RESEARCH ARTICLE

Reliability of Center of Pressure measures of Postural Stability in Anterior Cruciate Ligament Reconstructed Athletes: Effect of Vibration and Cognitive Load

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Abstract

Background: To evaluate intra and intersession reliability of the Center of Pressure (COP) parameters in Anterior Cruciate Ligament Reconstructed (ACLR) athletes with and without ankle vibration using a dual-task paradigm.

Methods: Postural sway of 14 ACLR individuals was assessed during a single-leg stance on a force platform. COP parameters were assessed with manipulating sensory inputs via vision and ankle vibration under single and dual-task conditions. The outcome variables included COP displacement in medial-lateral (ML) and anterior-posterior (AP) range, mean velocity (mV), and area. During dual-task conditions, the auditory Stroop Task was applied. Intraclass correlation coefficient (ICC) values and standard error of measurement (SEM) were assessed for relative and absolute reliability.

Results: The COP measures had moderate to very high intrasession reliability (ICC range: 0.51-0.93) for conditions with vibration and cognitive task, with the highest ICCs for mV and the lowest for area, regardless of eyes being open or closed. The intersession reliability was moderate to high for mV (ICC range: 0.60-0.82) and little to very high (ICC range: 0.21-0.97) for the range of ML and AP, as well as an area in conditions with vibration and cognitive task.

Conclusion: The mV is the most reliable COP parameter for assessing postural control under ankle vibration and dual-task conditions for both operated and non-operated sides. During closed-eye conditions, the application of vibration affected the intersession reliability with decreased ICCs on the operated side and increased ICCs on the non-operated side.

Level of evidence: III

Keywords: Anterior cruciate ligament reconstruction, Postural control, Stroop task, Test-retest reliability, Vibration

Introduction

Anterior Cruciate Ligament (ACL) reconstruction is one of the most common surgeries among athletes (1). There is a growing body of literature regarding postural control changes following ACL reconstruction (2). Postural stability, which is the ability to maintain the center of mass over the base of support, is crucial for normal daily activities and sports. Following sports injuries, especially post-ACL reconstruction, the decision to return to sports is dependent on optimal postural control (3). A commonly used method of evaluating postural stability is measuring the center of pressure (COP) excursions. COP is the location of the resultant ground reaction forces from the foot (2). Previous studies have reported altered COP sway in individuals with ACL

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reconstruction (2, 4).

Postural stability requires interaction among somatosensory inputs (proprioceptive, cutaneous, and joint), as well as visual and vestibular systems (5). Proprioceptive deficits may persist even after ACL reconstruction leading to inaccurate sensory inputs from the knee (6). The central nervous system down-weighs the sensory input of the knee and up-weighs the sensory inputs from other joints and sensory systems that provide more reliable information (7). Therefore, the manipulation of the sensory inputs gives more information to researchers and clinicians for evaluating postural stability. Excessive postural instability induced by disrupting critical sensory inputs involved in postural control, such as vision and ankle proprioception, could emphasize inaccurate sensory input of the reconstructed knee (8). A method commonly used to disturb proprioception inputs of the ankle muscles is by stimulating afferent activity from muscle spindles by the vibration of the muscle tendon (9). This is thought to lead to "kinesthetic illusions"(10). In addition, simultaneous vibration of the ankle muscles would alter proprioception inputs originating the ankle joint (11).

In addition to sensory inputs, cognition is an integral part of postural control. Previously postural control was thought to be automatic, while recent studies emphasize the role of cognitive processing (12, 13). Dual-task paradigms are used to assess the attentional requirements for regulating posture, in which a postural task is performed with a concurrent cognitive task (12). When the attentional resources required for simultaneous performance of the tasks exceed the limited attentional capacity, interference takes place, which may affect the performance of one or both tasks (13). In addition to postural control, athletic performance is dependent on high cognitive functioning. Therefore, attention needs to be divided between cognitive and balance tasks. Consequently, the application of the dual-task paradigm in assessing the postural stability of ACL reconstructed (ACLR) athletes is crucial.

In order to assess postural control under different circumstances, it is important to ensure that the observed differences between sessions in the COP measurements are related to real changes in the postural control system, rather than the random error in the measurement procedure (14). The reliability of COP measures has been investigated in different test conditions in the ACLR population (15, 16). Despite the extensive use of vibration in research regarding postural control, there are only two studies that have evaluated the reliability of COP parameters during ankle vibration in low back pain and healthy individuals in bipedal standing (7, 10). They both found moderate to high reliability for most of the COP parameters. In the current study, a single-limb stance was chosen because it is commonly used for predicting injury risk and for comparison between injured and uninjured limbs (4). Since the reliability of a parameter is dependent on population and test conditions, it is necessary to determine the intra and intersession reliability of the COP measures in the ACLR athletes under single and dual-task conditions with and without vibration (17).

