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OVERGROUND WALKING ALONG WITH COUNTING BACKWARDS INFLUENCES MOVEMENT VARIABILITY IN HEALTHY YOUNG AND OLDER ADULTS.

Rahul Soangra,
Thurmon E. Lockhart
School of Biological and Health Systems Engineering, Ira A. Fulton Schools of Engineering, Arizona State University, Tempe AZ, 85287, USA

Abstract

Performance of secondary task i.e. dual task affects certain aspects of gait, but the relationship between gait variability and dual tasking is not well understood. This study evaluated the effects of the dual-task paradigm on measures of movement variability changes in two healthy age groups. Seven young (age 22.6±2.5 years, height 170.3±9.3 cm and weight 69.6±15.5 Kgs) and seven old participants (age 71.14±6.5 years, height 174.5±10.2 cm and weight 78.5±18.2 Kgs) were recruited for this study. Since cognitive task such as mental arithmetic tasks (for example counting backwards by subtracting three digits) are self-generated, and are performed with selected spontaneous rhythm, so are used as secondary task while walking. An inertial measurement unit was affixed at sternum level and anterior-posterior angular velocities were used for determining stride intervals and peak accelerations during each stride. It was found that healthy older adults have significantly higher dynamic stability ($p<0.01$) and we also found that dual-tasking significantly increases complexity in stride interval time signals in both young and older adults ($p=0.01$). In conclusion the findings of this study elucidate that dual-task related changes in gait compensate with movement variability but may not predispose healthy young and older adults to falls.

Keywords

dual task; nonlinear variability; fall risk; inertial sensor

INTRODUCTION

Human movement variability may be defined as normal variations that occur while performing motor task across multiple repetitions [1]. A person being persistent and lacking variability in movement may indicate rigidness or inflexible motor behaviors and may have limited adaptability towards changing task and environmental demands, whereas greater than optimal variability characterizes human movement as noisy and unstable. An optimal amount of variability may be defined as the amount of variability necessary for healthy biological systems to be adaptable and flexible in unpredictable and ever changing environments. With aging there are several changes in muscle properties that, may influence movement execution. Some of these changes include reduced muscle cross section area[2] with reduction in strength and fiber type distribution [3] which reduces the movement speed. There is also decrease in motor units [4] and all these changes have implications for execution of movement in old age[5]. Old age and frailty may result in reduction of muscle strength and force production, which has a significant influence on movement trajectories and final position accuracy for rapid movements [6].

In addition, age-related deficits are pronounced during dual-tasking [7, 8]. The inability to perform in dual tasking has also been reported to increase risk of falls in older adults [9]. In older adults impaired walking performance is associated with impaired cognitive performance in dual task walking [10]. It is reported that frail older adults have higher variability of stride time while backwards counting [11], which has been reported to be related to its rhythmic character and not wholly attributable to attentional load. Although numerous studies have reported walking speed negatively influences stride time variability [12–15], despite suggesting that stride time is independent of walking speed [14, 15]. Hollman and colleagues [10] reported that older adults reduced their gait velocity by 20% and young adults from 7–8% in dual task walking condition. They also found increase in 1.3–1.5% increase in stride-to-stride variability in young adults and 2.9% in older adults, demonstrating that attention demanding tasks have a destabilizing effect on gait and that attentional processes are involved in walking. Dual-task is associated with slow speed may be because control of gait speed may involve higher order cognitive systems. Some researchers have shown that gait speed is dependent on Prefrontal Cortex (PFC) activation [16, 17] and others have linked gait speed with executive function [18]. Thus walking and secondary task, compete for these shared neural networks, this leads to cognitive motor interference (CMI) [19]. Gait speed and stride length are probably controlled by cortico-basal ganglia circuit through thalamus [20, 21], whereas cadence is controlled by brainstem and spinal cord [22, 23]. Dual task methods can help to determine the cognitive demand of gait control and has been used by many researchers [24, 25]. Dual-task related gait changes have been reported amongst several populations however firm conclusions are lacking. The objective of this study was to determine how nonlinear variability was influenced in healthy young and elderly during dual task overground walking.

