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Stability While Walking is Affected by Walking Speed and Cognitive Load

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Abstract

Aims: The aim of this study is to examine the effect of walking speed and cognitive load on learning gait stability in younger and older adults. **Materials and Methods:** Ten adults (five males and five females) and ten elderly (five males and five females) were healthy volunteers without a history of falls. He was asked to do three tasks on a treadmill with speed (preferred, fast, and slow) with/without cognitive load. The gait-stability ratio (GSR) for each of the above conditions was calculated in terms of both younger and older adults. Two-way repeated measures ANOVA was used to examine the mean differences at a significance level of 0.05. **Results:** The results showed that the cognitive performance score decreases with increasing speed. Moreover, at faster and slower speeds than prefer speed with/without cognitive load, GSR is higher, and this value was observed more in elderly than in adults ($P < 0.05$). **Conclusion:** The elderly, through different walking strategies, especially the lowering phase, provide more double support while walking, so that they will fall less with increasing steadiness.

Keywords: Dual-task, elderly, stability, walking speed

Introduction

The natural aging procedure renders the elderly with greater risk of falling with most of the falls in elderly age and while walking.[1] Thus, with increasing in the aging procedure, adaptation in the elderly walking pattern tends toward adopting the necessary strategies to increase gait stability. Although body capacity to move forward reduces, this strategy significantly reduces the likelihood of falling in the elderly by increasing stability.[2] Speed, step length, and double support are among the significant components in achieving stability and reducing falls among individuals.[3] To maintain the efficiency and smoothness in walking, the central nerve system (CNS) should consider changes in control strategies.[4] By controlling the movement of the lower limb joints, CNS adapts the walking pattern and thus reduces walking speed.[2] As cadence is the same in adults and the elderly, the elderly cover a shorter distance with shorter steps with the same number of steps compared to adults and this pattern makes the elderly have more time in the double support phase, causing a more stable walking pattern.[3] Different studies have stated the relationship between age with changes in walking pattern, gait stability, and balance, and age increase is associated with a decrease in motor function.[2,3,5]

In challenging situations, such as walking at different speeds and/or under various cognitive loads (including routine daily activities), there is a need for more movement actions and attention from CNS.[4] Change in walking speed affects access to response time and strategy selection.[6] Healthy people use different response strategies (lowering, elevation, and combine) following a trip to prevent falling.[5] Chiu and Chou stated that the youth and the elderly adapt to walking speed changes with different neuromuscular control strategies.[7] Ghanavati

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et al. argued that change in preferential speed could affect the variability and the dynamic phase of the walking phase.[4] Jordan *et al*. claimed that in a dynamic control system when people change their preferential speed, turbulence is created in the system. One of the basic concepts in the dynamic system approach is the concept of attractor. An attractor can be considered as a pattern of behavior that is in the formation of a system. With increasing in motor frequency, the two oscillators organs have nonlinear behavioral. Instability is not considered as a disorder in the implementations but fluctuations in the system output that has not been processed. Reduction in the freedom degrees of the joints is a way to get out of this instability and create a new attractor system.[8] The change in the speed of walking seems to increase the control effort of the system to conduct the task and can increase the risk of falling among the elderlies.[9]

The cognitive load is the mental resources needed to perform the task. Increase in the cognitive load in different tasks while walking (such as counting) imposes a different cognitive load on the central processing system.[10] According to the theory of capacity sharing in the dual-task paradigm, implementing additional tasks in walking may change walking features or the implementation of the second task or both.[11] Dubost *et al*. reported the increase in walking variability in the elderly while performing simple computational tasks.[12] Lindenberger *et al*. found that dual-task disorders appear to increase with age, and disorders such as a decrease in walking speed and an increase in the number of wrong steps during walking seem to appear.[13] However, variability more or less than the natural level can lead to unstable motion and increased risk of falling.[14]

It seems that the factors such as the speed of walking, done preferentially and nonpreferentially, and dual-task walking, which in many cases are cognitive, involve the individual. Some of the fall cases in the elderly occur when there is a need to focus on controlling posture and performing cognitive tasks simultaneously. Knowledge about motor control in healthy people can be used as a base for comparing the mechanism of disease change. The use of the dual motor and cognitive tasks seems effective and can be used both in the identification of the population at risk and in the evaluation of the results of rehabilitation programs for preventing falls in the elderly. However, no studies have examined the effects of the cognitive load and changes in walking speed in adults (as an efficient and correct pattern) and healthy elderly simultaneously. To address this issue, we hypothesize that increased cognitive load and walking speed will improve learning gait stability in older adults.