Materials and Methods

Subjects

In order to determine the sample size needed for this study, a simplified guide by Bujang et al. was applied {Bujang, 2017 #59} (18). Considering the ICC value of 0.5, an alpha level of 0.05, and a power of 0.9, the required number of subjects was determined to be 15. Since one subject did not attend his retest session, ultimately, 14 ACLR athletes (2 females and 12 males; age: 25.78±4.61 years, height: 173±6 cm, weight: 74.26±14.74 kg; body mass index: 24.80±4.43, and the Tegner activity score: 5.6±2.87) were included in the study. The inclusion criteria were age between 18 and 36 years, unilateral ACL reconstruction with or without associated meniscal injury, minimum six-month recovery time post-surgery, and being pain-free. On the other hand, the subjects with significant pathological issues in other lower extremity joints or ligaments or of the spine, as well as a history of neurological, visual, and vestibular impairments were excluded from the study. Out of 14 subjects, 10 cases were football and futsal players. All reconstruction surgeries were performed with an arthroscopically assisted anatomic double-bundle using autogenous hamstring tendons. The subjects were approved by their orthopedic surgeons for participation in this study.

Subjects were informed regarding the test protocol and possible risks as described in the consent form. The study met the ethical standards of the institutional review board of the University of Social Welfare and Rehabilitation Sciences, Tehran, Iran.

Procedure

Postural stability task

COP data were obtained using a 40×60 Force platform (Kistler, Instrument Company, Amherst, NY) (BioWare, type 2812A Version: 4.0.1.2). Data were sampled at 1000 Hz, low pass Butterworth filter type four, and cut off frequency of 50 Hz as the best compromise to reject noise power.

Postural sway was assessed in a single leg stance for both operated and non-operated limbs with varying levels of postural difficulty. Subjects were instructed to stand barefoot and relaxed with their arms hanging at their sides on the center of the force platform for 20 sec. They were told to stand with a straight-ahead position at a point approximately eye level on a wall five meters away while holding the contralateral limb at approximately 45 degrees of knee flexion. Three repetitions with a one-min rest period were performed in each condition. The rater, time, and environment of the test, as well as foot placement and rest period between trials, were equivalent among sessions. Two types of sensory feedbacks were manipulated that included visual feedback (eyes open and closed) and proprioceptive feedback (using two vibrators on the Tibialis Anterior and Achilles tendons/vibrators on and off). Vibrating the Achilles and Tibialis anterior tendons simultaneously was used to disrupt the sensory input of the ankle (9).

Auditory Stroop Task

For the secondary cognitive task, the auditory version of the Stroop task was chosen to allow manipulating the vision. The Persian translation of the auditory Stroop Task has been reported to be reliable and responsive in previous dual-task studies with different musculoskeletal disorders (10, 13, 19, 20). Through a headset (A4TECH Model: HS-5P, made in China), a series of “high” and “low” words were presented in either a high-pitched or a low-pitched voice in Persian. There were two types of stimuli, namely the congruent in which the word and the vocalized pitch matched, and the incongruent in which the word and the vocalized pitch differed. Stimuli were presented in a randomized order with the interval of 2000-3000 milliseconds; therefore, the subjects could not anticipate the initiation of stimuli and the response. Unlike the original auditory Stroop Task in which the participants were asked to name the pitch of the stimulus, in the current study, the subjects were asked to verbalize the opposite pitch from what they heard in order to increase task difficulty (13). The responses were recorded using the same headset. Each trial consisted of five or six stimuli presented across 20 sec. The mean reaction time (i.e., time differences between the stimulus onset and the response onset) and response were recorded for each trial. A custom-written MATLAB (R2010A, Mathworks, Natick, MA, USA) script was used for applying the auditory Stroop Task.

Protocol

In order to achieve acceptable reliability for COP parameters, the recommendations from a systematic review regarding standardized instructions were applied (21). Subjects were first familiarized with the standing position on the force platform and able to practice the auditory Stroop Task. Since the ACLR subjects of the current study could not maintain the single-leg stance position without falling over for longer than 20 sec (overall 60 sec in three trials), this trial length was considered to minimize contact with the ground. The subjects were asked to respond to the auditory Stroop Task as accurately and quickly as possible while standing on the force platform during the dual-task conditions. If postural stability was not maintained for 20 sec, the trial was not recorded, and the measurement was repeated. The order of testing conditions was randomized to minimalize the effect of fatigue and learning. To assess the intersession reliability, each subject was evaluated on two sessions in the same laboratory by the same examiner, at the same time of day and with a time interval of two to five days between the two sessions (3).

Data analysis

In order to determine the reliability of the measures, the average of three trials of the COP parameters in each condition was calculated. The calculated COP measures in this study were COP displacement in medial-lateral (ML) and anterior-posterior range (AP), mean velocity (mV), and area.

Statistical analysis

Statistical analysis was conducted in SPSS software (version 25.0, SPSS Inc, Chicago, IL, United States). A paired t-test was performed on the differences among scores obtained at test and retest sessions to determine the absence of systematic bias. A *p-value* less than 0.05 was considered statistically significant.

Shapiro-Wilk test was utilized to assess the normal distribution of variables. The majority of the COP measures showed normal distribution Tables 1 to 4; accordingly, the two-way random model of intraclass correlation coefficient ($ICC_{2,3}$) with 95% confidence intervals (CI) was calculated to report the relative reliability[33, 34]. The degree of reliability was determined by Munro’s classification for reliability coefficients (0.00-0.25– little, if any correlation; 0.26-0.49– low correlation; 0.50-0.69 – moderate correlation; 0.70-0.89– high correlation, and 0.90-1.00–very high correlation) (22).

