Intra- and Inter-session Reliability of Static and Dynamic Postural Control in Participants with and without Patellofemoral Pain Syndrome

Behnam Akhbari, PhD, PT;* Mahyar Salavati, PhD, PT;* Farshid Mohammadi, PhD;†
Ziaeddin Safavi-farokhi, PhD (cand.), PT*‡

ABSTRACT

Purpose: To determine the intra- and inter-session reliability of balance performance in people with patellofemoral pain syndrome (PFPS) and matched controls. **Methods:** In this methodological study, single-leg-stance performance of 15 participants with unilateral PFPS and 15 healthy matched controls was assessed using the Biodex Balance System (BBS) under 4 task difficulty levels (static and dynamic, with and without visual feedback). Intra-class correlation coefficients (ICCs), standard errors of measurement, and coefficients of variation were calculated for the overall stability index, anterior–posterior stability index, and medial–lateral stability index. **Results:** Static and dynamic postural performance during single-leg stance showed moderate to very high reliability in the PFPS group (ICCs = 0.53–0.96) and in healthy control participants (ICCs = 0.51–0.91). Both measures were more reliable with eyes closed than with eyes open. **Conclusion:** BBS stability indices appear to have acceptable reliability in people with PFPS, particularly in more challenging conditions, and may be incorporated into the evaluation and rehabilitation of this patient group.

Key Words: postural balance; Biodex Balance System; reproducibility of results; patellofemoral pain syndrome.

RÉSUMÉ

Objet : La présente étude avait pour objectif de déterminer la fiabilité intra et intersessionnelle de la performance de l'équilibre chez des sujets qui ont un syndrome fémoro-rotulien douloureux (SFRD) et chez un nombre équivalent de sujets en santé. **Méthodes :** Dans cette étude méthodologique, la performance lors d'un exercice debout sur une seule jambe a été examinée chez 15 sujets ayant un SFRD unilatéral et chez 15 témoins en santé, à l'aide d'un appareil Biodex Balance System (BBS) à quatre niveaux de difficulté différents (statique, dynamique, avec rétroaction visuelle et sans rétroaction visuelle). Le coefficient de corrélation intraclasse (CCI), l'erreur type de mesure (ETM) et le coefficient de variation (CV) ont été calculés pour l'indice de stabilité global (ISG), l'indice de stabilité antérieure et postérieure (ISAP) et l'indice de stabilité médio-latérale (ISML). **Résultats :** La performance de l'équilibre postural statique et dynamique lors d'un exercice debout sur une seule jambe a donné des résultats de fiabilité moyenne à très élevée chez les sujets ayant un SFRD (CCI = de 0,53 à 0,96) et les témoins en santé (CCI = de 0,51 à 0,91). Les mesures étaient plus fiables lorsque les participants avaient les yeux fermés comparativement à lorsqu'ils avaient les yeux ouverts. **Conclusion :** Les indices de stabilité calculés par l'appareil Biodex Balance System semblent présenter une fiabilité acceptable chez les sujets ayant un SFRD, surtout dans les conditions plus difficiles. Cet appareil pourrait être intégré dans l'évaluation et la réadaptation de ce groupe de patients.

Patellofemoral pain syndrome (PFPS) is one of the most common musculoskeletal disorders seen in adolescent and young adult populations.¹ PFPS is characterized by anterior peripatellar or retropatellar knee pain during activities such as squatting, running, jumping, and stair climbing or prolonged sitting with flexed knees.^{2,3} Although the exact etiology of PFPS is not known, structural factors such as leg-length discrepancy, bone misalignment, muscle weakness, and patellar misalignments are

thought to affect lower extremity mechanics and cause PFPS.^{4–6} Physiotherapy is the main treatment for PFPS, but some chronic conditions may benefit from surgery.⁷

Postural stability, or balance, is defined as the ability to maintain the centre of mass (COM) over the base of support (BOS) under static or dynamic conditions⁸ and is considered essential for independent daily activities. The control of balance is a complex motor control task involving numerous neuromuscular processes that are

From the: *Physiotherapy Department, University of Social Welfare and Rehabilitation Sciences, Tehran; †Department of Rehabilitation Sciences, Faculty of Kinesiology and Rehabilitation, The Katholieke Universiteit Leuven, Leuven, Belgium; ‡Neuromuscular Rehabilitation Research Center, Rehabilitation Faculty, Semnan University of Medical Sciences, Semnan, Iran.

