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Short communication

Mobile inertial sensor based gait analysis: Validity and reliability of spatiotemporal gait characteristics in healthy seniors

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ABSTRACT

Gait analysis is commonly used to identify gait changes and fall risk in clinical populations and seniors. Body-worn inertial sensor based gait analyses provide a feasible alternative to optometric and pressure based measurements of spatiotemporal gait characteristics. We assessed validity and relative and absolute reliability of a body-worn inertial sensor system (RehaGait®) for measuring spatiotemporal gait characteristics compared to a standard stationary treadmill (Zebris®). Spatiotemporal gait parameters (walking speed, stride length, cadence and stride time) were collected for 24 healthy seniors (age: 75.3 ± 6.7 years) tested on 2 days (1 week apart) simultaneously using the sensor based system and instrumented treadmill. Each participant completed walking tests (200 strides) at different walking speeds and slopes. The difference between the RehaGait® system and the treadmill was trivial (Cohen's d <0.2) except for speed and stride length at slow speed (Cohen's d, 0.35 and 0.49, respectively). Intraclass correlation coefficients (ICC) were excellent for temporal gait characteristics (cadence and stride time; ICC: 0.99–1.00) and moderate for stride length (ICC: 0.73–0.89). Both devices had excellent day-to-day reliability for all gait parameters (ICC: 0.82–0.99) except for stride length at slow speed (ICC: 0.74). The RehaGait® is a valid and reliable tool for assessing spatiotemporal gait parameters for treadmill walking at different speeds and slopes.

1. Introduction

Aging is accompanied by a decline of neuromuscular function that increases the risk of falling [1]. Spatiotemporal gait analysis is often used to identify seniors' fall risk [2], and most gait analysis methods are laboratory based and employ optometric systems or force sensors [2,3]. Mobile systems based on inertial sensors are gaining popularity especially for instrumented function tests but are rarely used for gait analysis in seniors. Previous studies have examined the validity and reliability of a portable gait analysis system at different walking speeds and slopes in young adults [5,6]. However, comparable data for seniors are not available.

Valid and reliable spatiotemporal gait analysis in seniors is a crucial prerequisite for detecting clinically and functionally relevant changes due to diseases and short- or long-term interventions [7]. Therefore, the objective of our study was to quantify validity and relative and absolute reliability of spatiotemporal gait characteristics of the RehaGait® compared to an instrumented treadmill system in seniors at different walking speeds and slopes.

2. Methods

2.1. Subjects

Twenty-four healthy seniors (13 men; age: 75.3 ± 6.7years; height: 1.65 ± 0.12m; body mass: 77.0 ± 12.6 kg; body mass index: 28.0 ± 7.3 kg/m^2) were enrolled in this study after providing informed consent. The study was approved by the local ethics committee. Exclusion criteria were any factors that may affect gait

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(medication, orthopaedic, neurologic or internal diseases and health impairments). Each participant was tested on 2 days (1 week apart) at the same daytime.

2.2. Testing equipment

The RehaGait® system (Hasomed GmbH, Magdeburg, Germany) comprises two inertial sensors [6]. Each sensor contains a 3-axial accelerometer, gyroscope and magnetometer. The sensors are attached to the lateral aspect of the shoe. Linear acceleration, angular velocity and the magnetic field are recorded at 500 Hz. The treadmill (Zebris FDM-T, Zebris medical GmbH, Isny, Germany) provides reliable spatiotemporal gait parameters [8] from dynamic pressure distribution (5378 force sensors; 120 Hz) and is a standard reference system [9–11]. Both system use manufacturer proprietary software to obtain temporal and spatial gait characteristics.

2.3. Testing procedure

Habitual walking speed of the participants was determined during the first visit as the average of three trials along a 10-m flat overground walkway using photoelectric timing gates (Witty, Microgate, Bolzano, Italy). Data for three walking speeds (habitual walking speed; 15% above habitual walking speed; 15% below habitual walking speed) and two slopes were recorded (0% slope; 15% slope; one 5-min trial per condition; 200 double steps (strides) [12] per trial). For each condition, participants performed six randomized 5-min walking trials on the instrumented treadmill while wearing the RehaGait® device.

2.4. Data acquisition and analysis

Spatiotemporal gait characteristics were simultaneously recorded by the treadmill and the RehaGait®. For both devices, walking speed (m/s), stride length (m), cadence (steps/min) and stride time (s) were recorded for each stride. Average values of 200 consecutive strides were computed for each participant, session and condition.

