (m)	<i>p</i> -value	Age (years)	<i>p</i> -value	BMI (kg/m ²)	<i>p</i> -value
20 $\geq$ 70 years	M (<i>n</i> = 60) W (<i>n</i> = 60)	81.25 (12.08) 66.87 (10.14)	$< 0.000^*$	1.80 (0.07) 1.67 (0.06)	$< 0.000^*$	49.55 (17.67) 49.43 (17.81)	0.992	25.05 (3.85) 24.10 (3.38)	0.136
20–30 years	M (<i>n</i> = 10) W (<i>n</i> = 10)	72.50 (8.89) 63.70 (7.30)	0.026 [*]	1.84 (0.05) 1.70 (0.06)	$< 0.000^*$	24.50 (2.76) 24.50 (3.03)	1.000	21.44 (1.85) 22.13 (1.92)	0.420
30–40 years	M (<i>n</i> = 10) W (<i>n</i> = 10)	81.10 (4.04) 71.80 (14.70)	0.088	1.83 (0.06) 1.67 (0.07)	$< 0.000^*$	33.30 (1.89) 35.00 (3.50)	0.193	24.27 (1.45) 25.52 (4.31)	0.395
40–50 years	M (<i>n</i> = 10) W (<i>n</i> = 10)	80.30 (15.67) 64.80 (7.52)	0.011 [*]	1.79 (0.06) 1.68 (0.06)	0.001 [*]	45.70 (3.23) 43.10 (2.42)	0.068	25.34 (6.61) 22.87 (1.97)	0.496
50–60 years	M (<i>n</i> = 10) W (<i>n</i> = 10)	89.50 (13.44) 63.40 (9.49)	$< 0.000^*$	1.82 (0.07) 1.65 (0.05)	$< 0.000^*$	54.60 (3.10) 54.20 (2.86)	0.768	27.04 (3.22) 23.29 (3.22)	0.018 [*]
60–70 years	M (<i>n</i> = 10) W (<i>n</i> = 10)	80.20 (8.79) 70.30 (10.02)	0.030 [*]	1.77 (0.04) 1.66 (0.06)	$< 0.000^*$	64.60 (2.59) 64.30 (3.53)	1.000	25.50 (2.51) 25.67 (3.59)	0.904
≥ 70 years	M (<i>n</i> = 10) W (<i>n</i> = 10)	83.90 (13.68) 66.90 (8.44)	0.004 [*]	1.77 (0.08) 1.64 (0.05)	0.001 [*]	74.50 (5.52) 75.70 (4.85)	0.612	26.69 (2.88) 24.83 (2.89)	0.166

Averages and standard deviations.

^{*} Sign difference between men and female ($p < 0.05$).

3. Results

There was no difference between the overall average ages of men (49.6 ± 17.7 years) and women (49.4 ± 17.8 years) or between the average ages of men and women in each group. In all age groups the men were significantly taller than the women (range: 1.77–1.84 m and 1.64–1.70 m respectively). Body weight was higher in men (range: 72.5–89.5 kg vs. 63.4–71.8 kg), but this difference was not significant for subjects in the 30–40 age group. BMI values were comparable for men and women (average of 25.1 ± 3.9 kg/m² vs. 24.1 ± 3.4 kg/m²), with the exception of the 50–60 age group where men showed higher BMI values (27.0 ± 3.2 kg/m² vs. 23.3 ± 3.2 kg/m²) (Table 1).

3.1. Repeatability and inter-observer reliability

The average values for most gait parameters were similar across both sessions. The paired *t*-test showed that there were no significant systematic differences (*p*-value < 0.05) in any of the gait parameters between both measurement days performed using different observers on the second day, indicating that gait was similar over time. The basic gait parameters (step length, cadence, speed, step time) showed high repeatability (VC 1.51–3.07%; ICC 0.902–0.997) and excellent inter-observer reliability (ICC 0.774–0.916). Data showing high repeatability (VC 5.96%; ICC 0.929) but fair-to-good inter-observer reliability (ICC 0.529) were obtained for the vertical displacement of the Centre of Mass. The irregularity and asymmetry showed lower repeatability (VC 29.25–47.88; ICC 0.509–0.787) and inter-observer reliability (ICC 0.010–0.351).