Correspondence to: Ziaeddin Safavi-farokhi, Physiotherapy Department, University of Social Welfare and Rehabilitation Sciences, Koodakyar Ave., Daneshjoo Blvd., Evin, Tehran, Iran; ziasafavi@yahoo.com.

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controlled by sensory components (vestibular, visual, and proprioceptive systems), central processing, and neuromuscular responses. An appropriate motor response requires an interaction of the intact neuromuscular system and sufficient muscle strength to return the COM within the BOS after perturbation.^{9,10}

Proprioceptive impairment and decreased muscle strength are two possible causes of balance impairments.¹¹ Sensory deficit and quadriceps atrophy seem to lead to decreased motor performance and decreased dynamic postural control in people with PFPS.^{11,12} Differences were also found in the proprioceptive acuity between people with PFPS and healthy controls.¹³ Musculoskeletal pathology and pain may alter proprioception information. So, the pain and abnormal tissue stresses may lead to abnormal proprioception in people with PFPS.¹⁴ In addition, pain may affect postural control, because patellar taping has been shown to decrease knee pain and improve balance performance.^{15,16}

Surprisingly, there has been little evaluation of the overall postural abilities of people with PFPS. In a study by Citaker and colleagues,¹⁷ participants with PFPS showed poorer balance on the symptomatic side than on the contralateral side during a 30-second static stance test. Although static postural control is a valuable measure, measuring the dynamic aspects of postural control may provide more precise information about knee function during functional activities.¹⁸ To the best of our knowledge, no previous study has evaluated the reliability of static or dynamic postural performance in people with PFPS. The reliability of these measures may have important clinical implications for rehabilitation, however, because they are widely used to evaluate the effectiveness of interventions. The aim of the current study, therefore, was to assess the intra- and inter-session test-retest reliability of static and dynamic balance in participants with PFPS and matched healthy controls, using the Biodex Balance System (BBS; Biodex Medical Systems, SD, Shirley, NY).

METHODS

Participants

We used a convenience sample of 15 participants (6 women, 9 men) with unilateral PFPS and 15 age- and sex-matched healthy participants, ages 18–30 years. The PFPS group had a mean age of 24.6 (SD 5.4) years, a mean height of 171.5 (SD 6.6) cm, and a mean weight of 73.5 (SD 8.3) kg; the control group had a mean age of 25.2 (SD 6.3) years, a mean height of 173.3 (SD 7.5) cm, and a mean weight of 74.9 (9.2) kg.

Participants with PFPS were included after diagnosis by a physiotherapist on the basis of a positive Clarke's test and non-traumatic anterior or retropatellar knee pain during weight-bearing activities or prolonged sitting with flexed knees.³ For Clarke's test, the participant was

positioned supine, with extended knees supported on the examination table; the examiner placed the web of his thumb and index finger against the superior pole of the participant's patella, and the participant was asked to perform an isometric contraction of the quadriceps muscle. The presence of pain indicated a positive diagnosis.¹⁹ Participants with a history of neuromuscular or musculoskeletal disorders; any balance, vestibular, or visual problems; or a significant injury to either lower extremity aside from unilateral PFPS were excluded from the study. The study was approved by the ethics committee of the University of Social Welfare and Rehabilitation Sciences, and all participants provided written informed consent.