METHODS

Participants:

Seven young and seven old participants were recruited for this study. The younger population consisted college students of Virginia Tech campus, and older adults were retired people in Blacksburg area. The recruited participants were in a general good health condition, with no recent cardiovascular, respiratory, neurological, and musculoskeletal abnormalities. All participants were first familiarized with laboratory equipment’s and were provided a verbal explanation of the experimental procedure. Participants were requested to wear laboratory clothes and shoes, fitting to their sizes. Height and weight of participants were noted below the ID numbers assigned to the subject. This study was approved by the Institutional Review Board (IRB) of Virginia Tech. All participants who participated in this study provided written consent prior to the beginning of data collection. Demographic information for the participants is provided in Table 1.

Protocol:

The experiment was divided into two sessions: normal session and dual-task session (Figure 1). Each session was separated by 4 days and each participant was randomly assigned to either normal or dual-task as his/her first session.

Participants were instructed to walk on square hallway with 20 meters straightway inside the building continuously for 5 minutes at their self-selected pace. Participants were also instructed that they have to walk uninterrupted and keep walking steadily in their self-selected pace. An experimenter walked behind the participant with the Bluetooth enabled laptop and sheet of paper with list of numbers starting from 1000 and serial subtraction of digit 3. Participant's gait data were acquired using inertial measurement (IMU) situated at the sternum level (Figure 2).

Dual task walking :

This study used a clear and standardized cognitive task, such as serial subtraction [26, 27]. This session was similar to normal walking session described above, except that the participants were counting backwards when walking. The investigator told a random number (between 0–1000) before the walking trial and participants had to subtract the number by three continuously until the end of trial. Participants performed 3 trials of walking. The investigator corrected the participants, if error was made in counting backwards.

Instrumentation:

The IMU node consisted of MMA7261QT tri-axial accelerometers and IDG-300 (x and y plane gyroscope) and ADXRS300, z-plane uniaxial gyroscope aggregated in the Technology-Enabled Medical Precision Observation (TEMPO) platform which was manufactured in collaboration with the research team of the University of Virginia [28, 29]. The data acquisition was carried out using a Bluetooth adapter and laptop through a custom built program in LabView (LabView 2009, National Instruments Corporation, Austin, TX). Data was acquired with sampling frequency of 120 Hz. This frequency is largely sufficient for human movement analysis in daily activities, which occurs, in low bandwidth [0.8–5Hz] [30]. The data was processed using custom software written in MATLAB (MATLAB version 6.5.1, 2003, computer software, The MathWorks Inc., Natick, Massachusetts).

Stride Interval Time series (SIT):

The temporal fluctuations in stride intervals time series has been widely used as a non-invasive technique to evaluate effects of neurological impairments on gait and its changes with aging and disease[31, 32]. A customized MATLAB algorithm was used to identify peaks from gyroscope signals from trunk mounted inertial sensor. The time difference from one peak to the other was considered as stride interval and all these consecutive intervals made up Stride Interval Time Series (SIT) (Figure 3).

Signal Magnitude Difference Time series (SMD):

The differences in peak heights of angular velocity signals are categorized as signal magnitude differences. These differences in magnitudes of angular velocity were used to construct a time series which was named as Signal Magnitude Difference (SMD) Time series. The total length of SMD time series is one less than the total number of strides walked by the subject.

Local dynamic stability computation:

According to Taken's theorem [33], any single dimensional time series can be used to reconstruct a multi-dimensional state space via time-delayed coordinate approach and this phase plot created contains information for the underlying dynamics of the system.

For each participant 50 continuous gait cycles were extracted from trunk anterior posterior angular velocities and resampled to 5000 frames. Rosenstein's algorithm was applied to compute average divergences between neighboring trajectories in the reconstructed state space [34]. The nearest neighbor points on separate strides diverge at a rate given by the max LE [35].

$$\lambda(i) = \left\langle \ln\left[D_j(i)\right]\right\rangle / \Delta t \qquad (1)$$

Where $D_j(i)$ is the Euclidean distance between the jth pair of nearest neighbors after i discrete time steps, Δt is the sampling period of the time series data and <…> denotes average over all values of j.