Materials and Methods

Subjects

Ten younger adults (age = 25.91 ± 3.42 and body mass index [BMI] = 24.10 ± 2.33) and ten healthy older adults (age = 66.65 ± 4.28 and BMI = 26.56 ± 2.35) without a history of falling participated as volunteers (sample size suggested by Byrne *et al*. and 80% power efficiency to detect group differences at 0.05 level).[15] All of the participants were in complete health and were excluded from the study if they had orthopedic, vestibular, or neurological disorders that affected walking or reducing the cognitive score. The older adults had the Mini–Mental State Examination score of 24 or higher.[16] The younger adults were matched to the older adults in terms of gender and BMI. All the individuals completed the informed consent form before participating.

Procedure

Walking task

Treadmill (HP-cosmos mercury® Med, Germany), with two piezoelectric force plates of Kistler Company, was used for walking. These force plates can output the number of steps, step length, cadence, and walking speed.[17]

Walking tests were performed at three speeds (preferential, 20% increase, and 20% decrease) at bare feet.[18] The preferred speed of the participants is by asking them to walk on the treadmill at a speed of 1 km/h and a gradual increase of 0.5 km/h to the speed stated by the participant. After recording the speed, the participants were again asked to step on the treadmill and confirm their desired speed at their preferred speed determined by them, with 0.5 km/h speed decrease or increase.[19] This method was repeated four times, and eventually, the preferential speed of each participant was determined. For each participant, six times the walking tasks were three times walking tasks with speed (preferential, fast, and slow) with/without cognitive load. Data recording were done on the treadmill for 90s.[4,7] It is noteworthy that for acquaintance of the participants with the laboratory environment and the test, after a full description of the test, each participant repeatedly practiced on a treadmill experiment several times. The time needed to rest between the tests was given to individuals. Safety considerations (Harness) were observed during the test.

Cognitive task

The cognitive task of the study was mental calculation task. The mental calculation task involves working memory[20] and is implemented by the participants having to decrease three by three from a random three-digit number, which continued for 90s. The participants were asked to reduce three by here from a random three-digit number, and their points were recorded while sitting on the chair and/or moving on the treadmill. Intervals, words, or false calculations were recorded for each of these tests. Meanwhile, all speech tests were recorded with a tape recorder. Participants did not have any previous training on this task. The cognitive performance scale (CPS) was calculated by Formula (1). Using this formula, the speed and precision of a person's cognitive task are taken into account. The higher the CPS indicates the weaker person's cognitive performance (less correct answer) while dual-task walking and vice versa.

Formula (1) Correct response rate =

$$\text{Response rate per second} \times \text{Percent of correct answers response}$$

The cognitive task was made to changes in correct response rate (CRR) due to the dual task to individual conditions. In

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this study, the cognitive function score was calculated for each task based on Formula (2).[4,21]

Formula (2) Cognitive Performance Scaü

$$\frac{ü_{\text{Task in sitting position}} - CRR_{\text{Task in dual task walking}}}{ü_{\text{Task in sitting position}}}$$

Gait stability

Measurements were stated in relation to walking speed, and step length changes were expressed by Cromwell and Newton.[2] This size includes gait-stability ratio (GSR), which is the cadence ratio (steps per second) to speed (m/s), whose unit is steps per meter. GSR expresses gait stability, and its increase shows the increase of steps per meter, meaning that the person has a double support level earlier and has better gait stability. The researchers stated that this method had good validity and can be used to evaluate and measure gait stability in the dynamic movement and reported the reliability of the test through intraclass correlation coefficient method for walking speeds as 0.91 and for a cadence as 0.75.[2] The test–retest reliability using the correlation coefficient for GSR was 0.81 in this study.

Ethical considerations

The research was approved by the Ethical Committee of Kharazmi University at Number 100/1000-K.A.P.