Procedure

The BBS is a valid instrument used to measure postural stability in static and dynamic conditions.²⁰ It has a circular platform that moves freely in the anterior–posterior (AP) and medial–lateral (ML) planes.²⁰ During the static postural task, the platform remains stationary, without tilting. The difficulty of the dynamic postural stability task can be varied from stability level 12 (minimum tilt, maximum stability) to stability level 1 (maximum tilt, minimum stability).⁸ A pilot study we conducted found that participants with PFPS were unable to complete the test at levels less than 4 while standing on their involved limb; for the present study, therefore, we set the stability level between 4 and 8. Participants were instructed to stand barefoot, with both hands placed on their iliac crests, and to place their unsupported foot behind the weight-bearing ankle. They were then told to maintain their centre of pressure in the smallest concentric ring (balance zone) on the BBS monitor²¹ (Figure 1). The platform was then locked, and the participant's foot position coordinates were marked on the platform as an array of (*x*, *y*) coordinates and recorded by the examiner,²² where *x* and *y* represent the degree of tilt

Figure 1 A front view of panel of the Biodex Balance System®.

around the AP and ML axes, respectively. The angle of the third metatarsal in reference to the y -axis was also recorded manually.⁸ Participants were instructed not to move their testing foot from the platform during the trials.

After a practice trial for 2 minutes, each participant was asked to perform static and dynamic balance tests. All the tests were supervised by the same evaluator. Balance tests were performed at four levels of postural difficulty (static or dynamic with eyes open or closed). During eyes-open conditions, participants were asked to look directly at a piece of paper placed on the wall at their eye level. Each measurement lasted 20 seconds and was repeated three times; average scores were used for analysis. Participants repeated the trial if they put their non-weight-bearing foot down or touched the handrails with their arms during the test. To avoid fatigue, participants were given a 1-minute rest between tests. Testing order was randomized to control for sequence effects. Only the involved limb of participants with PFPS and the matched limb of controls were tested. The whole procedure was repeated on the same day, to measure intra-session reliability, and again 3–5 days later, to measure inter-session reliability. The entire experimental procedure lasted approximately 40 minutes per participant.

Three stability indices—the anterior–posterior stability index (APSI), medial–lateral stability index (MLSI), and overall stability index (OSI)—have been calculated by Arnold and Schmitz,²⁰ using the following equations:

$$\text{APSI} = \sqrt{\frac{\sum(0 - Y)^2}{\text{number of samples}}}$$

$$\text{MLSI} = \sqrt{\frac{\sum(0 - x)^2}{\text{number of samples}}}$$

$$\text{OSI} = \sqrt{\frac{\sum(0 - Y)^2 + \sum(0 - X)^2}{\text{number of samples}}}$$

The indices measure the amount of deviation from the baseline position; therefore, a lower score indicates greater postural stability.

Data analysis

We used independent t -tests to check for differences in demographic data (age, sex, weight, and height) between the two groups and paired t -tests to compare differences in stability scores in test and retest sessions to check for systematic bias.

We used a two-way random model of intra-class correlation coefficients (ICCs) to assess relative intra- and inter-session reliabilities.²³ To determine reliability, we used Munro's classification for reliability coefficients, in which correlations of 0.26–0.49 indicate low correlation; 0.5–0.69, moderate correlation; 0.7–0.89, high correlation; and 0.9–1.00, very high correlation.²⁴ To estimate

measurement error, we computed the standard error of measurement (SEM). In addition, we calculated the minimal metrically detectable change (MMDC; 95% confidence interval of the SEM) and the coefficient of variation (CV; $\text{SD} / \text{mean} \times 100$).^{25,26} For all statistical analyses, we set the alpha level at 0.05. All data analysis was performed using SPSS Version 11.0 (SPSS Inc., Chicago, IL).

RESULTS

Independent t -tests revealed no significant difference in age ($p = 0.89$), weight ($p = 0.73$), or height ($p = 0.65$) between the two groups. Table 1 presents mean scores and standard deviations for stability measures under all testing conditions; we found no significant difference between test and retest mean scores for APSI, MLSI, and OSI, either with eyes open or with eyes closed, under either static or dynamic conditions ($p > 0.05$), which indicates an absence of systematic bias.