To express the absolute reliability, standard error of measurement (SEM) was used which was calculated as SEM=SD*SQRT (1-ICC), where “SD” was the standard deviation of the measurements (10). The minimal detectable change (MDC) was used to compute the change that could be considered clinically significant between the two measurements. MDC was determined as 95% CI of the SEM of the COP measures (1.96*SEM) (10). Moreover, the coefficient of variation (CV) was used for the comparison of the absolute reliability between COP measures and was calculated as CV= (SD/mean) *100 (10).

Results

Tables 1 and 2 show descriptive statistics of the COP measures in the operated and non-operated limbs, respectively [Tables 5; 6]. No significant differences were observed between test and retest mean scores in terms of all COP measures and testing conditions. This indicated no systematic bias (*P>0.05*). The calculated intrasession ICCs and intersession ICC, SEM, MDC, and CV values are presented in Tables 3 and 4 for the operated and non-operated limbs, respectively [Tables 7; 8].

Generally, intrasession ICC values were higher than those for intersession. For both, COP mV, and area had the highest and lowest ICC values, respectively. SEM and CV values were the lowest for mV and highest for the area.

The intrasession reliability for all COP parameters in conditions with vibration was moderate to very high (ICC range: 0.51 to 0.93) on both limbs. In conditions with vibration and the Stroop Task, the reliability was moderate to high (ICC range: 0.51 to 0.83) on both limbs. Conditions with the cognitive task reliability were moderate to very high for the operated side (ICC range: 0.51 to 0.92) and moderate to high (ICC range: 0.51 to 0.86) for the non-operated side, with the highest ICCs for mV and the lowest for area, regardless of eyes being open or closed. The intersession reliability for conditions with vibration was moderate to high for COP mV (ICC range:

Table 1. Normality tests for medial-lateral range of displacement in the operated and non-operated limbs of ACLR Subjects

Test Conditions				ACLR Group	
				Test	Retest
				Shapiro-Wilk *P-value*	Shapiro-Wilk *P-value*
Single task	Eyes open	Operated leg	Without Vibration	0.767	0.162
			With Vibration	0.751	0.172
		Non-operated leg	Without Vibration	0.488	0.145
			With Vibration	0.953	0.400
	Eyes closed	Operated leg	Without Vibration	0.069	0.343
			With Vibration	0.180	0.713
		Non-operated leg	Without Vibration	0.169	0.768
			With Vibration	0.834	0.273
Dual task	Eyes open	Operated leg	Without Vibration	0.081	0.928
			With Vibration	0.348	0.473
		Non-operated leg	Without Vibration	0.671	0.266
			With Vibration	0.816	0.082
	Eyes closed	Operated Leg	Without Vibration	0.756	0.376
			With Vibration	0.117	0.779
		Non-operated leg	Without Vibration	0.299	0.968
			With Vibration	0.547	0.998

Table 2. Normality tests for Anterior-Posterior range of displacement in the operated and non-operated limbs of ACLR Subjects

Test Conditions				ACLR Group	
				Test	Retest
				Shapiro-Wilk *P-value*	Shapiro-Wilk *P-value*
Single task	Eyes open	Operated leg	Without Vibration	0.415	0.528
			With Vibration	0.350	0.209
		Non-operated leg	Without Vibration	0.995	0.129
			With Vibration	0.815	0.783
	Eyes closed	Operated leg	Without Vibration	0.192	0.974
			With Vibration	0.257	0.684
		Non-operated leg	Without Vibration	0.736	0.111
			With Vibration	0.663	0.375
Dual task	Eyes open	Operated leg	Without Vibration	0.063	0.183
			With Vibration	0.137	0.884
		Non-operated leg	Without Vibration	0.299	0.547
			With Vibration	0.887	0.908
	Eyes closed	Operated leg	Without Vibration	0.056	0.926
			With Vibration	0.569	0.855
		Non-operated leg	Without Vibration	0.125	0.093
			With Vibration	0.071	0.598

Table 3. Normality tests for mean velocity in the operated and non-operated limbs of ACLR Subjects

Test Conditions				ACLR Group	
				Test	Retest
				Shapiro-Wilk *P-value*	Shapiro-Wilk *P-value*
Single task	Eyes open	Operated leg	Without Vibration	0.280	0.099
			With Vibration	0.565	0.636
		Non-operated leg	Without Vibration	0.136	0.918
			With Vibration	0.288	0.497
	Eyes closed	Operated leg	Without Vibration	0.158	0.127
			With Vibration	0.825	0.310
		Non-operated leg	Without Vibration	0.573	0.781
			With Vibration	0.089	0.128
Dual task	Eyes open	Operated leg	Without Vibration	0.470	0.187
			With Vibration	0.107	0.918
		Non-operated leg	Without Vibration	0.453	0.150
			With Vibration	0.962	0.130
	Eyes closed	Operated leg	Without Vibration	0.870	0.075
			With Vibration	0.095	0.266
		Non-operated leg	Without Vibration	0.628	0.715
			With Vibration	0.560	0.118

Table 4. Normality tests for area in the operated and non-operated limbs of ACLR Subjects