Statistical analysis

Kolmogorov–Smirnov test (KS test) was done to check the normality of distribution. The main and interactive effects of the group, cognitive load, and walking speed on dependent variables were performed using two-way repeated measures ANOVA with 95% of confidence level and Bonferroni's *post hoc* test.

Results

The individual characteristics of the participants are shown in Table 1. Data were normally distributed according to the K-S test ($P \geq 0.05$). The mean CPS in adult and elderly groups at different walking speeds is shown in Figure 1. The elderly seem to have complicated cognitive tasks and at a faster pace, weaker CPS [Figure 1].

The mean of the parameters involved in gait stability at different speed and with/without cognitive load is shown in Table 2, respectively.

As shown in Table 3, the results of two-way repeated measures ANOVA for GSR show that there is a significant difference between the younger adults and the older adults groups in different walking speeds without cognitive load ($F_{2,38}$ = 29.19, P = 0.031). There is a significant difference in older adults with cognitive load at different speeds for GSR. ($F_{2,9}$ = 33.71, P = 0.024). At the time of cognitive load, there is a significant difference between the younger adults and the older adults in walking with different speeds ($F_{2,38}$ = 31.01, P = 0.005). Furthermore, there is a significant difference between the younger adults and the older adults groups in the cognitive load ($F_{1,19}$ = 46.19, P = 0.002) [Table 3].

A *post hoc* test for comparing the means shows that increasing the walking speed without cognitive load has a negative effect on learning the gait stability in younger adults and older adults. It can be stated that the gait stability in older adults with fast- and slow-speed walking is more than that younger adults [Figure 2]. Furthermore, gait stability with fast- and slow-speed walking is more than younger adult, as well as in older adults by increasing and decreasing in prefer speed cause learning stability [Figure 3].

The results show that there is a significant difference in slow walking speed with/without cognitive load between age groups and the older adult has greater stability.

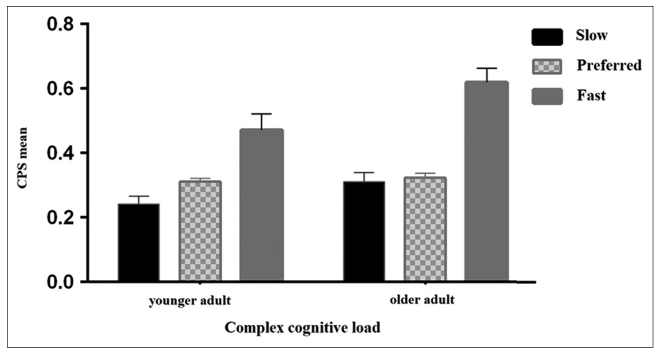

Figure 1: Cognitive performance scale mean with different walking speeds

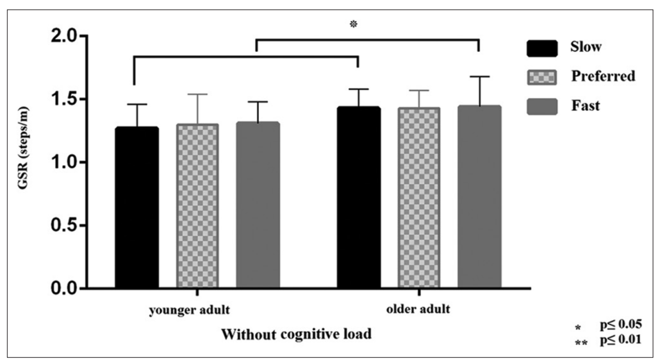

Figure 2: Bonferroni test results for the effect of walking speed on gait-stability ratio without cognitive load

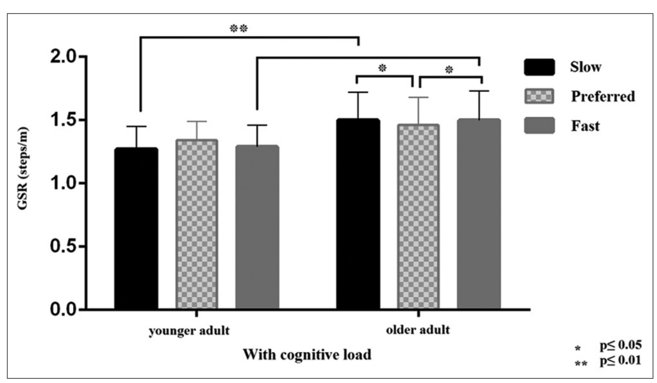

Figure 3: Bonferroni test results for the effect of walking speed on gait-stability ratio with the cognitive load