Intra- and inter-session reliability, SEM, MMDC, and CV of stability measures for the PFPS and control groups are presented in Tables 2 and 3. Intra-session reliability was high to very high (ICCs = 0.73–0.93) for participants with PFPS and moderate to very high (ICCs = 0.51–0.92) for controls; we found moderate to very high inter-session reliability for both participants with PFPS (ICCs = 0.53–0.96) and controls (ICCs = 0.51–0.91).

SEMs ranged from 0.2 to 1.2 in the PFPS group and from 0.2 to 0.6 in the control group; MMDCs ranged from 0.4 to 2.4 and from 0.1 to 1.2, respectively; and CVs ranged from 19.5% to 36.6% and from 18.9% to 37.3%, respectively.

DISCUSSION

Our results indicated that single-leg stance under static and dynamic balance measures with and without visual feedback are reliable outcomes in people with PFPS and healthy controls. In addition, for most stability measures, ICC values were higher during eyes-closed conditions than during eyes-open conditions.

Our results show moderate to very high relative reliability for stability indices, which indicates that the measurement error was small relative to the variability between participants, and therefore the possibility of type II error is limited.²⁷ The same levels of reliability have been found in patients with low back pain (LBP)²⁸ and in athletes after anterior cruciate ligament (ACL) reconstruction.²⁹ However, Pincivero and colleagues³⁰ reported lower levels of reliability, possibly because they used different levels of stability in their measurements.

Static balance measures showed the highest inter-session reliability for the MLSI in both groups. Under dynamic conditions, the APSI had the highest reliability in the patient group and the MLSI in the control group. Overall, it seems that the MLSI has the highest reliability compared to the other two stability indices, which is consistent with the results of previous studies in people

Table 1 Descriptive Test–Retest Data for Postural Measures under Different Task Conditions for Patients with Patellofemoral Pain Syndrome (PFPS) and Matched Controls

Condition and stability index	PFPS group (<i>n</i> = 15)			Control group (<i>n</i> = 15)		
	Mean (SD)		<i>p</i> -value*	Mean (SD)		<i>p</i> -value*
	Test	Retest		Test	Retest	
Static						
Eyes open						
APSI	1.6 (1.1)	1.5 (1.2)	0.25	1.3 (0.9)	1.5 (0.9)	0.16
MLSI	1.0 (0.6)	1.1 (0.5)	0.36	0.9 (0.4)	0.8 (0.3)	0.75
OSI	2.1 (1.1)	2.1 (1.1)	0.95	1.5 (0.5)	1.4 (0.6)	0.48
Eyes closed						
APSI	3.6 (2.0)	3.5 (2.0)	0.70	3.2 (0.8)	2.8 (0.7)	0.19
MLSI	1.9 (0.8)	1.8 (0.6)	0.30	1.6 (0.7)	1.5 (0.6)	0.14
OSI	4.4 (1.9)	4.3 (1.8)	0.60	4.1 (1.6)	3.6 (1.2)	0.11
Dynamic						
Eyes open						
APSI	1.9 (1.2)	1.8 (1.1)	0.83	1.6 (1.1)	1.5 (0.9)	0.34
MLSI	1.7 (0.7)	1.7 (0.7)	0.70	1.3 (0.6)	1.0 (0.7)	0.12
OSI	2.7 (1.3)	2.6 (1.2)	0.38	2.2 (0.9)	1.9 (0.8)	0.09
Eyes closed						
APSI	4.6 (1.9)	4.5 (1.8)	0.82	4.1 (1.7)	3.7 (1.3)	0.06
MLSI	2.6 (0.9)	2.4 (0.7)	0.37	2.3 (0.8)	1.9 (1.0)	0.08
OSI	5.7 (1.7)	5.6 (1.9)	0.46	5.2 (1.5)	4.9 (1.5)	0.07

*Paired *t* test on test–retest differences.

