Dynamic gait stability in healthy adults

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Abstract

Age-associated changes in gait characteristics have been interpreted as a more cautious, conservative gait pattern to maintain stability. As walking requires attention, cognitive impairments are likely to contribute to an increased fall risk in the elderly. In the present study we observed measures that quantify trunk movement patterns as indicators of dynamic balance during walking. Sixty seven healthy adults were recruited from the community and classified into two groups, young adults (N=34, 18-30 years) and middle-aged adults (N=33, 30-55 years). Walking at self-selected speed with and without performing a verbal dual task were measured for trunk accelerations with an accelerometer and harmonic ratio was the primarily observed gait parameter. Results indicate that dual task walking did not significantly contribute to altering gait stability although middle aged adults had lower ratios. This study concludes that harmonic ratio is an important measure of dynamic stability indicting age-related changes in walking.

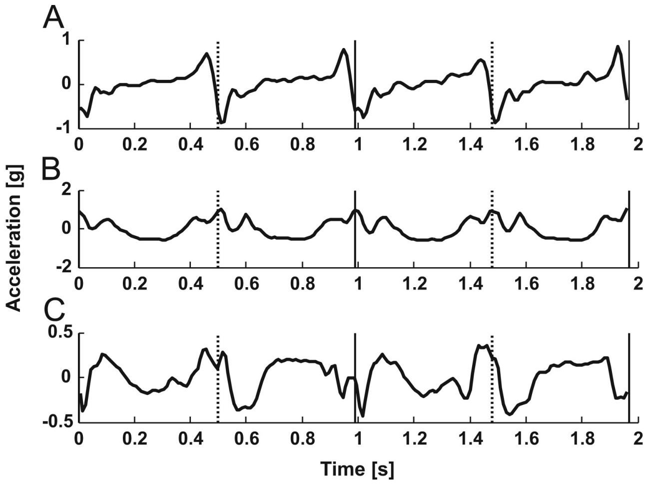
1 Introduction

Human gait changes during healthy aging. Older adults typically walk more slowly than younger adults, often taking shorter steps and spending more time with both feet on the ground between strides. [1]. This reduction in speed is thought to be related to changes in muscle strength, joint flexibility, and other physiological factors associated with aging. [2]. Age-associated changes in gait characteristics, such as lower walking speed, reduced step length and increased step time have been interpreted as a more cautious, conservative gait pattern to maintain balance and avoid potential hazards in the environment. [3]. However, these changes can also have negative consequences for mobility and physical function, as well as the risk of falls. [4]. As older adults become more vulnerable to falls, it is important to understand the changes in gait that occur during healthy aging and how they can be managed or improved to maintain mobility and independence.

Some of the measures assessing changes in gait quality due to aging are symmetry [5] , smoothness [6] , as well as measurements of trunk accelerations [1]. Body accelerations, measured using accelerometers, are a valuable technique for evaluating walking patterns. Accelerometry provides valuable insights into gait stability and the effects of aging, disease, and different walking conditions on walking patterns. They allow for assessments to be conducted in more naturalistic settings, where walking patterns may differ from those observed in a laboratory environment. For example, studies have shown that older adults exhibit greater variability in acceleration signals during walking, indicating decreased gait stability. [7]. Subsequently, this information can be used to develop interventions aimed at improving gait stability and reducing fall risk in older adults and other populations at risk of falls.

The harmonic ratio (HR) is one such common measure used to assess gait stability by evaluating the smoothness and rhythm of the acceleration signal during walking. It is calculated by dividing the power in the harmonics of the acceleration signal by the total power in the signal. [5]. The HR is most commonly extracted from trunk accelerations in the anteroposterior (AP), vertical (VT) and mediolateral (ML) directions. The VT and AP accelerations are biphasic within a stride due to the right and left steps, while the ML accelerations are monophasic. (Fig. 1). The HR calculated from trunk accelerations, unlike typical spatiotemporal parameters, is a summary measure of whole body movement. It has been shown that a decreased harmonic ratio is associated with increased risk of falls in older adults, as well as in individuals with neurological disorders affecting gait stability. [8]. Therefore, the harmonic ratio is a valuable tool for clinicians and researchers to evaluate gait stability and predict fall risk in different populations.