Test conditions				ACLR Group	
				Test	Retest
				Shapiro-Wilk *P-value*	Shapiro-Wilk *P-value*
Single task	Eyes open	Operated leg	Without Vibration	0.096	0.124
			With Vibration	0.111	0.269
		Non-operated leg	Without Vibration	0.172	0.581
			With Vibration	0.080	0.690
	Eyes closed	Operated leg	Without Vibration	0.879	0.523
			With Vibration	0.391	0.834
		Non-operated leg	Without Vibration	0.764	0.070
			With Vibration	0.116	0.744
Dual task	Eyes open	Operated leg	Without Vibration	0.803	0.564
			With Vibration	0.361	0.177
		Non-operated leg	Without Vibration	0.090	0.688
			With Vibration	0.288	0.118
	Eyes closed	Operated leg	Without Vibration	0.131	0.065
			With Vibration	0.405	0.139
		Non-operated leg	Without Vibration	0.270	0.460
			With Vibration	0.300	0.594

Table 5. Descriptive data of all COP measures in the operated limbs of 14 subjects with ACL reconstruction in dual-task paradigm associated with manipulated visual and somatosensory inputs

Test conditions			Variables	Test		Retest		
				Mean	SD	Mean	SD	*P*
Single task	Eyes open	Without Vibration	ML	2.51	0.40	2.62	0.40	0.48
			AP	3.60	0.85	3.40	0.62	0.50
			mV	3.11	0.61	2.80	0.41	0.14
			Area	4.46	2.10	4.05	1.58	0.56
		With Vibration	ML	2.64	0.43	2.51	0.44	0.44
			AP	3.97	0.76	3.74	0.82	0.46
			mV	3.48	0.98	3.13	0.59	0.26
			Area	4.93	3.03	4.23	2.01	0.48
	Eyes closed	Without Vibration	ML	5.07	1.60	4.75	1.38	0.57
			AP	6.79	1.85	6.13	1.17	0.27
			mV	7.34	2.17	6.62	1.72	0.34
			Area	10.10	3.23	9.47	3.94	0.65
		With Vibration	ML	5.29	1.29	4.58	0.66	0.08
			AP	6.91	1.98	6.96	1.76	0.94
			mV	8.20	2.02	7.04	1.70	0.11
			Area	12.27	4.44	10.79	4.22	0.37
Dual task	Eyes open	Without Vibration	ML	2.64	0.49	2.59	0.42	0.77
			AP	3.33	0.75	3.39	0.70	0.84
			mV	3.07	0.54	2.86	0.40	0.26
			Area	3.69	1.51	2.82	1.61	0.16
		With Vibration	ML	2.64	0.41	2.46	0.39	0.23
			AP	3.96	1.06	3.88	0.81	0.81
			mV	3.36	0.71	3.15	0.45	0.35
			Area	4.22	1.67	3.62	1.48	0.33
	Eyes closed	Without Vibration	ML	4.56	0.63	4.21	0.71	0.18
			AP	5.77	1.50	5.64	1.40	0.81
			mV	6.73	1.37	6.24	1.82	0.43
			Area	10.70	4.33	8.72	3.46	0.19
		With Vibration	ML	4.50	0.61	4.51	0.59	0.95
			AP	6.52	1.81	6.70	1.42	0.77
			mV	7.14	1.41	7.31	1.39	0.75
			Area	8.53	3.04	9.41	3.31	0.47

SD: standard deviation; P: *P-values* of paired t-test on test-retest differences, ML: range of medial-lateral, AP: range of anterior-posterior; mV: mean velocity.

Table 6. Descriptive data of all COP measures in non-operated limbs of 14 subjects with ACL reconstruction in dual-task paradigm associated with manipulated visual and somatosensory inputs

Test conditions			Variables	Test		Retest		
				Mean	SD	Mean	SD	P
Single task	Eyes open	Without Vibration	ML	2.51	0.38	2.49	0.47	0.91
			AP	3.63	0.62	3.62	0.73	0.98
			mV	3.25	0.70	2.99	0.54	0.28
			Area	4.20	2.06	4.16	2.16	0.96
		With Vibration	ML	2.49	0.37	2.53	0.42	0.75
			AP	4.12	0.82	3.92	0.89	0.54
			mV	3.47	0.65	3.43	0.68	0.89
			Area	4.25	1.78	4.66	2.56	0.63
	Eyes closed	Without Vibration	ML	5.34	1.49	4.04	1.25	0.06
			AP	8.08	3.22	5.90	2.05	0.07
			mV	7.39	1.70	5.99	2.07	0.06
			Area	12.46	6.09	9.52	4.68	0.16
		With Vibration	ML	5.05	1.37	4.87	1.49	0.74
			AP	8.08	2.94	7.89	2.25	0.85
			mV	8.22	2.07	7.39	1.63	0.25
			Area	11.75	4.41	11.43	4.62	0.85
Dual task	Eyes open	Without Vibration	ML	2.47	0.33	2.37	0.40	0.52
			AP	3.46	0.87	3.53	0.91	0.84
			mV	3.19	0.57	3.09	0.55	0.65
			Area	3.68	1.60	3.53	2.54	0.85
	Eyes open	With Vibration	ML	2.48	0.45	2.53	0.45	0.80
			AP	3.73	0.86	3.68	0.94	0.88
			mV	3.46	0.45	3.28	0.46	0.31
			Area	3.96	1.66	4.42	2.61	0.59
	Eyes closed	Without Vibration	ML	5.03	1.37	4.25	0.43	0.06
			AP	7.54	2.62	6.14	1.34	0.09
			mV	7.36	1.95	6.71	1.78	0.36
			Area	12.37	8.03	9.03	3.62	0.17
		With Vibration	ML	5.51	1.91	4.71	1.14	0.20
			AP	8.23	3.19	7.40	2.61	0.46
			mV	7.86	1.97	7.39	1.65	0.50
			Area	14.05	9.45	12.46	6.77	0.61

