Gait & Posture 55 (2017) 105–108

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Local dynamic stability and gait variability during attentional tasks in young adults

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ARTICLE INFO

Keywords:
Human gait
Cell phone
Dual-task
Kinematics
Local dynamic stability
Entropy

ABSTRACT

Cell phone use while walking may be a cognitive distraction and reduce visual and motor attention. Thus, the aim of this study was to verify the effects of attentional dual-tasks while using a cell phone in different conditions. Stability, regularity, and linear variability of trunk kinematics, and gait spatiotemporal parameters in young adults were measured. Twenty young subjects of both genders were asked to walk on a treadmill for 4 min under the following conditions: (a) looking forward at a fixed target 2.5 m away (walking); (b) talking on a cell phone with unilateral handling (talking); (c) texting messages on a cell phone with unilateral handling (texting); and (d) looking forward at the aforementioned target while listening to music without handling the phone (listening). Local dynamic stability measured in terms of the largest Lyapunov exponent decreased while handling a cell phone (talking and texting). Gait variability and regularity increased when talking on a cell phone, but no variable changed in the listening condition. Under all dual-task conditions, there were significant increases in stride width and its variability. We conclude that young adults who use a cell phone when walking adapt their gait pattern conservatively, which can be because of increased attentional demand during cell phone use.

1. Introduction

Attention and executive functions from cognitive areas are active during gait motor control. Performing gait in conjunction with another task, such as talking or typing on a cell phone, requires cognitive, neuromotor, physical, and memory skills; in addition, there is a competition for visual attention between the two tasks [1–4]. Thus, the dual-task paradigm has been used to evaluate the role of concurrent attentional demand in the motor control of human gait; in this setting, increased risk of falling, kinematic variability, and gait instability were observed [5–7]. Studies showed that dual-tasks using the cell phone, including texting, reading, and playing logical games, have an impact on the locomotion motor ability [1,2,8,9]. However, such dual-tasks are not executed spontaneously. To date, dual-tasks routinely practiced by young people using the cell phone have not been investigated, including unilateral handling texting and talking, and listening to music.

According to TeleGeography, in 2013, 77% of the people worldwide used cell phone text messaging as a communication method. In 2015, there were 7.1 billion active devices, and there were 7.3 billion people [10]. When using a cell phone, individuals need to focus on a small portable screen, which requires increased levels of manual dexterity, head and neck flexion, and concentration, all of which leads to reduced visual information input from the individual's surroundings, increased working memory use, and executive control requirement [9,11]. Furthermore, several studies have shown the dangers of concurrent cell phone use while driving or walking, which may lead to an accident [1] or even death [2,8,11].

To maintain stability, executive and attention functions alter gait patterns during dual-task walking, as reported in young adults walking on a treadmill while using a cell phone [9]. In addition, when walking overground, the dual-task paradigm using cell phone increased the variability in spatiotemporal gait parameters, which has been related to decreased walking speed [2,8,10,12,13]. Schabrun et al. [10] also found increased trunk variability when individuals walked on a treadmill with a constant speed that was equal to normal the over-the-ground speed [10]. Similarly, Kao et al. [1] found a significantly greater trunk variability in treadmill walking during dual-task while using cell phone. Although studies evaluating regularity while walking and dual-task are scarce, one study was an examination of the effect of cell phone texting on the postural stability of young adults; the results from this

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http://dx.doi.org/10.1016/j.gaitpost.2017.04.019
Received 27 June 2016; Received in revised form 12 April 2017; Accepted 13 April 2017

study indicated that gait regularity did not change [14].

Gait variability is influenced by the ability to optimally control gait from one stride to the next [15]. Variability is quantified using linear or nonlinear measures; because the variations in human movement are distinguishable from noise, they have a deterministic origin, being neither random nor independent. Variability can be quantified using linear measures, such as magnitude variability (e.g., the average standard deviation along strides) [16], or nonlinear measures, such as entropy that quantifies the structure of the temporal variability or regularity of a time series [17]. Similarly, stability can be quantified using measures derived from nonlinear dynamics, such as the largest Lyapunov exponent (λs), which is a nonlinear measure of local dynamic stability (LDS) [5,18,19]. Variability refers to the motor system's ability to perform in a wide variety of tasks and environmental constraints; stability refers to the dynamic ability to recover from an external perturbation, including dual-task. Thus, linear (trunk and spatiotemporal parameters variability) and nonlinear variables (entropy and stability) were computed in the present study.

Since trunk kinematic data are the most sensitive to differences between different groups [20] and because maintaining stability of the upper body is critical for human locomotion [21], we computed gait features from trunk kinematics. Therefore, the objective of the present study was to verify the effects of attentional dual-tasks using a cell phone on gait LDS, regularity, linear variability, and spatiotemporal parameters in young adults. We hypothesized that LDS decreases under the proposed dual-task conditions while linear variability increases correspondingly.