3.2. Reference data

In general, men took significantly larger steps (0.80 ± 0.08 m vs. 0.71 ± 0.07 m), showed significantly higher vertical displacement

(5.04 ± 1.09 cm vs. 4.47 ± 0.87 cm), significantly higher step time (0.55 ± 0.03 s vs. 0.51 ± 0.03 s), significantly faster speed (1.49 ± 0.20 m/s vs. 1.40 ± 0.17 m/s) and had significantly lower cadence (110.51 steps/min ± 6.30 vs. 118.43 ± 6.94 steps/min) than women. Even when scaled for leg length, the differences between gender in step length and frequency remained significant, while the speed and vertical displacement corrected for leg length showed similar values in both genders (respectively 0.50 ± 0.06 vs. 0.49 ± 0.06, 0.06 ± 0.01 vs. 0.05 ± 0.01). The irregularities (respectively 0.017 ± 0.008, 0.016 ± 0.008) were comparable for men and women. These effects of gender on step length, step time, speed (except age ≥ 70 years), cadence (except 20–29 age group), were observed in all age categories, although the differences were not always significant. A significantly reduced step length, cadence and speed were observed with increasing age (Table 2). These general age and gender effects are comparable with previous studies (Table 3).

4. Discussion

The purpose of this study was to collect a reference database for healthy gait in men and women over different age groups using an accelerometer. First we investigated the repeatability and inter-observer reliability of AGA.

Results showed that AGA is repeatable for determining basic gait parameters such as speed and cadence in healthy subjects in non-laboratory situations such as hospital settings. The measurements obtained for vertical displacement, asymmetry and irregularity showed only fair-to-good repeatability and inter-observer reliability. Basic gait parameters showed similar variations for age and gender to those reported in previous studies, making the accelerometer a suitable device for gait analysis in healthy subjects outside laboratory settings. These results

Table 2
Gait parameters per age category for both genders.

Gait parameters		20–29 (10 M/10 F)	30–39 (10 M/10 F)	40–49 (10 M/10 F)	50–59 (10 M/10 F)	60–69 (10 M/10 F)	≥70 (10 M/10 F)	n = 120
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Not scaled								
Step length (m)	M	0.83 (0.07)*	0.88 (0.06)*	0.82 (0.05)*	0.80 (0.07)*	0.77 (0.08)*	0.73 (0.09)	0.80 (0.08)*
	W	0.75 (0.06)	0.75 (0.05)	0.73 (0.03)	0.72 (0.07)	0.66 (0.07)	0.66 (0.08)	0.71 (0.07)
Speed (m/s)	M	1.55 (0.18)	1.67 (0.13)*	1.55 (0.10)	1.45 (0.18)	1.42 (0.14)	1.25 (0.21)	1.49 (0.20)*
	W	1.50 (0.15)	1.47 (0.13)	1.46 (0.13)	1.44 (0.14)	1.29 (0.14)	1.27 (0.21)	1.40 (0.17)
Step time (s)	M	0.54 (0.03)*	0.53 (0.02)	0.53 (0.02)*	0.56 (0.05)*	0.55 (0.02)*	0.57 (0.04)*	0.55 (0.03)*
	W	0.50 (0.03)	0.51 (0.02)	0.50 (0.03)	0.50 (0.03)	0.52 (0.04)	0.52 (0.04)	0.51 (0.03)
Cadence (st/min)	M	112.32 (5.79)*	114.06 (3.80)	113.55 (3.99)*	107.94 (8.17)*	109.51 (3.39)*	105.66 (7.41)*	110.51 (6.30)*
	W	120.24 (6.96)	118.02 (5.83)	119.52 (7.47)	120.72 (6.04)	116.53 (5.60)	115.56 (9.24)	118.43 (6.94)
VD (cm)	M	4.98 (1.02)	5.69 (1.31)*	5.40 (0.76)*	4.97 (1.01)	4.92 (1.13)*	4.30 (0.97)	5.04 (1.09)*
	W	5.16 (1.01)	4.54 (0.93)	4.60 (0.60)	4.44 (0.39)	3.80 (0.78)	4.27 (0.91)	4.47 (0.87)
Asymmetry	M	0.035 (0.019)	0.036 (0.028)	0.039 (0.027)	0.040 (0.020)	0.034 (0.014)	0.042 (0.018)	0.038 (0.020)
	W	0.028 (0.015)	0.035 (0.022)	0.030 (0.028)	0.032 (0.021)	0.027 (0.015)	0.032 (0.010)	0.031 (0.009)
Irregularity	M	0.015 (0.004)	0.015 (0.007)	0.014 (0.002)	0.016 (0.005)	0.019 (0.010)	0.023 (0.017)	0.017 (0.008)
	W	0.017 (0.005)	0.014 (0.003)	0.017 (0.005)	0.013 (0.002)	0.018 (0.006)	0.019 (0.007)	0.016 (0.008)
Scaled								
Sc step length	M	0.90 (0.07)	0.96 (0.08)*	0.92 (0.04)	0.88 (0.08)	0.86 (0.08)	0.83 (0.09)	0.89 (0.08)*
	W	0.89 (0.07)	0.90 (0.05)	0.88 (0.06)	0.87 (0.06)	0.80 (0.08)	0.80 (0.09)	0.85 (0.08)
Sc frequency	M	0.57 (0.03)	0.58 (0.02)	0.57 (0.02)	0.55 (0.04)*	0.55 (0.01)	0.53 (0.04)	0.56 (0.03)*
	W	0.59 (0.03)	0.58 (0.03)	0.58 (0.03)	0.58 (0.03)	0.56 (0.03)	0.56 (0.04)	0.58 (0.03)
Sc VD	M	0.05 (0.01)	0.06 (0.02)	0.06 (0.01)	0.05 (0.01)	0.06 (0.01)	0.05 (0.01)	0.06 (0.01)
	W	0.06 (0.01)	0.06 (0.01)	0.05 (0.01)	0.05 (0.00)	0.05 (0.01)	0.05 (0.01)	0.05 (0.01)
Sc speed	M	0.52 (0.06)	0.56 (0.05)*	0.53 (0.03)	0.49 (0.06)	0.48 (0.05)	0.44 (0.07)	0.50 (0.06)
	W	0.52 (0.05)	0.52 (0.04)	0.51 (0.05)	0.51 (0.05)	0.45 (0.05)	0.45 (0.07)	0.49 (0.06)