SD: standard deviation; P: *P-values* of paired t-test on test-retest differences, ML: range of medial-lateral, AP: range of anterior-posterior; mV: mean velocity.

Table 7. Intrasession and intersession reliability of COP measure in dual-task paradigm associated with manipulated visual and somatosensory inputs in operated limbs

Test conditions			Variables	Intrasession		Intersession			
				test	retest				
				ICC	ICC	ICC	SEM	MMDC	CV
Single task	Eyes open	Without Vibration	ML	0.66	0.73	0.67 (0.24, 0.88)	0.13	0.37	12.89
			AP	0.76	0.68	0.62 (0.16, 0.86)	0.28	0.78	18
			mV	0.80	0.84	0.67 (0.24, 0.88)	0.17	0.48	15.93
			Area	0.51	0.50	0.63 (0.17, 0.86)	0.68	1.89	37.17
		With Vibration	ML	0.71	0.70	0.43 (-0.10, 0.77)	0.25	0.69	12.84
			AP	0.67	0.72	0.41 (-0.13, 0.76)	0.47	1.29	15.06
			mV	0.91	0.81	0.76 (0.41, 0.92)	0.19	0.52	20.60
			Area	0.69	0.72	0.45 (-0.09, 0.78)	1.39	3.86	36.46
	Eyes closed	Without Vibration	ML	0.83	0.88	0.95 (0.85, 0.98)	0.07	0.20	30
			AP	0.71	0.70	0.35 (-0.20, 0.73)	0.99	2.75	18.26
			mV	0.87	0.87	0.79 (0.46, 0.93)	0.41	1.14	25.82
			Area	0.53	0.53	0.56 (0.07, 0.84)	1.57	4.34	28.52
		With Vibration	ML	0.70	0.77	0.70 (0.29, 0.89)	0.29	0.81	17.24
			AP	0.66	0.71	0.40 (-0.14, 0.76)	1.12	3.10	20.34
			mV	0.80	0.93	0.68 (0.26, 0.89)	0.60	1.65	22.57
			Area	0.53	0.53	0.52 (0.01, 0.82)	2.07	5.73	27.43
Dual task	Eyes open	Without Vibration	ML	0.70	0.69	0.67 (0.24, 0.88)	0.15	0.42	14.94
			AP	0.73	0.69	0.40 (-0.14, 0.76)	0.43	1.20	16.66
			mV	0.73	0.70	0.61 (0.15, 0.86)	0.18	0.51	14.18
			Area	0.62	0.60	0.58 (0.09, 0.84)	0.66	1.84	40.30
		With Vibration	ML	0.77	0.72	0.53 (0.02, 0.82)	0.19	0.53	11.76
			AP	0.68	0.63	0.60 (0.12, 0.85)	0.38	1.05	18.15
			mV	0.83	0.75	0.78 (0.44, 0.92)	0.13	0.36	15.69
			Area	0.56	0.51	0.34 (-0.21, 0.73)	1.05	2.90	30.43
	Eyes closed	Without Vibration	ML	0.73	0.75	0.73 (0.34, 0.90)	0.18	0.51	13.92
			AP	0.76	0.73	0.71 (0.31, 0.90)	0.42	1.16	21.22
			mV	0.82	0.92	0.72 (0.33, 0.90)	0.45	1.23	21.29
			Area	0.53	0.56	0.50 (-0.02, 0.81)	1.96	5.43	33.36
		With Vibration	ML	0.69	0.69	0.50 (-0.02, 0.81)	0.30	0.84	10.22
			AP	0.70	0.73	0.36 (-0.19, 0.74)	1.04	2.89	18.78
			mV	0.79	0.80	0.60 (0.13, 0.85)	0.56	1.55	15.92
			Area	0.57	0.54	0.21 (-0.34, 0.65)	2.51	6.95	21.31

ICC: Intraclass correlation coefficient, SEM: standard error of measurement, MMDC: minimal metrically detectable change, CV: coefficient of variation, ML: range of medial-lateral, AP: range of anterior-posterior, mV: mean velocity.