RESULTS

Variability analysis for 5-minute walk:

Various nonlinear measures such as maximum Lyapunov exponent, sample entropy and detrended fluctuation analysis (DFA) were evaluated for 5 minutes of normal walking and dual-task walking data. It was also found that dynamic stability of older adults was significantly higher than the younger counterparts (p=0.008) (Figure 4). But dual-tasking did not affect dynamic stability while walking. We found that dual tasking increased sample entropy significantly in both young and older adults (p=0.017).

DISCUSSION

The findings support the use of inertial sensors as a tool for understanding variability in healthy young and older adults and augments preexisting knowledge of variability structure in healthy young and elderly. We found that elderly have higher dynamic stability than younger counterparts, which is consistent with the findings of other previous studies[35]. Dynamic stability is measured by Lyapunov exponent readily differentiated younger and older adults. Older individuals had significantly higher maxLE exponents than younger adults (Figure 4). We also found that during dual task overground walking both younger and older adults were found to have more complexity in SIT signals than that during normal walking (Figure 5). This is in contrast to already reported results that dual-tasking increases fall risk[36, 37].

In fact, the reduced capacity to adapt to stress is attributed to the loss of complexity with aging and disease [38]. This reduced complexity [38], is dependent on the nature of the intrinsic dynamics of the system and one's ability for short time adaptive change, which is required to meet an immediate task demand is reduced [39]. This study has found that the complexity of participants was higher during dual-tasking and therefore dual-tasking does not predispose both young and elderly to increased fall risk. We also acknowledge that the study is limited with small population size and all the participants are healthy. Previous studies have reported for elderly fallers or with any pathology like Multiple scleorosis [36, 40]. The measures derived in this study serve as ground work for future research and will provide an understanding of movement variability to reduce falls in frail older individuals, and in designing effective interventions to reduce fall risk and establish a link between fall risk and variability in human movement.

CONCLUSIONS

Inertial sensors are appealing for unconstrained and non-invasive ambulatory measurements with heuristic approach to summarizing variability measures. Previous studies on dual task suggest that older individuals have stride-to-stride fluctuations, step width and stride time variability are influenced by attention loading and are related to fall risk. This study concludes that probably dual-tasking does not affect healthy human gait such to predispose it to fall risk. This study uses inertial sensors to provide new insights into the factors that regulate gait variability in healthy young and older adults and the practical application of measures of the variability in the clinical settings.

