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The reliability of local dynamic stability in walking while texting and performing an arithmetical problem

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ABSTRACT

In the recent years, local dynamic stability of walking was frequently used to quantify motor control. Particularly, dual-task paradigms are used to assess a shift in gait control strategy to test walking in real life situations. Texting short messages while walking is a common motor-cognitive dual task of daily living. To able to monitor possible intervention effects on motor-cognitive dual-task performance, the test-retest reliability of the measure has to be evaluated. Since the reliability of the effects of cognitive tasks including texting while walking on local dynamic gait stability has not been assessed yet, this will be evaluated in the current study. Eleven young individuals were included. Gait data was registered twice (test-retest interval: seven days) using an inertial sensor fixed on the subjects' trunks in three conditions: normal walking, walking while texting a message and walking while reciting serials of 7. Short-term finite maximum Lyapunov Exponents were quantified to assess local dynamic stability. The test-retest reliability was calculated using intra-class correlation coefficients and Bland and Altman Plots (bias and limits of agreement). ICC values of the current study show that in normal walking and walking while texting, outcomes are comparable and indicate mostly good to excellent reliability. The reliability values were almost always the lowest in walking while reciting serials of 7. Local dynamic stability derived from kinematic data of walking while cell phone texting can be reliably collected and, in turn, be used as an outcome measure in clinical trials with repeated measures design.

1. Introduction

In the recent years, local dynamic stability (LDS) of human walking was frequently used to quantify motor control during gait. LDS estimates the ability of humans to resist small internal (e.g. neuromuscular noise) or external (e.g. wind) perturbations [1,2] which is often quantified with the finite maximum Lyapunov Exponent (λ). There is a considerable body of evidence revealing that λ is able to efficiently distinguish between specific cohorts as for example between young and old cohorts [3], between fallers and non-fallers [4–6] or between patients with knee arthrosis and controls [7]. Furthermore, gait stability measures might be sensitive to detects subtle changes due to cognitive impairments [8].

In human walking, 1) cognitive executive functions and 2) automatic control processes are involved [9]. Automatic processes lead to more reliable efferent motor commands with short delays, are hardly affected by executive control processes, and are less sensitive to potential stressors. Executive functions, by contrast, are needed in complex walking situations where automatism has not been learned. Thus, automaticity in gait is functionally important and determined by several factors (impairment of proprioception sensation, pain, state anxiety, etc.). One frequently applied approach to assess a shift in gait control strategy uses a motor-cognitive dual-task paradigm. Dual-task costs are associated with a shift (at least in part) from automaticity to a more executive control strategy in normal walking [10]. However, while this approach traditionally used linear gait variability measures to quantify the degree of automaticity of walking, a few studies also reported effects of an additional cognitive load during walking

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on measures of LDS. Here, young and healthy individuals show slightly more stable gait patterns when simultaneously performing a cognitive task [11] whereas in older people and in neurologic diseased patients, gait stability decreases [8,12].

Texting short messages while walking is a common motor-cognitive dual task. Also, the scientific community has already started to employ texting while walking in order to analyse motor-cognitive dual-task costs of every-day life situations in the laboratory. As such, the walking characteristics were reported to change when subjects are simultaneously texting [13–15]. Another positive aspect of using daily living activities as a dual task is that those might not be so affected by repeated measures designs due to the possible learning effects precisely because they are very common to the subjects. Thus, it has been shown that walking while texting is a feasible method to test motor-cognitive dual-task performance of everyday life situations. However, the evaluation of the reliability of a measure is a prerequisite of its usage. While the inter-session test-retest reliability of LDS of walking without performing a dual task has frequently been evaluated [16–19], e.g. in order to check its value for clinical trials with repeated measures design, the reliability of LDS measures in dual-task gait conditions including texting while walking has (to the best of our knowledge) not been reported, yet.

Taken together, LDS of walking in a motor-cognitive dual-task situation seems to be able to extract more information regarding gait performance as compared with normal walking. As differences in the type of the dual task differently change gait characteristics [20], it could be possible that the reliability of the assessment of gait pattern characteristics also changes between performing different dual tasks. However, information about how test-retest reliable these measures are and consequently about to what extent these measures would be suitable to examine possible positive effects caused by specific interventions is still lacking. The aim of this study is, therefore, to evaluate the test-retest reliability of LDS in motor-cognitive dual-task walking with a conventionally used cognitive dual task (reciting serials of 7: S7) and with a dual task which reflects an activity of daily living (walking while texting on cell phone: ToC).

2. Methods

Gait data of 11 (age: 24.1 ± 5.2 years; female: 4; male: 7) healthy and young students at Otto von Guericke University Magdeburg (Germany) owning a cell phone and using it on a daily basis were included. After briefing about the research protocol, which complied with the principles of the Declaration of Helsinki, all participants provided their written informed consent.

