Effect of Dual-Tasking on Variability of Spatiotemporal Parameters in Subjects with and without Anterior Cruciate Ligament Deficiency Using Linear Dynamics

Salman Nazary-moghadam [1], Behnam Akhbari [1], Ali Esteki [2], Mahyar Salavati [1*], Sohrab Keyhani [3], Afsaneh Zeinalzadeh [4]

1. Department of Physiotherapy, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran.
2. Department of Biomedical Engineering and Physics, School of Medicine, Shahid Beheshti University of Medical Sciences and Health Services, Tehran, Iran.
3. Akhtar Hospital, School of Medicine, Shahid Beheshti University of Medical Sciences and Health Services, Tehran, Iran.
4. Department of Physiotherapy, Faculty of Rehabilitation Sciences, Tehran University of Medical Sciences, Tehran, Iran.

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ABSTRACT

Purpose: The present study aimed to determine the effect of dual-tasking on spatiotemporal characteristics in subjects with and without Anterior Cruciate Ligament Deficiency (ACLD) using linear dynamics.

Methods: In this mixed model design study, spatiotemporal parameters were measured in 22 patients with ACLD (25.95±4.69 y) and 22 control subjects (24.32±3.37 y) while they were walking with different levels of gait velocity (high velocity, self-selected velocity, low velocity) in isolation or concurrently with auditory Stroop task. Coefficient of Variation (CV) was used to calculate variability of step length, step time and step width as dependent variables using custom-made MATLAB code. Mixed model of analysis of variance and post hoc analyses were used for data analysis.

Results: The results showed that interactions of group by gait velocity due to cognitive difficulty were not significant for all mentioned variables (P>0.05). Group Interactions due to cognitive task difficulty were significant only in CV of step width (P=0.05). Interactions of motor task difficulty by cognitive difficulty were significant for CV of step length, step time, and step width in all participants (P<0.05). The main effects of gait velocity in all dependent variables were significant (P<0.05).

Conclusion: Results showed that step width variability is a more sensitive measure for detecting interaction of group due to cognitive task difficulty compared to variability of step length and step time. Future studies could test this hypothesis in ACL deficient subjects using different measures.

Keywords:

Gait, Anterior cruciate ligament, Attention, Variability

1. Introduction

Gait in human is a motor behavior that has automatic and rhythmic components [1]. When humans walk freely, some variations in gait spatiotemporal parameters are seen between each step. Variability in gait always inherent to human movement and can be measured in both spatial and temporal characteristics such as step length, step time, and step width, which makes it possible to recognize any gait deviation from normal ones [2-5]. Results showed that spatiotemporal variability in elderly fallers [2, 3], older frail fallers [4], and patients with Parkinson disease [5] differs from control subjects.

In addition to gait examination, variability in spatiotemporal parameters can be an objective predictor of falling. Several studies performed in recent years, demonstrated that Central Nervous System (CNS) plays an important

* Corresponding Author:
Mahyar Salavati, PhD
Address: Department of Physiotherapy, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran.
Phone: +98 (21) 22180039 Fax: +98 (21) 22180013
Email: mahyarsalavati@gmail.com

role in gait performance [2, 3, 6-8]. For example, step width variability is correlated to fall in elderly persons who walked near the self-selected speed [3]. Brach et al. revealed that CNS deficiencies changes stance time variability, especially in slow walking [9]. Also recent studies revealed that sensory impairments have important role on step width variability in fast walkers [3, 9]. Although there are different studies about the effect of neural deficiencies and sensory impairment on variability of spatiotemporal parameters, no study has been examined the variability of the mentioned parameters in musculoskeletal disorders, which have sensory deficits as a result of deafferentation [10].

Performing motor tasks need some degree of attention [11]. Based on "limited capacity theory" of attention, if the subjects were exposed to cognitive load whenever they were concurrently walking, these tasks would compete to engage some degree of attention. This competition results in performance decrement for one of these tasks or both of them [12].

This is more evident, especially when the central nervous system is structurally impaired. For example, stride time variability increases significantly during dual-tasking in older adults. Dual-task paradigms are methods for studying attention and postural control (gait) in which the primary task (gait) and a secondary task (cognitive) are being performed together. Auditory Stroop task is one of the cognitive tasks that has been frequently used during the dual-task paradigm [13, 14].