In addition to assessing gait stability using accelerometry and other techniques, it is also important to evaluate individuals under conditions that challenge their postural control system. They can provide valuable information on the ability of an individual to adapt to changes in their environment and maintain balance during gait. [9]. Moreover, it has been observed that a more



[5] Figure 1: The L3/L4 acceleration signal for (A) anterio-poster, (B) vertical and (C) mediolateral directions with right (vertical solid) and left (vertical dotted) heel contacts. [Note: the gravitational component has been removed].

conscious and cautious gait pattern, which is often adopted by older adults, may require more cognitive control and attention. This may result in a more attention-demanding form of locomotion, which could potentially affect gait stability. When walking requires more cognitive control and becomes less automated, it may be more prone to be influenced by concurrent cognitive tasks, also known as dual tasks. When individuals are asked to perform two or more tasks simultaneously, their performance on at least one of the tasks tends to decline. [10]. In principle, concurrent tasks can be given equal or different priorities such as to maximize gains or minimize risks; while young people typically prioritize gait [11], older people tend to assign higher priority to the secondary task [12]. Even in healthy individuals, dual tasks have been shown to affect walking performance, including gait speed and stability. [13]. Therefore, assessing gait stability under dual-task conditions may provide additional insights into adaptive changes in walking. The aim of the study was to investigate the relationship between executive function and gait stability in healthy adults to observe normal age related gait pattern, that is, the differential effects of dual tasking on a gait parameter in two age groups of healthy adults.

2 Methods

2.1 Participants

The study population consisted of cognitively intact adults; a young adult group (N=34, 18-30 years) and middle-aged adult group (N=33, 30-55 years). Participants recruited by word of mouth, colleagues, students, family, from sport or leisure clubs. Participants are included if they are free of orthopaedic and neurological conditions. Participants were excluded if their BMI ≥ 25 indicating being heavy, suffering from a recent (sport related) injury of the lower leg ($<$ 6 months), and under treatment (e.g., medication, monitored by doctor) for cardiovascular and/or respiratory diseases. Eligible participants were informed both orally and in written (email information letter) by the researcher/students. The principal researcher's contact information was given in the information letter. Informed consent was signed by the eligible participants before start of the study. In this study the data was collected, processed, and archived in accordance with the General Data Protection Regulation (GDPR) and the FAIR (Findable, Accessible, Interoperable, Reusable) principles under the responsibility of the Principal Investigator.

2.2 Assessments

To evaluate executive function, a letter fluency task was performed where participants are asked to name as many words as possible that start with the given letters. Participants were instructed not to repeat words, use synonyms, and/or proper nouns. The responses were recorded to be able to count the number of correct words. The baseline test was conducted seated comfortably as a single task of letters 'd', 'a' and 't' for 1 minute each. During the dual-task condition, letters were grouped by difficulty so that each grouping contained two letters 'r' and 'g' that were considered easy and one letter 'p' that was considered moderate.

To assess gait, participants were asked to walk for three minutes at a self-selected pace up and down a 10 m long course, once under single and once under dual task condition. During the walking trials, trunk accelerations in three orthogonal directions were measured with an ambulant accelerometer (ActiGraph; 4.6cm x 3.3cm x 1.5 cm; 19 gram; 100 Hz sf; dynamic range +/-8G), fixed with an elastic belt near the level of the third lumbar spine segment. Sample frequency was 100 Hz. In dual task walking, participants were asked to perform the second letter fluency task consisting 3 minutes of walking during three different letter tasks 'r', 'g' and 'p' for a total (1 min for each letter).

Vertical, anterior–posterior and medio-lateral acceleration time-series were analysed using MATLAB R2007b (The MathWorks Inc.). All time series were corrected for horizontal tilt [?] and low pass filtered with a third order Butterworth filter with a cut-off frequency of 20 Hz. Outliers in the stride time data, caused by bends in the circuit, were removed from the data using a median filter. [?] To investigate dynamic stability during walking, vertical, anterior–posterior and medio-lateral acceleration patterns were examined using a harmonic ratio (Hratio). [5]

2.3 Statistical Analysis

Statistical analysis was performed using RStudio 2022.02.2. Assumptions of normality and variance were met. Independent sample t test was used to determine the mean difference in dual task decrement between groups (Group x Condition interaction effects) on difference scores (dual task–single task). To test for correlations between executive function and gait parameters Pearson correlation coefficients were computed, only correlations higher than 0.50 were reported and level of significance was set at $p < 0.05$. Data visualization was subsequently performed and interpreted.

3 Results

Age Group	N	Mean ± SD (years)
Young	34	22.0±2.21
Middle-age	32	48.8±3.92

Table 1: Descriptive Statistics of participants.

Table 1 presents the descriptive statistics of participants with mean age in years. Inspection of Q-Q Plots revealed that Harmonic ratio was normally distributed for both groups and that there was homogeneity of variance as assessed by Levene's Test for Equality of Variances. Therefore, an independent t-test was run on the data with a 95% confidence interval (CI) for the mean difference indicating some influence of executive function on gait stability.

The results of the independent t-test performed on Harmonic Ratio are indicated in Table 2 for vertical acceleration, Table 3 for anterior-posterior acceleration and Table 4 for medio-lateral acceleration of gait parameter. Although younger adults demonstrated greater stability, there was with no significant difference between age groups in harmonic ratio, thus rejecting null hypothesis. This indicates that executive function during walking does not significantly effect gait stability in healthy adults.