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Table 8. Intrasession and intersession reliability of COP measure in dual-task paradigm associated with manipulated visual and somatosensory inputs in non-operated limbs

Test conditions			Variables	Intrasession		Intersession			
				test	retest				
				ICC	ICC	ICC	SEM	MMDC	CV
Single task	Eyes open	Without Vibration	ML	0.70	0.71	0.36 (-0.19, 0.74)	0.27	0.76	11.64
			AP	0.66	0.63	0.68 (0.25, 0.88)	0.22	0.61	15.74
			mV	0.81	0.83	0.83 (0.55, 0.94)	0.11	0.30	18.91
			Area	0.54	0.53	0.34 (-0.21, 0.73)	1.38	3.84	34.29
		With Vibration	ML	0.65	0.66	0.78 (0.45, 0.93)	0.09	0.24	13.54
			AP	0.61	0.76	0.39 (-0.16, 0.75)	0.53	1.47	15.21
			mV	0.84	0.81	0.78 (0.44, 0.92)	0.15	0.41	17.10
			Area	0.58	0.53	0.58 (0.09, 0.84)	0.92	2.56	39.55
	Eyes closed	Without Vibration	ML	0.80	0.85	0.41 (-0.13, 0.76)	0.81	2.26	21.96
			AP	0.84	0.78	0.45 (-0.08, 0.78)	1.44	4.00	31.75
			mV	0.87	0.89	0.50 (-0.01, 0.81)	0.94	2.61	23.76
			Area	0.53	0.55	0.40 (-0.14, 0.76)	3.21	8.90	32.05
		With Vibration	ML	0.74	0.76	0.97 (0.90, 0.99)	0.05	0.14	28.48
			AP	0.74	0.71	0.91 (0.74, 0.97)	0.24	0.66	31.57
			mV	0.81	0.76	0.79 (0.47, 0.93)	0.38	1.06	22.05
			Area	0.52	0.56	0.60 (0.13, 0.85)	1.80	5.00	29.85
Dual task	Eyes open	Without Vibration	ML	0.66	0.65	0.69 (0.28, 0.89)	0.11	0.31	13.22
			AP	0.74	0.73	0.49 (-0.03, 0.80)	0.45	1.26	18.91
			mV	0.86	0.78	0.80 (0.48, 0.93)	0.12	0.32	16.29
			Area	0.63	0.77	0.60 (0.13, 0.85)	0.82	2.29	44.16
		With Vibration	ML	0.66	0.71	0.76 (0.40, 0.92)	0.11	0.30	16
			AP	0.67	0.70	0.69 (0.28, 0.89)	0.28	0.77	20.54
			mV	0.72	0.73	0.75 (0.38, 0.91)	0.12	0.33	12.46
			Area	0.54	0.65	0.77 (0.42, 0.92)	0.50	1.39	47.84
	Eyes closed	Without Vibration	ML	0.73	0.69	0.28 (-0.28, 0.69)	0.65	1.81	15.73
			AP	0.65	0.73	0.48 (-0.05, 0.80)	1.04	2.88	22.07
			mV	0.84	0.86	0.82 (0.52, 0.94)	0.34	0.95	24.46
			Area	0.72	0.51	0.63 (0.18, 0.87)	2.14	5.93	48.22
		With Vibration	ML	0.77	0.73	0.83 (0.55, 0.94)	0.26	0.72	28.18
			AP	0.73	0.70	0.83 (0.56, 0.94)	0.48	1.34	34.31
			mV	0.82	0.83	0.82 (0.52, 0.94)	0.33	0.92	28.49
			Area	0.66	0.64	0.69 (0.27, 0.89)	2.52	6.97	53.65

ICC: Intraclass correlation coefficient, SEM: standard error of measurement, MMDC: minimal metrically detectable change, CV: coefficient of variation, ML: range of medial-lateral, AP: range of anterior-posterior, mV: mean velocity.

0.60 to 0.82) and little to very high for the range of ML, AP, and area (ICC range: 0.21 to 0.97) on the operated and non-operated sides.

The intersession reliability for conditions with the cognitive task was moderate to high for mV (ICC range: 0.60 to 0.78) on the operated side, and high (ICC range: 0.75 to 0.82) on the non-operated side. The ICC values for the COP range of ML, AP, and area were low to high on both sides (ICC range: 0.21 to 0.83).

Discussion

The current study investigated the intra and intersession reliability of the COP parameters in ACLR athletes during single and dual-task conditions with and without ankle vibration. The results of the present study revealed moderate to very high intrasession reliability of all COP parameters in conditions with vibration and a cognitive task, with the highest ICCs for mV and the lowest for area. The results of intersession reliability in conditions with vibration and cognitive tasks revealed moderate to high correlations for mV and low to very high correlations for ML, AP, and area. Higher reliability was reported in the studies on ACLR individuals during the single-leg stance (15, 16), compared to the present study, which could be explained by different testing conditions and duration.

The intersession reliability of the COP parameters was affected when ankle vibration was applied in the absence of visual input, compared to the conditions with vision. However, this change was found to be different between the operated and non-operated sides, with decreased reliability on the operated side and increased reliability for the non-operated one. Findings on the non-operated side are similar to healthy subjects in the studies by Harringe et al. and Doyle et al., in which the difficult conditions with removing sensory inputs showed higher reliability (23, 24). Findings on the operated side are consistent with the results of previous studies on ACLR subjects and other musculoskeletal disorders in which the intersession ICCs of postural control parameters were lower during conditions in which the disturbed ankle sensory inputs were accompanied by the absence of vision (13, 25). The knee proprioceptive impairment in the ACLR subjects can be the reason for the observed results since the lack of reliable somatosensory inputs may make the postural control system more reliant on visual information (10, 20). On the other hand, vision plays an important role according to the difficulty of the task needed to be accomplished. More challenging tasks result in more postural control mechanisms relying on vision.