APSI = anterior–posterior stability index; MLSI = medial–lateral stability index; OSI = overall stability index.

Table 2 Intra- and Inter-Session Reliability of the Postural Measures under Different Task Difficulty Conditions in Patients with Patellofemoral Pain Syndrome (PFPS)

Eyes and stability index	Intra-session		Inter-session			
	Test ICC	Retest ICC	ICC	SEM	MMDC	CV, %
Static						
Open						
APSI	0.82	0.87	0.62	2.0	0.4	19.5
MLSI	0.92	0.86	0.80	4.0	0.8	32.9
OSI	0.84	0.81	0.53	5.0	1.1	23.8
Closed						
APSI	0.75	0.83	0.71	6.0	1.1	28.9
MLSI	0.93	0.90	0.96	2.0	0.4	32.8
OSI	0.86	0.83	0.90	5.0	0.9	23.4
Dynamic						
Open						
APSI	0.85	0.86	0.70	6.0	1.2	32.5
MLSI	0.88	0.90	0.74	3.0	0.6	21.4
OSI	0.87	0.85	0.79	5.0	0.9	25.3
Closed						
APSI	0.80	0.73	0.81	1.1	2.1	36.6
MLSI	0.89	0.92	0.71	9.0	1.8	34.1
OSI	0.80	0.90	0.64	1.2	2.4	28.9

ICC = intra-class correlation coefficient; SEM = standard error of measurement; MMDC = minimal metrically detectable change; CV = coefficient of variation;

APSI = anterior–posterior stability index; MLSI = medial–lateral stability index; OSI = overall stability index.

with low back pain with stability levels of 5 and 328 and athletes following anterior cruciate ligament reconstruction, using stability levels of 8 and 6.29. However, Schmitz and Arnold's⁸ study in 19 healthy participants aged 24.4 (SD 4.2) years showed that the OSI was the most reliable

measure. This inconsistency may be due to different population and stability levels used in the latter study.

Boling and Shumway-Cook stated that atrophy and decreased strength in the quadriceps muscles are among the most serious problems in participants with PFPS,^{11,12}

Table 3 Intra- and Inter-Session Reliability of the Postural Measures under Different Task Difficulty Conditions in Healthy Individuals

Eyes and stability index	Intra-session		Inter-session			
	Test ICC	Retest ICC	ICC	SEM	MMDC	CV, %
Static						
Open						
APSI	0.61	0.51	0.51	3.0	0.7	18.9
MLSI	0.84	0.90	0.75	4.0	0.8	35.7
OSI	0.74	0.87	0.63	3.0	0.6	23.2
Closed						
APSI	0.82	0.75	0.54	5.0	1.1	22.1
MLSI	0.91	0.90	0.90	2.0	0.4	27.1
OSI	0.83	0.87	0.73	5.0	0.9	21.1
Dynamic						
Open						
APSI	0.75	0.60	0.59	5.0	0.1	29.6
MLSI	0.85	0.83	0.83	3.0	0.7	33.5
OSI	0.80	0.85	0.80	4.0	0.8	27.0
Closed						
APSI	0.92	0.88	0.81	6.0	1.2	26.4
MLSI	0.91	0.90	0.91	3.0	0.6	37.3
OSI	0.91	0.89	0.82	6.0	1.2	24.9

ICC = intra-class correlation coefficient; SEM = standard error of measurement; MMDC = minimal metrically detectable change; CV = coefficient of variation; APSI = anterior-posterior stability index; MLSI = medial-lateral stability index; OSI = overall stability index.

who have a muscle imbalance between anterior and posterior muscle groups around the knee joint. In the sagittal plane, the quadriceps are known to be important muscles for balance performance. Carter showed that relative reliability is based on the idea that, if a measure is reliable, each member of a group will maintain his/her approximate ranking within that group across repeated measurement.^{31(p.239-40)}

We found higher reliability values for most stability indices in the eyes-closed condition for both the PFPS and control groups. This finding agrees with those of Hinman,³² who reported higher ICCs for these measures in healthy participants aged 18–65 years under more challenging postural conditions. Higher ICC values in the eyes-closed conditions may be related to the higher between-subjects variance in these conditions relative to the eyes-open conditions.