Fig. 2 is a scattered box plot of harmonic ratio in the vertical acceleration where centre of distribution is positively skewed for in dual task walking for young adults, indicating greater stability. Fig. 3 is a scattered box plot of harmonic ratio in the anterio-posterior acceleration between two walking conditions. The distribution of data is approximately symmetric for both age groups and include potential outliers. Fig. 4 is a scattered box plot of harmonic ratio in the medio-lateral acceleration. The centre of distribution is higher for middle age adults and positively skewed for single task walking condition.

Age Group	Walking condition	N	HR_V				
			Mean	t	df	p	95% CI
Young	Single task	34	4.648	1.2386	64.363	0.22	[-0.144, 0.616]
	Dual task	32	4.412				
Middle-age	Single task	34	4.908	1.0238	58.94	0.310	[-0.266, 0.825]
	Dual task	32	4.629				

Table 2: Harmonic Ratio (Vertical)

Age Group	Walking condition	N	HR_AP				
			Mean	t	df	p	95% CI
Young	Single task	34	4.477	-0.243	65.365	0.808	[-0.588, -0.460]
	Dual task	32	4.541				
Middle-age	Single task	34	4.684	0.849	61.733	0.398	[-0.308, 0.765]
	Dual task	32	4.456				

Table 3: Harmonic Ratio (Antero-Posterior)

Age Group	Walking condition	N	HR_ML				
			Mean	t	df	p	95% CI
Young	Single task	34	2.293	-0.804	61.497	0.424	[-0.506, 0.216]
	Dual task	32	2.438				
Middle-age	Single task	34	2.848	0.524	61.906	0.601	[-0.230, 0.394]
	Dual task	32	2.766				

Table 4: Harmonic Ratio (Medio-lateral)