The role of vision increases in the single-limb stance (26). This would mean that postural sway variations over time were higher when removing both ankle proprioception and vision inputs on the operated side.

Consistent with the findings of the present study, Baldini et al. reported lower reliability for COP sway area among other COP parameters (27). The COP area is a measure of the area that the COP traverses. Therefore, the reliability of the area may have been influenced by the foot position change throughout the trials which was inevitable for the subjects who were about to fall. Other parameters may not be as sensitive to the orientation of the foot position in respect to the axis of the force plate. Lafond et al. showed that the sway area had low reliability when averaging trials that were less than five trials in healthy elderly people (28).

The COP mV showed the highest intra and intersession reliability for conditions with cognitive task and vibration. Accordingly, Karimi et al. showed that the mV was the most reliable variable of postural control in subjects with non-specific low back pain, especially in more challenging conditions with eyes closed and adding vibration during dual-tasking (10). This parameter represents the total distance traveled by the COP over time. Gray et al. (29) suggested that COP sway velocity is reliable due to not being dependent on the changes of COP position. This acceptable correlation limits the possibility of type 2 error and allows mV to discriminate postural control deficiency between groups and sides of injury. In agreement with the findings of the current study, several researchers reported the highest reliability for COP mV in the same population and other musculoskeletal disorders, such as low back pain or ACL deficient subjects (15, 25, 30). Consistent with the previous studies, the highest absolute reliability was related to mV and the range of ML (15, 25). These two parameters had also the lowest MDC among conditions with cognitive task and ankle vibration. The more accurate measure leads to smaller SEM and MDC (22).

It is clinically important to ensure that the observed differences in the COP measurements post-rehabilitation or surgery under different sensory conditions and cognitive loading are related to real changes in the postural control system. These measurements could be used to decide whether it is safe to return to sport. Moreover, considering the growing body of evidence investigating the effects of vibration in postural control studies, the reliability information of the COP parameters while using such an intervention is required for future research.

Regarding the limitations of the present study, it can be stated that the results may not be generalized to other test conditions or other cognitive tasks. Similarly, the type of sports (soccer and futsal) included in the study may affect the generalizability of our findings. In addition, the reliability of COP parameters was not assessed in a group of healthy participants matched according to age, height, weight, and physical activity level. It is suggested that a healthy control group be investigated to compare the reliability results of healthy and ACLR individuals. Moreover, the results of the current study may be more generalized to male athletes, who were the majority of the participants.

Intra and intersession reliability of the COP measures were not affected by applying ankle vibration during opened-eye conditions. However, during closed-eye conditions, the application of the vibration affected the intersession reliability, with decreased ICCs on the operated side and increased ICCs on the non-operated side. The COP mV demonstrated the highest reliability in all postural stability conditions, and the least reliable parameter was the COP sway area. Altogether, COP measures of the single-leg stance (the range of ML, AP, and mV) are reliable outcomes in the ACLR athletes during single and dual-task conditions while using vibration.