We found the smallest SEM, and therefore the smallest measurement error on repeated measurements, for the static APSI and MLSI and the dynamic MLSI in the PFPS group and for the static and dynamic MLSI in the control group. These results confirm that MLSI can detect smaller changes in an individual's balance performance than the other two stability indices. Parraca and colleagues³³ found similar SEMs with older adult participants (mean age 66 [SD 5.5] years). We also found smaller MMDC and CV values for the MLSI in most cases, which suggests that this measure has higher sensitivity than the other two stability indices.

LIMITATIONS

The main limitation of our study is that the results cannot be generalized to other groups, which means

that further research is needed to investigate, first, the reliability of BBS measures in people with various types of knee pain; second, the reliability of BBS measures in people with PFPS during cognitive tasks; and, third, the reliability of BBS measures at different levels of platform stability and for trials of different lengths.

CONCLUSION

Although our findings cannot be generalized, the results suggest that BBS measures of static and dynamic balance are reliable in people with PFPS and may be used in evaluation and rehabilitation for this population.

KEY MESSAGES

What is already known on this topic

People with patellofemoral pain syndrome (PFPS) may have problems with dynamic balance; poor proprioceptive outcomes have also been reported in this population.

What this study adds

Static and dynamic balance tests obtained using the Biodex Balance System are reliable in people with PFPS and may be used for evaluation and rehabilitation in this population.

REFERENCES

1. Kujala UM, Kvist M, Österman K. Knee injuries in athletes. Review of exertion injuries and retrospective study of outpatient sports clinic material. *Sports Med.* 1986;3(6):447–60. <http://dx.doi.org/10.2165/00007256-198603060-00006>. Medline:3538273
2. Piva SR, Fitzgerald GK, Irrgang JJ, et al. Associates of physical function and pain in patients with patellofemoral pain syndrome. *Arch Phys Med Rehabil.* 2009;90(2):285–95. <http://dx.doi.org/10.1016/j.apmr.2008.08.214>. Medline:19236982