Although there is no structural destruction in CNS of patients with ACLD, there may be some loss of verbal memory and slower reaction time in these patients [15]. These events increase the probability of CNS dysfunction functionally [15]. This dysfunction may be deleterious in these patients, particularly when they experience some cognitive load simultaneous with different levels of walking velocity. However, the aim of the present study was to examine variability of spatiotemporal parameters (step length variability, step time variability, and step width variability) in different walking velocities under single- and dual-task conditions in patients with ACLD.

2. Materials & Methods

To examine the hypotheses, a mixed-model design is used. Twenty-two patients with ACLD and 22 control subjects volunteered through nonprobability-convenient sampling. The males with anterior cruciate ligament tear were referred from orthopedic section of Akhtar University Hospital, Tehran, Iran. Two groups were matched with respect to their age, height, weight, and physical activity before the injury (Table 1). The time range between ACL rupture and experiment was 6-34 months. Patients with unilateral, complete ACL rupture were included if they have not undergone knee surgical treatment. In both groups those participants with neurologic deficiency, orthopedic disorder, auditory and visual deficiencies were excluded.

All subjects were instructed to know the process of experiment and asked to read and sign a consent form. Also a questionnaire that contained injury and demographic information was completed by each subject for excluding any subjects that lacked inclusive study conditions. The present study was approved by Ethics Committee of University of Social Welfare and Rehabilitation Sciences.

Motor task

Vicon Motion System (Oxford Metrics, Oxford, UK) with 5 cameras optoelectronics system was used to measure step length, step time, and step width. The participants walked on motorized treadmill (Stingray, M8000i,

Table 1. Demographic information in patients with anterior cruciate ligament deficiency (ACLD) and control group.

Variables	ACLD (n=14)		Control (n=14)		P Value
	Mean	SD	Mean	SD	
Age (y)	25.95	4.69	24.32	3.37	0.46
Height (cm)	179.23	5.93	177.77	5.45	0.19
Weight (kg)	83.00	13.70	77.91	24.02	0.40
Tegner sport activity level (-)	8.09	1.63	7.32	1.78	0.39
Walking velocity (m/s)	0.98	0.13	0.95	0.14	0.14

P-values refer to statistical significance of independent t tests between mean scores of ACLD and control groups.

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Table 2. Results of analysis of variance for 3 measures of spatiotemporal coefficient of variation (CV) during walking: F ratios and P values by variable.

	Step length CV		Step time CV		Step width CV	
Independent variables	F	P	F	P	F	P
Main effect						
Group	0.18	0.67	0.09	0.77	0.94	0.34
Gait velocity	17.34	**0.00**	4.61	**0.02**	24.36	**0.00**
Cognitive task difficulty	0.11	0.75	1.66	0.21	0.11	0.74
Interaction						
Group×Gait velocity	0.76	0.47	0.15	0.86	0.11	0.90
Group×Cognitive task difficulty	1.06	0.31	0.83	0.37	3.97	**0.05**
Gait velocity×Cognitive task difficulty	10.97	**0.00**	4.35	**0.02**	3.97	**0.02**
Group×Gait velocity×Cognitive task difficulty	1.40	0.25	0.35	0.71	0.18	0.84

P values lower than 0.05 are highlighted in bold.

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and Taiwan) as multiple strides are needed to have better judgment about variability of spatiotemporal gait parameters. Three markers were attached to sacrum, left heel, and right heel to measure the mentioned variables based on Zeni study through custom-made MATLAB code [16]. The Zeni algorithm calculates step length, step time, and step width throughout gait cycle. After extraction of gait spatiotemporal variables, coefficient of variation (CV) was calculated using the equation through the Excel software (Microsoft office 2010). Step length CV, step time CV, and step width CV, were the dependent variables of the present study. The dependent variables were measured whenever the subjects walked on three levels of gait velocity (self-selected velocity, high velocity 20% faster than self-selected velocity, low velocity 20% slower than self-selected velocity). Participants were exposed to 2 levels of cognitive task difficulty with and without auditory Stroop task. Finally, two groups walked on treadmill under 6 conditions for 95 seconds. The familiarization period with treadmill lasted 6 minutes to ensure that subjects have similar gait pattern with over-ground walking [17].