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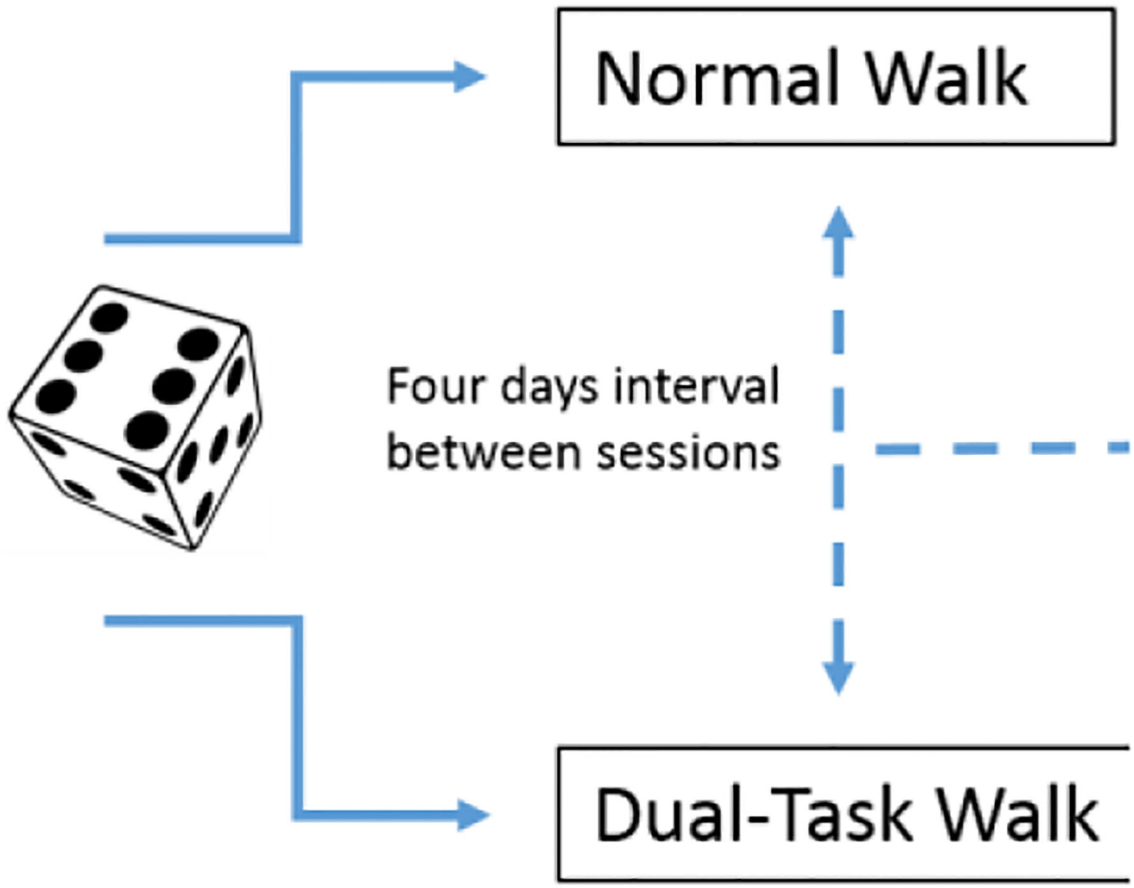

Figure 1.
Participants were assigned to normal or dual-task session randomly and the listed tests were conducted

Figure 2:
Attachment of IMU sensors at sternum level using Velcro strap.