2. Methods

2.1. Subjects

Twenty healthy young subjects (10 males and 10 females, 24.5 ± 3.3 years old, 69.0 ± 13.7 kg, and 1.62 ± 36.7 m) were recruited into the study after obtaining written informed consent that was approved by the local research ethics committee. The inclusion criteria were an age of between 18 and 30 years and cell phone use. The exclusion criteria were any cognitive or musculoskeletal disease or impairment and disabling surgery in the last 12 months.

2.2. Equipment and procedures

For gait assessment, kinematic analysis was performed using a 3D motion capture system comprising of 10 infrared cameras operating at 100 Hz (Vicon Nexus, Oxford Metrics, Oxford, UK). Nine reflective markers were attached to the lateral malleoli, heels, and heads of the second and the fifth metatarsals (bilaterally) and the spinous process of the second thoracic vertebrae (T2). Our stability analysis was focused on trunk motion because maintaining stability of the upper body is critical for human locomotion [22].

To isolate the effect of the attentional task, the same average speed found in the previous pilot study (4 km/h) was adopted for all subjects under the following conditions: (a) looking forward at a fixed target 2.5 m away (walking); (b) talking on a cell phone with unilateral handling (talking); (c) texting messages on a cell phone with unilateral handling (texting); and (d) looking forward at the aforementioned target while listening to music without handling the phone (listening). Each experimental condition was tested randomly in two 4-min trials with a 2-min rest periods between trials. The first trial was used for protocol familiarization, and only the results of the second trial were analyzed.

The subjects used their own cell phones because they were familiar with the devices. An experimenter in another room asked questions and sent messages to the subjects during the corresponding trials, and no special instructions were provided about language, orthographic correction, correct answers, and a needed number of typed words. The questions pertained to general and personal knowledge with the purpose of causing cognitive distractions through informal conversation.

2.3. Data analysis

Before data analysis, except for calculating the short-term largest Lyapunov exponent (λs) and sample entropy (SEn), kinematic data were low-pass filtered using a fourth-order, zero-lag Butterworth filter with a cut-off frequency of 6 Hz. All parameters were calculated for 150 strides. The first and last 15 s of each trial were discarded [19]. A customized MATLAB code was used for data analysis.

The LDS was assessed by λs calculated using Rosenstein's algorithm [25]. Briefly, the mediolateral (ML), anteroposterior (AP), and vertical (V) T2 marker velocities were calculated from that marker data by using the three-points method [26]. Next, the velocity signal was time-normalized to 15,000 samples by preserving differences in stride time between strides [23]. A high-dimension attractor was constructed using the normalized ML, AP, and V T2 marker velocities and their delayed copies. A delay of 10 samples was used based on the mean value of the minimum of the mutual information function across all data, and a dimensionality of 5 was found to be sufficient based on the results of a global false nearest-neighbor analysis. For each point in the state-space, the nearest neighbor was found, with a minimal distance of a mean period corresponding to one step, and the Euclidean distance between these points was tracked for 10 strides. Then, a time vs log of the Euclidian distance curve was calculated for all neighboring points. Next, a divergence curve was calculated as the mean of those time-distance curves. The short-term λs was calculated as the slope of the linear fit of the first 50 samples (the time needed for one step) in the divergence curve. Thus, λs indicates the relative rate of divergence over one step, resulting from a small perturbation in the initial conditions. This method assumes that motor control ensures a dynamically stable gait if the divergence remains low between trajectories in a reconstructed state space that reflects gait dynamics [23].

Sample entropy (SEn) was calculated to quantify the degree of regularity of temporal variations of ML, AP, and V trunk velocities. SEn is the negative natural logarithm of the conditional probability of two m-dimensional delayed vectors that are close within a tolerance r, remain close in the $(m + 1)$ dimensional state space without allowing self-matches [24,25]. The parameter values of $m = 2$ and $r = 0.2$ were selected. SEn reflects the likelihood that similar patterns of observations will not be followed by additional, similar observations. A time series containing numerous repetitive patterns – one that is predictable – has a relatively small SEn whereas a less predictable process has a higher SEn.

To compute gait cycle variability (VAR), trunk acceleration during each stride was time-normalized (0–100%). At each of the 101 normalized time points, the SD of ML trunk acceleration over 150 strides was calculated. Next, the average SD of these 101 SDs was calculated [16].

Gait spatiotemporal parameters and their SDs in the trial were also used to assess changes in gait linear variability and pattern. Step width (SW) was determined as the ML distance between two consecutive heel-strikes, and the average step length (SL) was calculated from the average treadmill speed and the average step frequency ratio [26]. Step frequency (SF) was determined as the inverse of the average duration between two consecutive heel-strikes between limbs (i.e., left followed by right, or right followed by left), which were detected as the zero-cross of the heel markers' AP velocity [27].

2.4. Statistical analysis

Data that conformed to a normal distribution (Shapiro-Wilk test, $p > 0.05$) were analyzed using a repeated measure analysis of variance (ANOVA) with paired comparisons as post-hoc tests. Data that did not conform to a normal distribution were analyzed with the