Averages and standard deviations for the gait parameters.

* Sign difference between men and women (*p* < 0.05).

Table 3
Gait parameters published in previous studies categorized per gender or age (20–29 years and >60 years).

All together						Young				Elderly					
<i>n</i>	Speed (m/s)	Cadence (st/min)	Step length (m)	<i>n</i>	Age (years)	Speed (m/s)	Cadence (st/min)	Step length (m)	<i>n</i>	Age (years)	Speed (m/s)	Cadence (st/min)	Step length (m)		
60				30	20–40	1.37 (0.13)		0.76* (0.06)	30	60–80	1.27 (0.16)		0.71* (0.07)		
72				20	21	1.32 (0.16)		0.66* (0.06)	52	>65	1.21 (0.16)		0.61* (0.06)		
27				12	21–28		111.0 (8.7)	0.78* (0.05)	15	62–78		110.5 (7.3)	0.69* (0.08)		
61				30	22–40	1.44 (0.13)	111.4 (6.7)	0.77 (0.06)	31	76–87	1.17 (0.21)	107.9 (10.3)	0.64 (0.08)		
282	1.48 (0.17)	120.6 (7.2)	0.74 (0.07)	49	20–29	1.57 (0.13)	120.0* (7.2)	0.79* (0.06)	53	60–69	1.41 (0.10)	119.4* (4.8)	0.71* (0.04)		
120	1.45 (0.19)	114.5 (6.8)	0.76 (0.08)	20	20–29	1.53 (0.17)	116.2 (6.4)	0.80 (0.07)	20	60–69	1.34 (0.15)	113.1 (5.4)	0.72 (0.08)		
All together						Men								Women	
<i>n</i>	Speed (m/s)	Cadence (st/min)	Step length (m)	<i>n</i>	Age (years)	Speed (m/s)	Cadence (st/min)	Step length (m)	<i>n</i>	Age (years)	Speed (m/s)	Cadence (st/min)	Step length (m)		
240	1.23 (0.15)	121.8 (9.4)	0.60 (0.04)	15	20–29	1.23 (0.11)	118.8 (7.8)	0.62 (0.04)	15	20–29	1.24 (0.17)	124.8 (9.0)	0.59 (0.06)		
282	1.48 (0.17)	120.6 (7.2)	0.74 (0.07)	24	20–29	1.59 (0.13)	116.4 (7.2)	0.83* (0.06)	25	20–29	1.54 (0.12)	123.6* (7.2)	0.75* (0.05)		
98				51	24	1.19 (0.11)	111.8 (6.4)	0.64* (0.05)	47	23	1.11 (0.11)	112.5 (6.5)	0.58* (0.06)		
120	1.45 (0.19)	114.5 (6.8)	0.76 (0.08)	10	20–29	1.55 (0.18)	112.3 (5.8)	0.83 (0.07)	10	20–29	1.50 (0.15)	120.2 (7.0)	0.75 (0.06)		
						Senden									

* Parameters measured for strides and recalculated to steps assuming that one stride equals two steps.