2.5. Statistical analysis

All statistical analyses were performed in SPSS Version 22 (IBM Corporation, Amonk, NY). Separate 2 (device: RehaGait® vs. treadmill) × 3 (speed: normal vs. slow vs. fast) × 2 (slope: flat vs. inclined) repeated measures analysis of variance (rANOVA) were conducted for speed, stride length, cadence and stride time. Follow-up paired *t*-tests with Bonferroni correction were used as post-hoc tests. Pairwise effect sizes were calculated using Cohen's d (trivial: $d < 0.2$; small: $0.2 \leq d < 0.5$; moderate: $0.5 \leq d < 0.8$; large $d \geq 0.8$) [13]. The agreement between RehaGait® and treadmill data and the between-day repeatability of data collected on two different days was analyzed for each parameter and condition by calculating the systematic bias (mean difference between devices/days) and the limits of agreement (1.96*standard deviation of the difference between both devices/days) to obtain a 95% random error component [7] and presented as Bland-Altman plots [14]. The intra-class correlation coefficients (ICC) with their 95% confidence intervals were calculated using a two-way, random single measure analysis for each condition. Point estimates of the ICC were rated as excellent (0.9–1), good (0.74–0.9), moderate (0.4–0.73) and poor (0–0.39) [15].

3. Results

RehaGait® walking speed agreed well with the speed set on the treadmill tachometer (Table 1). Independent of speed and slope, no main "device" effect was found ($P > 0.05$). Pairwise comparison revealed trivial effect sizes (Cohens'd <0.2) except for speed and stride length at slow speed (Cohen's d, 0.35 and 0.49, respectively). No significant interaction effects were observed ($P > 0.05$). The limits of agreement for the RehaGait® and the instrumented treadmill are depicted in Fig. 1. No main effects for "speed" and "slope" were observed (Table 1).

No significant main "time" effect was found for any gait characteristics ($P > 0.05$). Both devices had excellent reliability for all gait characteristics except good reliability of the RehaGait® for stride length at 0% slope and stride time at 15% slope (Table 2). The limits of agreement for repeated measurements of stride length, cadence and stride time with the RehaGait® were similar at both slopes.

4. Discussion

We assessed the validity and reliability of the RehaGait® compared to a stationary treadmill at different speeds and slopes in healthy seniors. We found adequate validity for stride length and time as well as cadence between both systems at normal speed. Only trivial to small differences between both devices were observed. Between day reliability was excellent for temporal gait characteristics and good for stride length. However, RehaGait® and the treadmill cannot be used interchangeably in all persons at slow speeds.

To date, the effects of walking at different speeds and slopes on spatiotemporal gait characteristics have not been examined in seniors. Increased walking slope might increase stride length [16]. Indeed, Donath et al. [4] observed greater stride length at 15% slope compared to level walking in young adults. In contrast, seniors in our study did not adapt to a greater slope by increasing stride length. Moreover, stride time and cadence did not change notably during inclined walking. Our results are opposed to earlier findings that revealed decreases in cadence with increasing uphill slope at least for slow speeds [17]. However, speed was kept constant for walking at both slopes in our study, and hence adjustments of gait patterns to the changing environment by changing speed were not possible.

The average difference in spatiotemporal gait parameters was small. Other body-worn sensor based spatiotemporal gait analyses revealed differences of 8 cm for stride length on level overground walking [18]. Deviations in spatiotemporal gait characteristics in older adults between an accelerometer based gait analysis and the GAITRite® of less than 0.02 m/s walking speed, 1 cm step length and 2 ms step time have been reported [19]. The agreement between RehaGait® and treadmill data observed in our study was better than that of other wearable technology [11]. Hence, although the slight differences between the two systems may be caused by the underlying algorithms [6], the RehaGait® can be employed to validly assess spatiotemporal gait characteristics in seniors.

In conclusion, our results showed that inertial sensor based treadmill gait analysis are valid and reliable. The applicability of such systems in the context of clinical and research questions regarding clinically relevant parameters must be determined in each specific target group [8] because only selected gait parameters can be assessed. Future research should focus on surrogate measures for risk of falls and neuromuscular and musculoskeletal conditions that can be assessed using body-worn inertial sensors in free-living environments.