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Walking stability during cell phone use in healthy adults☆

Pei-Chun Kao [a,*], Christopher I. Higginson [b], Kelly Seymour [c], Morgan Kamerdze [b], Jill S. Higginson [c]

[a] Department of Physical Therapy, University of Delaware, Newark, DE 19716, USA
[b] Department of Psychology, Loyola University Maryland, Baltimore, MD 21210, USA
[c] Department of Mechanical Engineering, University of Delaware, Newark, DE 19716, USA

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ABSTRACT

The number of falls and/or accidental injuries associated with cellular phone use during walking is growing rapidly. Understanding the effects of concurrent cell phone use on human gait may help develop safety guidelines for pedestrians. It was shown previously that older adults had more pronounced dual-task interferences than younger adults when concurrent cognitive task required visual information processing. Thus, cell phone use might have greater impact on walking stability in older than in younger adults. This study examined gait stability and variability during a cell phone dialing task (phone) and two classic cognitive tasks, the Paced Auditory Serial Addition Test (PASAT) and Symbol Digit Modalities Test (SDMT). Nine older and seven younger healthy adults walked on a treadmill at four different conditions: walking only, PASAT, phone, and SDMT. We computed short-term local divergence exponent (LDE) of the trunk motion (local stability), dynamic margins of stability (MOS), step spatiotemporal measures, and kinematic variability. Older and younger adults had similar values of short-term LDE during all conditions, indicating that local stability was not affected by the dual-task. Compared to walking only, older and younger adults walked with significantly greater average mediolateral MOS during phone and SDMT conditions but significantly less ankle angle variability during all dual-tasks and less knee angle variability during PASAT. The current findings demonstrate that healthy adults may try to control foot placement and joint kinematics during cell phone use or another cognitive task with a visual component to ensure sufficient dynamic margins of stability and maintain local stability.
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1. Introduction

The number of falls and/or accidental injuries associated with cellular phone use during walking has been increasing [1]. Using a cell phone while driving was evidenced to increase the risk of motor vehicle collisions [2]. Currently, most states ban text messaging and a number of states prohibit drivers from using hand-held cell phones [2]. Although walking is thought to be a more automatic motor task compared to driving, cell phone use may cause cognitive distraction, reduced visual attention to the environment, and altered physical demands such as reduced arm swinging and altered head orientation [3]. Distraction from cell phone use was shown to affect pedestrian behavior, for example, reducing situation awareness and increasing unsafe pedestrian behavior while crossing the street [4]. However, few studies have examined the impact of cell phone use on gait [3,5]. Previous studies showed reduced walking speed, increased lateral deviation from a straight line and greater variation in lateral foot placement when using a cell phone [3,5]. Those results suggest that walking stability might be compromised during cell phone use, which would lead to an increased risk of falls. Thus, a better understanding of the effects of cell phone use on walking stability may help develop safety guidelines for pedestrians.

The effects of cell phone use on gait stability can be estimated by employing a dual-task walking paradigm. During dual-task walking, subjects are usually required to perform an attention demanding task while walking [6]. Growing evidence demonstrates that walking is not a fully automated motor activity but requires executive function, attention, and the ability to adapt to environmental complexity [7]. When performing two tasks simultaneously, each of which requires a certain level of attention, the total

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* Corresponding author at: 201 STAR Health Science Complex, 540 S. College Avenue, Newark, DE 19713, USA. Tel.: +1 302 831 8666; fax: +1 302 831 4234.
E-mail address: kaop@udel.edu (P.-C. Kao).

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attention required may exceed the total information processing capacity of an individual and thus, lead to a negative influence on the performance of either task [6]. Previous studies showed that both healthy younger and older adults reduced their walking speed and increased gait variability while performing a cognitive task [8,9]. In addition, the changes in performance during dual-task walking were strongly associated with an increased risk of falls in older adults and neurologically impaired individuals [10]. It was also shown that older adults had more pronounced dual-task interferences than younger adults when the cognitive task required visual information processing [11,12]. Thus, cell phone use may have greater impact on walking stability in older adults than in younger adults. However, increased gait variability was often used as an index of reduced stability and walking speed, a confounding factor for gait variability [13], was not controlled in those studies. It is not clear if the increased gait variability during dual-tasking resulted from the reduced walking speed or reflected reduced stability.

Altered physical demands associated with the cell phone manipulation such as reduced arm swinging and altered head orientation may also play an important role in modifying walking performance in addition to cognitive distractions. Arm swinging was suggested to help stabilize the body and enhance lateral balance during walking [14]. It has been shown that the vertical ground reaction moment and the rate of metabolic energy consumption during walking increased when arm swinging was eliminated [14,15]. Thus, reducing arm swinging due to cell phone manipulation might reduce walking stability or result in energetically costly stabilization strategies such as increasing trunk muscle activation or adjusting step width [14]. Moreover, during the cell phone use, the gaze is somewhat fixed to the phone and the head position is tilted downward in relation to the direction of walking, which may increase variations of sensory signals from the vestibular and/or visual system for controlling balance during walking [16].