Cognitive task

Auditory Stroop task is a modified version of Stroop task that was usually used in dual-task paradigm. During walking, participants were exposed to cognitive load through auditory Stroop task. They should answer the

Table 3. Between groups' comparison of spatiotemporal coefficient of variation (CV) in 6 conditions of gait velocity and cognitive task difficulty for patients with ACLD and control groups.

Level of gait velocity	Variables	No cognitive load			With the cognitive load		
		ACLD Mean (SD)	Control Mean (SD)	P value	ACLD Mean (SD)	Control Mean (SD)	P value
High velocity	Step length CV	9.86 (4.78)	8.79 (1.14)	0.33	9.27 (5.29)	8.17 (0.80)	0.34
	Step time CV	10.15 (3.47)	9.18 (1.03)	0.95	8.89 (0.94)	9.96 (3.57)	0.27
	Step width CV	10.17 (4.42)	9.51 (1.49)	0.22	11.32 (2.86)	11.00 (3.11)	0.97
Self-selected velocity	Step length CV	9.50 (5.16)	9.62 (3.30)	0.51	8.17 (0.37)	8 .44 (0.73)	0.73
	Step time CV	8.80 (0.63)	9.31 (1.86)	0.58	12.76 (6.64)	11.21 (5.21)	0.50
	Step width CV	9.97 (1.73)	10.48 (2.66)	0.26	11.14 (3.41)	10.39 (1.87)	0.59
Low velocity	Step length CV	7.95 (1.71)	8.66 (1.99)	0.24	8.20 (2.63)	7.97 (0.95)	0.20
	Step time CV	8.40 (0.38)	8.84 (0.84)	0.39	8.64 (0.99)	8.54 (0.50)	0.53
	Step width CV	8.71 (2.02)	9.42 (2.03)	0.46	9.82 (2.30)	9.52 (1.08)	0.65

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Table 4. Results of paired t test for 3 measures of spatiotemporal coefficient of variation (CV) parameters during 3 levels of walking velocity in dual- and single-task conditions in all participants: t and P values by variable.

Walking velocity	Variable	No cognitive load Mean (SD)	With the cognitive load Mean (SD)	Mean difference	t	p
High velocity	Step length CV	9.10 (3.19)	8.71 (3.74)	-0.39	-1.24	0.22
	Step time CV	9.63 (4.36)	8.31 (0.58)	-1.32	-1.47	0.16
	Step width CV	8.21 (1.77)	7.85 (1.20)	-0.35	-1.41	0.17
Self-selected velocity	Step length CV	9.68 (1.38)	9.06 (5.89)	-0.62	-1.48	0.15
	Step time CV	9.06 (1.38)	11.99 (5.89)	2.93	2.29	**0.03**
	Step width CV	8.62 (0.67)	8.60 (0.67)	-0.01	-0.08	0.94
Low velocity	Step length CV	9.51 (2.61)	11.25 (1.17)	1.74	3.95	**0.00**
	Step time CV	10.21 (1.38)	10.82 (2.81)	0.56	0.83	0.42
	Step width CV	9.07 (2.03)	9.72 (1.81)	0.65	1.92	0.06

P values lower than 0.05 are highlighted in bold.

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questions while performing walking on the treadmill. The participants should recognize speaker's voice that was modified by 'high pitch' and 'low pitch' when he utters the words 'high' and 'low'. For example, if the speaker uses the word 'high' with 'low pitch', participants should answer with word 'low' as soon as they hear the question.

Statistical analysis

Kolmogorov–Smirnov test was used to compare the sample with a reference probability distribution. Since the spatiotemporal CV was normally distributed, parametric analysis was used for statistical analysis. To examine the main effect and interaction of the following factors for spatiotemporal CV parameters, 2×3×2 (2 groups, 3 levels of gait velocity, 2 levels of cognitive task difficulty) mixed model of analysis of variance (Three-way ANOVA) was used. Also, post hoc analyses including paired t test and independent t test was performed.