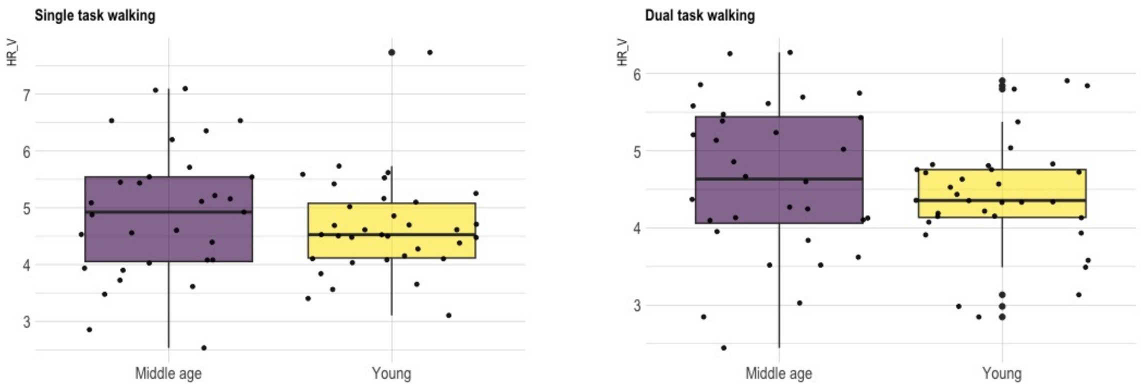


Figure 2: Box plot for HRatio_V between age groups

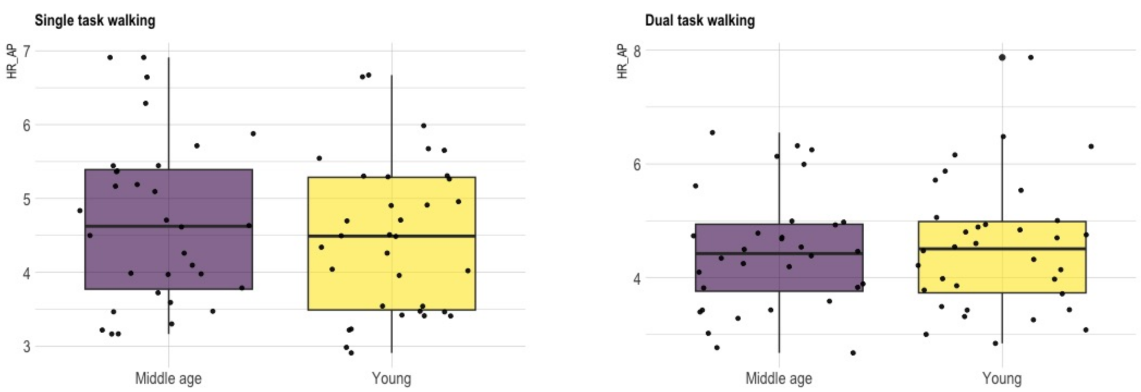


Figure 3: Box plot for HRatio_AP between age groups

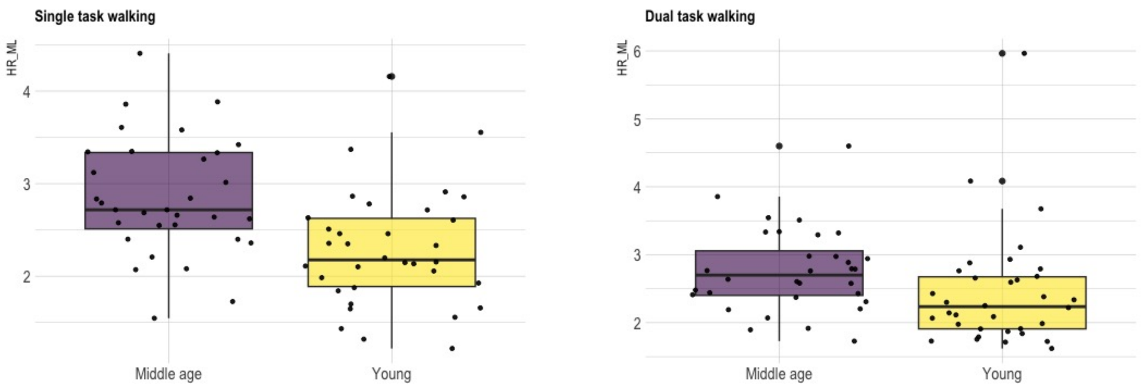


Figure 4: Box plot for HRatio_ML between age groups

4 Discussion

The harmonic ratio (HR) method is a valuable tool for investigating changes in gait patterns, particularly step-to-step symmetry within a stride. The HR method uses the even and odd harmonics of the acceleration signal in the anterior-posterior (AP) and vertical (VT) directions to represent biphasic symmetry and deviation from symmetry, respectively. However, the magnitude differences between odd and even harmonics only provide a partial understanding of gait acceleration, which is a complex combination of phase and amplitude of the harmonic components. Different pathologies may impact phase differently, yet result in the same HRs. Additional spatial and temporal analyses or instrumentation, such as 3-D kinematics and kinetics, may be necessary to separate these two aspects of gait acceleration. By providing insight into the smoothness and rhythm of the acceleration signal, HRs offer a unique perspective on gait stability and can potentially serve as a valuable diagnostic tool for detecting early changes in gait patterns associated with aging and neurological disorders. Furthermore, HRs may have clinical utility in the assessment of therapeutic interventions designed to improve gait stability in these populations.

Our results indicate that adult subjects exhibited the same degree of 'smoothness' in their acceleration patterns, as evidenced by the lack of significant differences between the two groups with regard to the harmonic ratio accelerations. These results support previous study by [14] who measured accelerations of the upper trunk in young and older adults, and found that there were no differences in peak accelerations between the two groups although older adults with self-reported balance problems exhibited less smooth trunk movements than normal older adults and young adults. However, they were unable to derive any meaningful information from the medio-lateral harmonic ratio. [15] found lateral accelerations of the pelvis to be too variable to enable the harmonic ratio to be calculated accurately, while [14] did not find any differences in the medio-lateral trunk harmonic ratio between young subjects and older people with balance problems.

A limitation of this technique is that accelerometry assumes that controlling the motion of the center of mass is the primary task when walking. While this is generally true, it is important to note that other factors, such as maintaining balance and avoiding obstacles, also contribute to gait stability. HRs are a global measure that do not account for phase of gait and do not explain where deviations from symmetry occur. Research has shown that lower HRs can be found in healthy older adults with spatiotemporal parameters similar to young adults [16]; [17] and in individuals in the early stages of Parkinson's disease with similar speed and stride length as healthy controls [18]. These findings suggest that HRs are capable of characterizing subtle alterations in locomotor mechanisms that may not be recognized through typical spatiotemporal gait characteristics used to describe mobility.

Some studies investigating dual-task walking have found that older adults have a decreased performance when asked to walk at their preferred speed while simultaneously performing another task [19]. However, other studies have not found an age-related deficit in dual-task performance [20]. The inconsistency in findings between studies may be due to the use of different secondary tasks in each study. A meta-analysis conducted by [21] found that age-related deficits while walking significantly increased when the secondary task involved executive or memory functions, such as verbal fluency tasks or mental imaging. However, when the secondary task was simple, such as reaction or discrimination tasks, age-related deficits did not increase significantly. This suggests that the complexity of the secondary task plays a role in the impact it has on walking performance in aging. Overall, these results indicate that the use of the HR method can provide valuable insight into gait stability and may serve as a diagnostic tool for detecting early changes in conservative gait patterns associated with healthy aging.

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