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References

1. Majewski M, Susanne H, Klaus S. Epidemiology of athletic knee injuries: A 10-year study. Knee. 2006;13(3):184-8.
2. Sugimoto D, Howell DR, Micheli LJ, Meehan III WP. Single-leg postural stability deficits following anterior cruciate ligament reconstruction in pediatric and adolescent athletes. J Pediatr Orthop B. 2016;25(4):338-42.
3. Hadian MR, Negahban H, Talebian S, Salavati M, Jafari AH, Sanjari MA, et al. Reliability of center of pressure measures of postural stability in patients with unilateral anterior cruciate ligament injury. J Appl Sci. 2008;8(17):3019-25.
4. Moussa AZB, Zouita S, Dziri C, Salah FB. Single-leg assessment of postural stability and knee functional outcome two years after anterior cruciate ligament reconstruction. Ann Phys Rehabil Med. 2009;52(6):475-84.
5. Shumway-Cook A, Horak FB. Assessing the influence of sensory interaction on balance: suggestion from the field. Phys Ther. 1986;66(10):1548-50.
6. Mohammadi-Rad S, Salavati M, Ebrahimi-Takamjani I, Akhbari B, Sherafat S, Negahban H, et al. Dual-tasking effects on dynamic postural stability in athletes with and without anterior cruciate ligament reconstruction. J Sport Rehabil. 2016;25(4):324-9.
7. Kiers H, Brumagne S, van Dieën J, Vanhees L. Test–retest reliability of muscle vibration effects on postural sway. Gait Posture. 2014;40(1):166-71.
8. Guskiewicz KM, Perrin DH. Research and clinical applications of assessing balance. J Sport Rehabil. 1996;5(1):45-63.
9. Shanbehzadeh S, Salavati M, Talebian S, Khademi-Kalantari K, Tavahomi M. Attention demands of postural control in non-specific chronic low back pain subjects with low and high pain-related anxiety. Exp Brain Res. 2018;236(7):1927-38.
10. Abad SKG, Akhbari B, Salavati M, Moghaddam ST, Saeedi A, Seydi M, et al. Reliability of postural control during double-leg standing in subjects with nonspecific chronic low back pain: Dual-task paradigm and manipulated visual and somatosensory inputs. J Bodyw Mov Ther. 2021;26:49-56.
11. Quercia P, Demougeot L, Dos Santos M, Bonnetblanc F. Integration of proprioceptive signals and attentional capacity during postural control are impaired but subject to improvement in dyslexic children. Exp Brain Res. 2011;209(4):599-608.
12. Huxhold O, Li S-C, Schmiedek F, Lindenberger U. Dual-tasking postural control: aging and the effects of cognitive demand in conjunction with focus of attention. Brain Res Bull. 2006;69(3):294-305.
13. Mohammadirad S, Salavati M, Takamjani IE, Akhbari B, Sherafat S, Mazaheri M, et al. Intra and intersession reliability of a postural control protocol in athletes with and without anterior cruciate ligament reconstruction: a dual-task paradigm. Int J Sports Phys Ther. 2012;7(6):627.
14. Dijkers M, Kropp G, Esper R, Yavuzer G, Cullen N, Bakdalieh Y. Reporting on reliability and validity of outcome measures in medical rehabilitation research. Disabil Rehabil. 2002;24(16):819-27.
15. Ferdowsi F, Shadmehr A, Mir SM, Olyaei G, Talebian S, Keihani S. The reliability of postural control method in athletes with and without ACL reconstruction: a transitional task. J Phys Ther Sci. 2018;30(7):896-901.
16. Kouvelioti V, Kellis E, Kofotolis N, Amiridis I. Reliability of single-leg and double-leg balance tests in subjects with anterior cruciate ligament reconstruction and controls. Res Sports Med. 2015;23(2):151-66.
17. Nazary-Moghadam S, Salavati M, Esteki A, Akhbari B, Keyhani S, Zeinalzadeh A. Reliability of Knee Flexion-Extension Lyapunov Exponent in people with and Without Anterior Cruciate Ligament Deficiency. J Sport Rehabil. 2019:1-16.
18. Bujang MA, Baharum N. A simplified guide to determination of sample size requirements for estimating the value of intraclass correlation

coefficient: a review. Arch Orofac Sci. 2017;12(1).

19. Nazary-Moghadam S, Salavati M, Esteki A, Akhbari B, Keyhani S, Zeinalzadeh A. Reliability of kinematic measures in subjects with anterior cruciate ligament deficiency during dual-task walking. J Bodyw Mov Ther. 2017;21(4):852-9.
20. Zeinalzadeh A, Talebian S, Naghdi S, Salavati M, Nazary-Moghadam S, Zeynalzadeh Ghoochani B. Effects of vision and cognitive load on static postural control in subjects with and without patellofemoral pain syndrome. Physiother Theory Pract. 2018;34(4):276-85.
21. Ruhe A, Fejer R, Walker B. The test–retest reliability of centre of pressure measures in bipedal static task conditions–a systematic review of the literature. Gait Posture. 2010;32(4):436-45.
22. Domholdt E, Carter RE, Lubinsky J. Rehabilitation research: principles and applications. 4th ed. St. Louis, MO: Elsevier Saunders; 2011.
23. Doyle RJ, Hsiao-Wecksler ET, Ragan BG, Rosengren KS. Generalizability of center of pressure measures of quiet standing. Gait Posture. 2007;25(2):166-71.
24. Harringe ML. Swedish TeamGym: Injury incidence, mechanism, diagnosis and postural control. Stockholm: Karolinska Institute; Department of Molecular Medicine and Surgery; 2007.
25. Salavati M, Hadian MR, Mazaheri M, Negahban H, Ebrahimi I, Talebian S, et al. Test–retest reliabty of center of pressure measures of postural stability during quiet standing in a group with musculoskeletal disorders consisting of low back pain, anterior cruciate ligament injury and functional ankle instability. Gait Posture. 2009;29(3):460-4.
26. Hazime FA, Allard P, Ide MR, Siqueira CM, Amorim CF, Tanaka C. Postural control under visual and proprioceptive perturbations during double and single limb stances: insights for balance training. J Bodyw Mov Ther. 2012;16(2):224-9.
27. Baldini A, Nota A, Assi V, Ballanti F, Cozza P. Intersession reliability of a posturo-stabilometric test, using a force platform. J Electromyogr Kinesiol. 2013;23(6):1474-9.
28. Lafond D, Corriveau H, Hébert R, Prince F. Intrasession reliability of center of pressure measures of postural steadiness in healthy elderly people. Arch Phys Med Rehabil. 2004;85(6):896-901.
29. Gray VL, Ivanova TD, Garland SJ. Reliability of center of pressure measures within and between sessions in individuals post-stroke and healthy controls. Gait Posture. 2014;40(1):198-203.
30. Mazaheri M, Salavati M, Negahban H, Parnianpour M. Test-retest reliability of postural stability measures during quiet standing in patients with a history of nonspecific low back pain. Biomed Eng. 2010;22(03):255-62.