The purpose of this study was to investigate how people maintain walking stability during a cell phone dialing task. Specifically, we would like to explore the effects of dual-tasking on subjects' local dynamic stability [13] and dynamic margins of stability [17]. To control walking speed during dual-tasking, we examined treadmill walking. We compared the cell phone dialing task with two classic cognitive tasks, the Paced Auditory Serial Addition Test [18] and Symbol Digit Modalities Test [19], which challenge *auditory* working memory and *visual* information processing speed, respectively. During the PASAT, subjects were auditorily presented a single digit number every 2 s and were instructed to add each new digit to the one immediately prior to it. During the SDMT, subjects were instructed to hold a letter size of testing paper with both hands while reading the symbols, thus eliminating arm swinging and resulting in an altered head orientation similar to the cell phone dialing task. We also compared older and younger adults to examine the age-related changes in dual-task walking. We hypothesized that both healthy younger and older adults would show reduced walking stability during the cell phone dialing task and the two cognitive tasks compared to walking only. We expected to see greater dual-tasking effects on walking stability in older adults than in younger adults. We also expected to see that the cell phone dialing task and SDMT would have greater effects on gait compared to the PASAT because these two tasks would lead to altered physical demands in addition to cognitive distraction.

2. Methods

2.1. Subjects

Seven healthy younger (five female, age: 20.4 ± 2.2 years) and nine older subjects (seven female, age: 61.1 ± 10.0 years) gave written informed consent to participate in this study. Both universities' Institutional Review Boards approved the protocol.

2.2. Experimental protocol

All subjects walked on a treadmill at their self-selected speed (younger subjects: 1.11 ± 0.15 m/s, older subjects: 1.07 ± 0.27 m/s) and under four different conditions: walking only, while performing the Paced Auditory Serial Addition Test (PASAT), a cellular phone dialing task (phone) and Symbol Digit Modalities Test (SDMT). During the PASAT, subjects were presented a single digit number by way of audio recording every 2 s and asked to add the most recent number to the number just presented, thereby disregarding their own verbal response and inhibiting the tendency to maintain a running total [18]. During the phone dialing task (phone), subjects were visually presented a series of 10-digit phone numbers one at a time and asked to dial the numbers on a standard flip phone (Motorola Razor) with both hands. During the SDMT [19], subjects were provided with a reference key where nine different symbols correspond to the numbers 1–9, followed by a list of 110 symbols on a letter size page held by the subject. Subjects were asked to rapidly state the number associated with each symbol in the order presented [19]. These tasks were chosen to include a more ecological task as well as traditional tasks known to assess different but partially overlapping elements of cognition. Each walking trial was tested for 2 min and in a pseudo-randomized order.

2.3. Data acquisition and analysis

Kinematics and ground reaction forces were recorded while subjects walked on an instrumented treadmill (1200 Hz, Bertec Corp., Columbus, OH, USA). The 3-D kinematic data were recorded using an 8-camera video system (60 Hz, Motion Analysis Corporation, Santa Rosa, CA, USA) with reflective markers attached on the feet, legs, pelvis, trunk, and over the C7 vertebra. Commercial software (Visual3D, C-Motion Inc., Germantown, MD, USA) was used for the initial data processing.

We quantified local stability by computing short-term local divergence exponents (LDE) of the trunk motion based on the reconstructed state spaces of C7 vertebral marker movement [13,20]. This local stability measure quantifies the sensitivity of the human locomotor system to the naturally occurring small perturbation during walking [21]. Techniques to quantify local stability are well established [22,23]. Briefly, we extracted and analyzed the first 90 continuous strides of each trial because it was the minimum number of continuous strides across trials. We then re-sampled the data to 9000 total data samples, approximately 100 data samples per stride [22]. Delay embedded state spaces were reconstructed independently from the mediolateral, anteroposterior, and vertical velocities of non-filtered C7 vertebral marker data using the original data and their time delayed copies [20]:

$$S(t) = [v(t), v(t+\tau), v(t+2\tau), v(t+3\tau), v(t+4\tau)], \quad (1)$$

where $S(t)$ is the 5-dimensional state vector, $v(t)$ is the original 1-dimensional C7 vertebral marker velocity data, and τ is the time delay. We used fixed time delays of 30, 25, and 15 data samples for the mediolateral (ML), anteroposterior (AP), and vertical (VT) directions, respectively, for all trials [23]. LDE quantified how quickly neighboring movement trajectories in a state space diverge over time. We first identified nearest neighbors and calculated the logarithmic Euclidean distances between neighboring trajectories in the state space as a function of time. The logarithmic divergences were then averaged over all pairs of initial nearest neighbors. Short-term LDE was estimated from the slope of a linear

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