3. Results

Demographic properties of all participants including age, height, weight, Tegner sport activity level and walking velocity were demonstrated in Table 1. The results showed that there were no significant differences in demographic variables between subjects with and without ACLD (Table 1). Also the result of Chi-squared test showed that there is not statistical significant difference in sex and leg dominance between ACLD and healthy groups.

Prior to analysis of differences, hypothesis of equal variances is accepted and it is concluded that there is not a difference between the variances in two groups. ANOVA results for the variables 'step length CV', 'step time CV', and 'step width CV' are presented in Table 2. Results showed that only the main effect of gait velocity was statistically significant in all dependent variables. Interaction of group by cognitive task difficulty was not statistically significant with the exception of 'step width CV'. Interaction of gait velocity by cognitive task difficulty was statistically significant for all dependent variables.

Table 3 presents between groups' comparison of all dependent variables in 3 levels of task difficulty as well as 2 levels of cognitive task difficulty. Table 4 shows the significances between different levels of walking velocities in dual- and single-task conditions in all participants. According to Table 4, in all participants the values of step

Table 5. Results of paired t test for step width coefficient of variation (CV) parameters during dual- and single task in both ACLD and healthy groups separately: t and P values by variable.

Variable	Group	No cognitive load Mean (SD)	With the cognitive load Mean (SD)	Mean difference	t	p
Step width CV	ACLD	8.28 (1.48)	8.77 (1.89)	0.48	2.60	0.01
	Healthy	8.97 (1.73)	8.69 (1.11)	-0.28	-1.18	0.24

P values lower than 0.05 are highlighted in bold.

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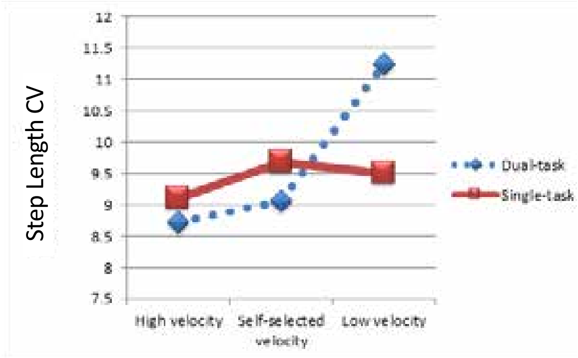

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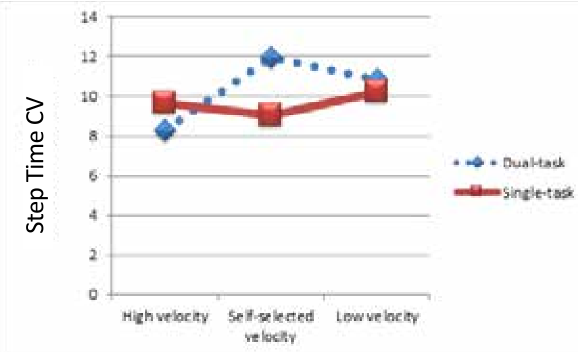

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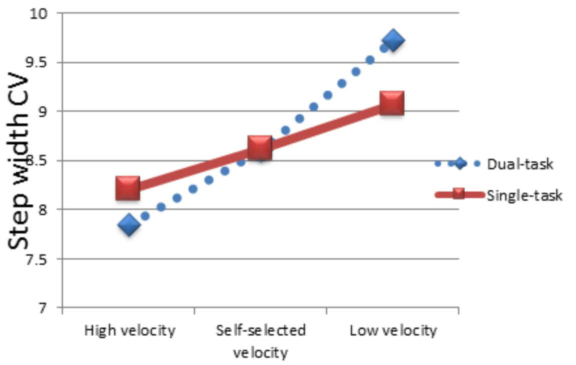

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Figure 1. Interactions plots showing step length coefficient of variation (CV) (A), step time CV (B) and step width CV (C) as a function of gait velocity and cognitive difficulty.

length CV in dual-task condition significantly increased compared to single-task in low velocity. Furthermore, irrespective to group CV of step length variability and step width variability in self-selected velocity were similar in dual- and single-task conditions but CV of step time significantly increased in dual-task condition compared to single-task condition. Table 5 shows the significances between different levels of group in dual- and single-task conditions. According to Table 5, CV of step width in dual-task condition significantly increased compared to single-task in ACLD participants.