correspond to findings of other studies on AGA systems. Mackey et al. found that the IDEEA (system composed of five biaxial-accelerometers) showed high inter-session reliability (ICC 0.71–0.89). Lower intra-session reliability, measured using repeatability calculations, were shown for the IDEEA compared to three-dimensional gait analysis [10]. In a test–retest setup, a triaxial AGA-test was shown to be reliable, showing ICC of 0.94–0.96 [15]. Also, Maffiulett et al. found high intra-session reliability for an accelerometer gait analysis system (VC 2.73–5.72%; ICC 0.97–0.99) [9]. Other motion analysis systems such as gyroscopes showed high intra- and inter-session reliability (ICC 0.94–0.98 vs. ICC 0.91–0.95) and low VCs (1.34–1.57%) for cadence, speed, gait cycle time and stride length [24]. Force plates showed VCs of 1.65–2.58% and ICCs of 0.99–0.99 indicating high intra-session reliability [9]. Our results were as good as those found in other studies and indicate that the production of basic gait parameters using AGA is robust and unaffected by differences in performance techniques used by different observers. This is an important requirement for clinical use where different observers have to conduct the gait test on several occasions.

Some parameters scored more poorly and are probably more sensitive to experimental conditions and device capability. The acquisition frequency of 100 Hz is a limiting factor in accurately determining gait parameters such as vertical displacement, asymmetry and irregularity. A low sampling rate increases the chance of producing temporal aliasing, especially in heel strike detection which needs to be precise, particularly for gait variability parameters like asymmetry and irregularity. Healthy gait is expected to be symmetric and regular, which is reflected in very low, near to zero, variability values. Because of the definition used to express the asymmetry and irregularity, a small change will result in a relatively big difference which may explain their low variance coefficients. Higher sampling frequencies are needed for these definitions of asymmetry and irregularity to resolve variability differences at 0.01. Alternatively, other measures of variability could be used for more robust outcomes [25]. For instance, Auvinet et al. used an accelerometer measuring with a sampling frequency of 50 Hz while calculating reliable asymmetry and irregular values by applying autocorrelations [18]. One would expect gait asymmetry and irregularity to be more pronounced in pathological gait, assuming that these parameters can be used for group comparisons, for instance to identify pathological gait. However, more research is needed to investigate the use of these parameters for individual use and long term studies.

The basic gait data presented in the current study corresponded with previous published reports. The observation that men walk faster and take bigger steps, while having a lower cadence than women, is commonly reported in many studies using laboratory-based gait analysis systems [4,5,7,26]. Moreover, the typical effects of age on basic gait parameters observed in previous studies, including slower speed, shorter step length and longer step times in the elderly, are also found in the current study [4,8,27]. Moreover, ageing is generally associated with decreased foot clearance which is adopted by the elderly to compensate for balance impairment [6]. This characteristic corresponds to the small decrease in vertical displacement shown in the older population in our data. This parameter is relevant when analysing patients or the elderly because a higher vertical displacement while walking corresponds to higher energy expenditure, resulting in more effort to walk a certain distance. However, more research is needed on this topic because existing research about the relation between vertical displacement and walk efficiency is contradictory [29].

The collected reference data corresponded more closely with gait data produced using different acceleration-based techniques than with gait data produced by laboratory-based gait analysis systems. There was a high level of correspondence in basic gait parameters with the reference data for healthy subjects collected by Auvinet et al. who used two accelerometers [18]. Only a slightly higher speed (2.6% vs. 5.2%), cadence (3.3% vs. 5.6%) and a slightly shorter step length (1.3% vs. 1.4%) for young and older subjects was observed. Moreover, small differences (0–3.6%) were observed when comparing the gait of men and women.

AGA-based studies analysing gait of younger (20–29 years) and older (60–69 years) subjects showed differences ranging from 1.4% to 17.5% for step length, 5.8–13.7% for speed and 2.3–4.6% for cadence compared to our reference data. Studies using laboratory-based method showed 17–26% slower speed, 21–25% shorter step length and 0.5–6.4% higher cadence compared with our data. These differences with our reference database can partly be attributed to the length of the walkway. A relatively long walkway (20–28 m), as is used in the current study, reflects normal conditions, while narrow and short walkways (e.g. 5.5 m [7]), as usually used in laboratory settings, requires the subject to start and brake frequently which has a relatively large effect on the walking pattern and its measurement. Moreover, several studies calculated gait parameters over a stride, which may explain the differences in step length between our database and lab based values [5,18]. Although some discrepancy was found between the collected reference database and data obtained with laboratory-based methods, the gait parameters of our database lie within the ranges that have been obtained for healthy individuals.

5. Conclusion

This study collected a reference database for healthy gait using an acceleration-based gait test. Repeatable basic gait output was obtained from the accelerometer which showed general comparability with the temporal-spatial gait parameters produced by validated advanced motion analysis systems. These promising results and the favourable characteristics of the accelerometer make the device suitable for use outside the laboratory, for instance in clinical settings.

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Conflict of interest

None of the authors had financial and personal relationships with other people or organisations that could inappropriately influence their work.

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