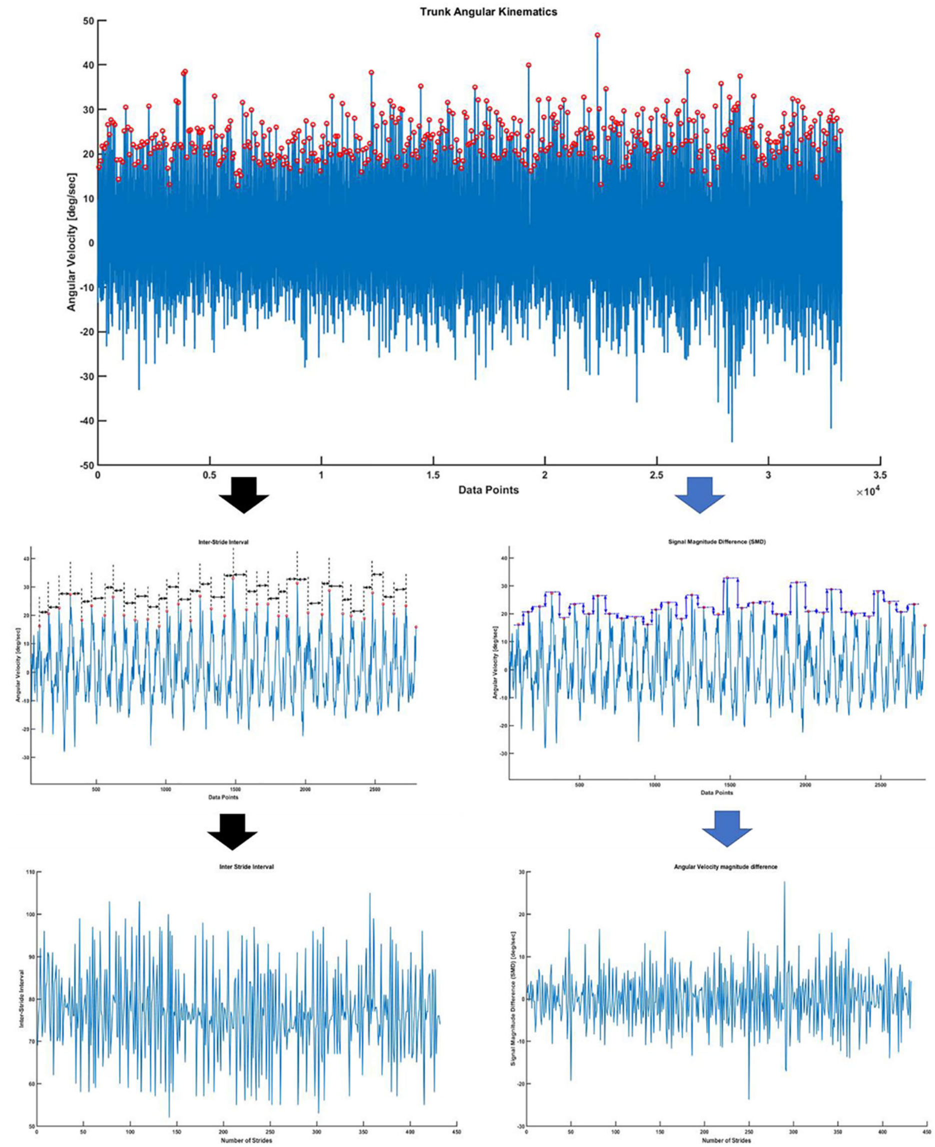

Figure 3:

Schematic diagram of derivation of SID and SMD time series from angular velocity signals from trunk IMU during walking on treadmill.