A wireless inertial motion tracker (MTw, Xsens Technologies B.V., Enschede, The Netherlands; range of measurement of angular velocity: ± 1200 deg/s, range of measurement of acceleration: ± 160 m/s^2) was fixed on the subjects' trunks, another on the subjects' right forefoot. The sensor measures linear accelerations with a sampling rate of 100 Hz and it has been reported that with these sensors, local dynamic stability can be reliably and validly assessed [21]. After a familiarization trial of normal treadmill walking, the participants were asked to walk one trial on a treadmill with a speed of 6 km/h for 3 min in each of the three conditions: 1) Normal treadmill walking, 2) walking while reciting serials of 7 backwards starting with a random four-digit number, and 3) walking while texting throughout the entire 3 min one long predefined text which was applied clearly visible in front of the treadmill. Kinematic data were captured twice (within a test-retest interval of seven days).

All calculations were done using MATLAB (version 2013a, The MathWorks BV, Natrick, USA). To quantify short-term finite maximum Lyapunov Exponent, heel strikes of 100 consecutive strides were identified based on local minima of the sagittal angular velocity data of the foot as described in more detail in Hamacher [22]. The acceleration data of these 100 strides were time normalized to 10,000 samples. Thereafter, we reconstructed four different state-spaces based on 1) the one dimensional (1D) and medio-lateral (m-l), 2) 1D anterior-posterior (a-p) and 3) 1D superior-inferior (s-i) directions or 4) we used all 3 dimensions (3D) of acceleration data (in the same state space) of the trunk. To reconstruct high-dimensional state-spaces, time delayed copies were used [23,24] where the time delay was quantified using the first minimum mutual information approach [25] and the number of time delayed copies were determined with the global false nearest neighbours method [26]. We used the algorithm of Rosenstein, Collins [24] for the calculation of λ. The divergence of initially nearest neighbours was tracked. The slope of the logarithmic mean divergence curve from approximately 0 to 0.5 strides was defined as short time LDS.

The inter-session test-retest reliability comparing the test-retest trials was calculated using the intra-class correlation coefficients (ICC, 2.1; absolute agreement) [27] and the bias and limits of agreement (LoA) [28]. The bias is the mean of all differences between measurements by the two time points on the same subject. The reference interval (mean ± 1.96 x standard deviation) is defined as LoA. The LoA provide information about how much random variation occurs between both measurements. ICC-values between 0.0 and 0.40 were considered poor, from 0.40 to 0.59 fair, from 0.60 to 0.74 good, and from 0.75 to 1.00 excellent [29]. In addition, to evaluate potential differences between tests and retests, we performed Student's t-tests (repeated measures design).

3. Results

The Lyapunov Exponents (λ) of all signals used across the different walking conditions and their standard deviations are presented in Table 1. Regarding normal walking, the values ranged from 1.016 (3D) to 1.111 (s-i). In the walking while reciting serials of 7 condition, the values ranged from 0.886 (3D) to 1.019 (s-i). When walking while cell phone texting, λ ranged from 0.943 (a-p) to 1.047 (s-i).

Table 2 shows values of the ICC, bias, LoA and *p*-values for trunk parameters of the different experimental conditions. No significant differences within conditions from pre-test to post-test were found. The ICC values for normal walking ranged from 0.583 (3D)

Table 1
Means and standard deviations of gait parameters of the maximum finite Lyapunov Exponent (λ) in pre- and post-test in different 1D directions and in 3D in normal walking, walking while reciting serials of 7 and in walking while texting on a cell phone (Anterior-posterior: a-p, medio-lateral: m-l, superior-inferior: s-i).

λ	Normal walking		Walking + serial 7		Walking + texting on cell phone	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
	M ± SD	*M* ± SD	*M* ± SD	*M* ± SD	*M* ± SD	*M* ± SD
a-p	1.031 ± 0.091	1.047 ± 0.084	0.960 ± 0.087	0.968 ± 0.132	0.943 ± 0.080	0.970 ± 0.077
m-l	1.081 ± 0.154	1.066 ± 0.114	1.016 ± 0.132	0.991 ± 0.206	1.015 ± 0.097	0.976 ± 0.109
s-i	1.092 ± 0.126	1.111 ± 0.150	1.005 ± 0.133	1.019 ± 0.194	1.017 ± 0.096	1.047 ± 0.129
3D	1.016 ± 0.075	1.030 ± 0.097	0.912 ± 0.072	0.886 ± 0.115	0.951 ± 0.097	0.966 ± 0.108