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There is a significant difference in prefer walking speed without cognitive load of the younger adult group with the older adult group with/without cognitive load, and the older adult has greater stability. There is a significant difference in fast walking speed of older adult group with/without cognitive load, and at the time of the cognitive load, learning gait stability improve. Moreover ultimately, in younger adults with/without cognitive load, there is a significant difference with the older adult with/without cognitive load, and it can be said that the older adult has a greater learning gait stability than the younger adult [Figure 4].

Table 1: Descriptive characteristic of participants

Group	Number and gender	Characteristics	Mean±SD
YA	5 men and 5 women	Age (years)	25.91±3.42
		Height (m)	1.68±2.92
		Weight (kg)	65.68±1.30
		BMI (kg/m²)	24.11±2.33
OA	5 men and 5 women	Age (years)	66.65±4.28
		Height (m)	1.60±2.02
		Weight (kg)	69.59±3.89
		BMI (kg/m²)	26.56±2.35

SD: Standard deviation, BMI: Body mass index, YA: Younger adults, OA: Older adults

Discussion

Many falls in the elderly occur during walking and simultaneous with cognitive tasks.[13] The results indicated that walking fast relative to walking slowly or at the preferential speed significantly worsen the cognitive performance. This decrease, especially in the case of cognitive tasks, was more difficult and tougher in the elderly. The results of this section of the study are consistent with the results of previous studies. Studies showed that the cost of the dual task for cognitive function increases with the motor task getting harder.[22] Hollman *et al*. stated that less gait speed in the elderly compared with middle-aged and younger groups, and this speed is reduced more often when dual tasks. There are also variations in walking speeds between the elderly and young people in the normal state and dual-task mode while walking.[14] Walking and simultaneously performing complex cognitive tasks, working memory, and sustained attention can explain the implementation of walking along with cognitive tasks[23] (such as three-point deductions). It seems that harder the cognitive task becomes the more the cost of the dual task for walking increases, and vice versa, which is completely in line with the results of our study.[21]

The results showed that the GSR was higher at speeds faster and slower than the preferred speed with/without cognitive

Table 2: Mean and standard deviation of parameters involved in gait stability at different speed and with/without cognitive load

Cognitive load	Participants	Walking speed	Cadence(steps/s)	Velocity (m/s)	GSR (steps/m)	Step length (m)	Double support (s)
With cognitive load	YA	Preferred	1.89±0.19	1.41±0.32	1.34±0.15	0.70±0.16	0.65±0.011
	OA		1.73±0.26	1.18±0.20	1.46±0.22	0.54±0.17	0.93±0.27
	YA	Slow	1.42±0.15	1.12±0.12	1.27±0.18	0.65±0.11	0.66±0.32
	OA		1.31±0.13	0.91±0.22	1.45±0.22	0.53±0.09	0.92±0.16
	YA	Fast	2.24±0.17	1.75±0.14	1.29±0.17	0.78±0.16	0.59±0.11
	OA		2.30±0.14	1.54±0.10	1.50±0.23	0.64±0.07	0.82±0.18
Without cognitive load	YA	Preferred	1.85±0.22	1.42±0.29	1.30±0.24	0.72±0.04	0.63±0.12
	OA		1.72±0.12	1.20±0.18	1.43±0.14	0.59±0.09	0.85±0.21
	YA	Slow	1.45±0.10	1.14±0.21	1.27±0.19	0.66±0.08	0.66±0.09
	OA		1.38±0.19	0.96±0.14	1.43±0.15	0.55±0.07	0.91±0.29
	YA	Fast	2.23±0.15	1.70±0.22	1.31±0.17	0.75±0.06	0.60±0.06
	OA		2.07±0.25	1.44±0.19	1.44±0.24	0.63±0.10	0.79±0.33