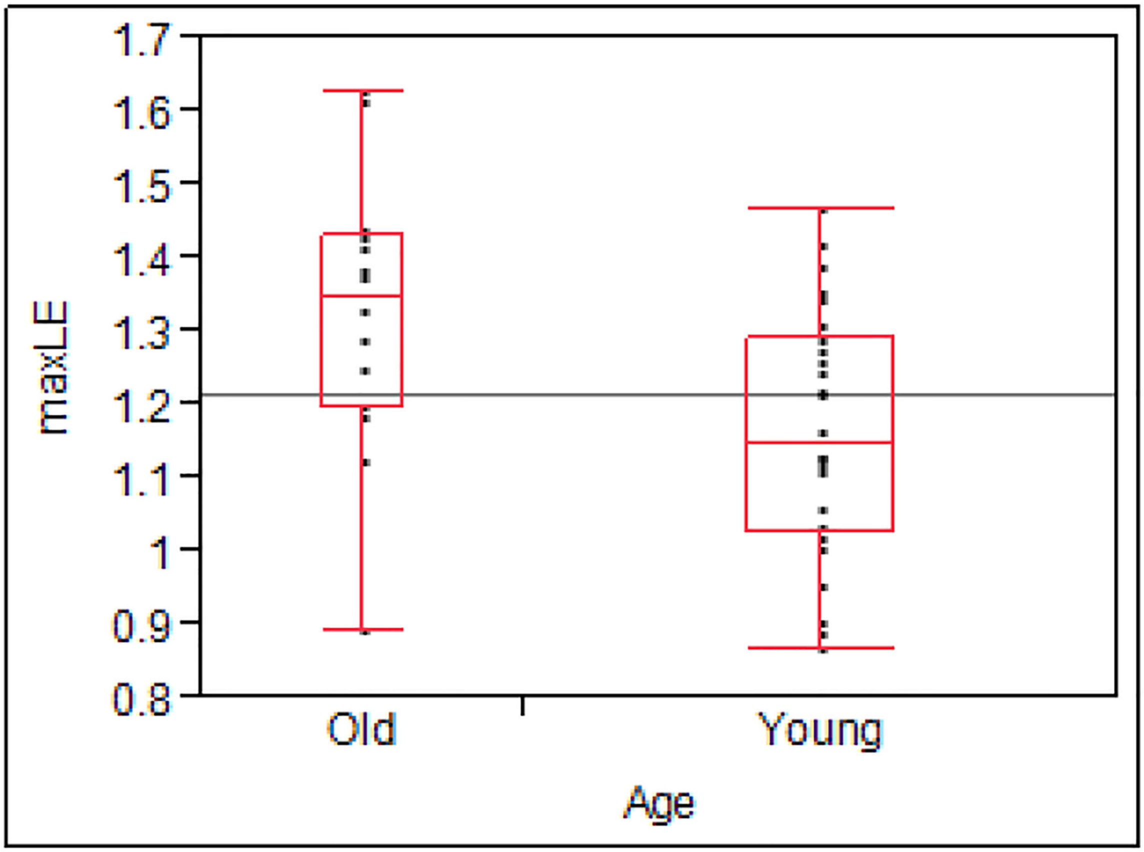

Figure 4.
max LE for young and older individuals

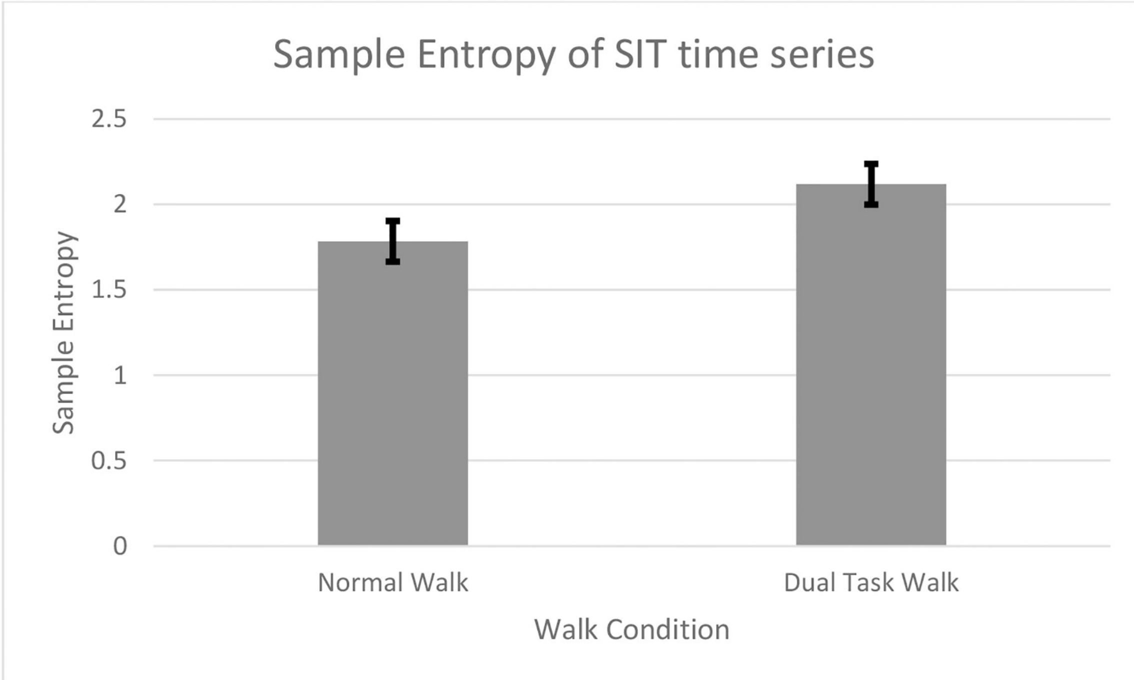

Figure 5:
Sample Entropy of SIT signals for normal and dual task condition

Table 1

Background characteristics of study participants

	Age Group			
	Old		**Young**	
	Mean	**SD**	**Mean**	**SD**
Age	71.143	6.5174	22.643	2.5603
Height [cm]	174.571	10.2446	170.376	9.3302
Weight [Kg]	78.559	18.2576	69.651	15.5270
BMI	25.529	4.2731	23.786	4.0004