Table 6 shows the significances between different levels of cognitive task difficulty in ACLD and healthy groups. According to Table 6, the values of step width CV in single-task condition significantly decreased in ACLD subjects compared to healthy subjects. Figure 1 shows Interactions plots of step length CV, step time CV and step width CV as a function of gait velocity and cognitive difficulty in all participants. Figure 2 shows Interactions plots of step width CV as a function of group and cognitive difficulty.

4. Discussion

The present study was the first study which investigated effect of dual-tasking on variability of spatiotemporal characteristics in patients with ACLD at different levels of walking velocity.

Results showed that velocity changed the variability of spatiotemporal characteristics in both groups. However, Owings et al. showed that walking velocity did not affect step kinematic variability and this finding was not compatible with the findings of the present study. A possible explanation for this discrepancy is the difference between the walking velocities in two mentioned studies. Owings et al. used the preferred velocity and slow velocity that was 10% slower than self-selected velocity in their study [8]. However, in our study both groups were examined in self-selected velocity as well as high and low velocity which were 20% upper and lower than self-selected velocity. Also, Dingwell et al. stated that variability is more prominent at very high or very low speeds [18].

Results showed that variability of step length and step time have similar behavior in single- and dual–task conditions in ACLD and healthy groups. Because walking is a well-learned and more-automatic task, it may require

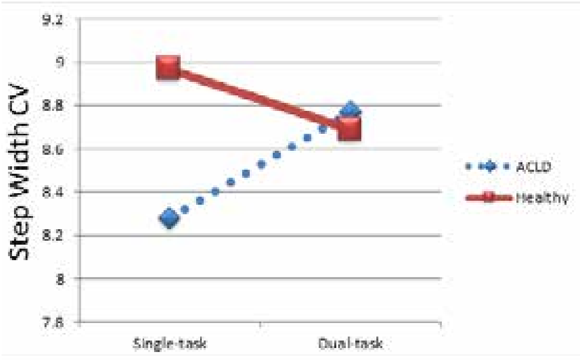

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Figure 2. Interactions plots showing step width coefficient of variation (A) as a function of group and cognitive difficulty.

Table 6. Results of independent t test for step width coefficient of variation (CV) parameters in both ACLD and healthy groups in dual- and single task separately: t and P values by variable

Variable	Cognitive load	ACLD Mean (SD)	Healthy Mean (SD)	Mean difference	t	p
Step width CV	No cognitive load	8.28 (1.08)	8.97 (1.73)	0.48	0.69	**0.04**
	With the cognitive load	8.77 (2.18)	8.69 (1.09)	-0.28	-0.08	0.45

P values lower than 0.05 are highlighted in bold.

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more dynamic balance task to differentiate variability of spatiotemporal parameters between two groups [19]. Also, strategies for compensating dual-task effect, were not significant enough to cause differences between mentioned variables [20]. These findings were supported by Negahban et al. study which investigated effect of dual-tasking in different levels postural difficulty in patients with ACLD and control group [21].

Evidently, variability of step width is a more sensitive measure than other ones to differentiate interaction of group by cognitive task difficulty. On the contrary to step length and step time, step width is medial-lateral stability parameters. This result was in agreement with the results of Brach et al. who studied fall history in older adults who walk at or near normal gait speed. Although Brach et al. study used different target population, it seems that step width variability was more correlated to the falling history than the variability of step length and step time when their samples walked with speed upper than 1.0 m/s [3].

Also Owings declared that step width variability is a more significant index of postural control than step length variability and step time variability [8, 22]. Grabiner et al. demonstrated that step width variability significantly decreased 16% in visual Stroop test condition and these findings were different with the result of present study. Participants in their study walked on motorized treadmill for 10 minutes while performing visual Stroop task. Apparently, visual inputs play more important role in dynamic postural control than auditory cues [23]. The difference between step width variability in their study with our findings may be related to effect of visual suppression in dynamic postural control.

Considering the present study, the future research should investigate the effect of dual task on variability of kinematic measures like variability of knee flexion-extension angle. Also, more challenging motor and cognitive tasks can be conducted on patients with ACLD or different musculoskeletal disorders.

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Conflict of interest

The authors declare that there are no financial and personal relationships with other persons or institutions that could inappropriately affect their work.

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