YA: Younger adults, OA: Older adults, GSR: Gait-stability ratio

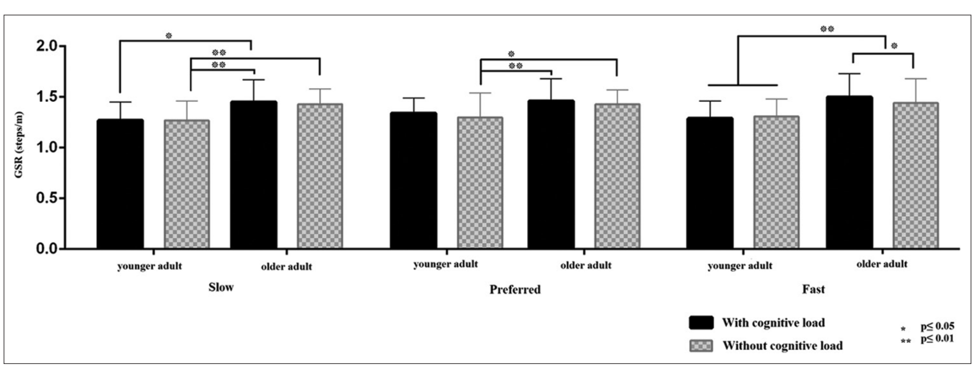

Figure 4: Bonferroni test results with/without cognitive load with different walking speed on gait-stability ratio

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Table 3: Results of two-way repeated measures ANOVA for gait-stability ratio

	YA	OA	Intergroup
Walking speed	0.514	<0.01	<0.05
Cognitive load	0.310	<0.05	<0.01
Walking speed × cognitive load	0.487	0.334	0.741

YA: Younger adults, OA: Older adults

load, which was more in the older adults than in younger adults. Cromwell and Newton argued that GSR levels are higher in the elderly, meaning that the elderly take more steps in the same distance, and hence their gait stability increases with this mechanism. Increase in gait stability while walking makes the elderly compensate for the reduction in balance to some extent. Thus, by maximizing gait stability, the elderly creates a pattern of motion that provides greater resistance to disorder, acting as a mechanism for protection against fall.[2] However, this mechanism reduces the forward speed of the elderly and seems that the speed is sacrificed for stability while stepping.

There was a difference in the nonpreferential rates of GSR between the older and younger adult groups in the study. More prudent walking pattern needs more cognitive control, and an elderly person will sacrifice more attention to control than the younger person.[12,24,25] Thus, walking turns into a complex multitasking behavior from a rhythmic and automated behavior, whose control is more difficult that makes the person more likely to fall.[25] This difference was also more in the simultaneous implementation of complex cognitive tasks to maintain vertical posture, and CNS must integrate sensory input and retrieve weight distribution information from different sensory systems (vision system, vestibular system, and sensory system) and continually regulate the neuromuscular system.[26] Although this process is automatic, using dual tasks, various studies have shown that tasks such as walking at different speeds and performing complex cognitive tasks need significant resources. Thus, there is always competition on limited resources for control posture and implementation of dual functional and cognitive tasks.[27]

In severe motor load cases (walking speed) or cognitive tasks in a dynamic system, control effort increases, and in elderly with a severe loss of sensory, musculoskeletal, cognitive systems, etc.,[23] more pressure is imposed on the system and the control system uses different mechanisms such as slowing down, increasing GSR, and increasing double support time for reducing this effort, so that the elderly appears to be more steady in everyday activities and the risk of falling reduces. It seems that by designing exercise for the elderly at different speeds and with cognitive actions, learning various strategies by varying the step length, step speed, and double support in the elderly can happen, which ends in increased GSR and reduces the risk of falling of the elderly.

The sleep, rest, and nutritional status of the participants were not controlled by the researcher before the tests. Treadmill use could also be a potential limitation for the study as treadmill kept walking the speed of the individual constant in all conditions that could artificially alter the natural variability and attention needs of walking, but as each participant used to be tested according to the same controlled conditions and their cognitive load and walking speed, one can state that walking on the ground differs a little from the current measured values, which were among the limitations of the study.

Conclusion

In difficult motion load (walking speed) or additional cognitive conditions in a dynamic system, control effort increases, and the control system tries to reduce the control effort on the system. This is because the control capacity is limited, and the system uses different mechanisms to compensate for this disorder, which is more tangible among the youth and has better performance. Nonetheless, the older adults use more double support while walking by different walking strategies, especially the lowering phase and hence that with increasing in GSR falling decreases.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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