3. Nijs J, Van Geel C, Van der auwera C, et al. Diagnostic value of five clinical tests in patellofemoral pain syndrome. *Man Ther*. 2006;11(1):69–77. <http://dx.doi.org/10.1016/j.math.2005.04.002>. Medline:15950517
4. Callaghan MJ, Oldham JA. Quadriceps atrophy: to what extent does it exist in patellofemoral pain syndrome? *Br J Sports Med*. 2004;38(3):295–9. <http://dx.doi.org/10.1136/bjsm.2002.002964>. Medline:15155431
5. Powers CM. The influence of altered lower-extremity kinematics on patellofemoral joint dysfunction: a theoretical perspective. *J Orthop Sports Phys Ther*. 2003;33(11):639–46. <http://dx.doi.org/10.2519/jospt.2003.33.11.639>. Medline:14669959
6. White LC, Dolphin P, Dixon J. Hamstring length in patellofemoral pain syndrome. *Physiotherapy*. 2009;95(1):24–8. <http://dx.doi.org/10.1016/j.physio.2008.05.009>. Medline:19627682
7. Crossley K, Bennell K, Green S, et al. A systematic review of physical interventions for patellofemoral pain syndrome. *Clin J Sport Med*. 2001;11(2):103–10. <http://dx.doi.org/10.1097/00042752-200104000-00007>. Medline:11403109
8. Schmitz R, Arnold B. Intertester and intratester reliability of a dynamic balance protocol using the Biodex Stability System. *J Sport Rehabil*. 1998;7(2):95–102.
9. Hemami H, Barin K, Jalics L, et al. Dynamics, stability, and control of stepping. *Ann Biomed Eng*. 2004;32(8):1153–60. <http://dx.doi.org/10.1114/B:ABME.0000036651.26026.a3>. Medline:15446511
10. Alexandrov AV, Frolov AA, Horak FB, et al. Feedback equilibrium control during human standing. *Biol Cybern*. 2005;93(5):309–22. <http://dx.doi.org/10.1007/s00422-005-0004-1>. Medline:16228222
11. Boling MC, Padua DA, Marshall SW, et al. A prospective investigation of biomechanical risk factors for patellofemoral pain syndrome: the Joint Undertaking to Monitor and Prevent ACL Injury (JUMP-ACL) cohort. *Am J Sports Med*. 2009;37(11):2108–16. <http://dx.doi.org/10.1177/0363546509337934>. Medline:19797162
12. Shumway-Cook A, Woolacott MH. Motor control theory and practical applications. 2nd ed. Philadelphia: Lippincott Williams & Wilkins; 2001.
13. Callaghan MJ, Selfe J, McHenry A, et al. Effects of patellar taping on knee joint proprioception in patients with patellofemoral pain syndrome. *Man Ther*. 2008;13(3):192–9. <http://dx.doi.org/10.1016/j.math.2006.11.004>. Medline:17296323
14. Baker V, Bennell K, Stillman B, et al. Abnormal knee joint position sense in individuals with patellofemoral pain syndrome. *J Orthop Res*. 2002;20(2):208–14. [http://dx.doi.org/10.1016/S0736-0266\(01\)00106-1](http://dx.doi.org/10.1016/S0736-0266(01)00106-1). Medline:11918299
15. Loudon JK, Wiesner D, Goist-Foley HL, et al. Intrarater reliability of functional performance tests for subjects with patellofemoral pain syndrome. *J Athl Train*. 2002;37(3):256–61. Medline:12937582
16. Aminaka N, Gribble PA. Patellar taping, patellofemoral pain syndrome, lower extremity kinematics, and dynamic postural control. *J Athl Train*. 2008;43(1):21–8. <http://dx.doi.org/10.4085/1062-6050-43.1.21>. Medline:18335009
17. Citaker S, Kaya D, Yuksel I, et al. Static balance in patients with patellofemoral pain syndrome. *Sports Health*. 2011;3(6):524–7. <http://dx.doi.org/10.1177/1941738111420803>. Medline:23016053
18. Hoffman M, Schrader J, Kocaja D. An investigation of postural control in postoperative anterior cruciate ligament reconstruction patients. *J Athl Train*. 1999;34(2):130–6. Medline:16558555
19. Doberstein ST, Romeyn RL, Reineke DM. The diagnostic value of the Clarke sign in assessing chondromalacia patella. *J Athl Train*. 2008;43(2):190–6. <http://dx.doi.org/10.4085/1062-6050-43.2.190>. Medline:18345345
20. Arnold BL, Schmitz RJ. Examination of balance measures produced by the Biodex Stability System. *J Athl Train*. 1998;33(4):323–7. Medline:16558529
21. Karimi N, Ebrahimi I, Kharizi S. Reliability of postural balance evaluation using the Biodex balance system in subjects with and without low back pain. *J Postgrad Med Inst*. 2008;22:95–101.
22. Pereira HM, de Campos TF, Santos MB, et al. Influence of knee position on the postural stability index registered by the Biodex Stability System. *Gait Posture*. 2008;28(4):668–72. <http://dx.doi.org/10.1016/j.gaitpost.2008.05.003>. Medline:18573663
23. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res*. 2005;19(1):231–40. Medline:15705040
24. Domholdt E. Rehabilitation research: principles and applications. 3rd ed. St. Louis (MO): Elsevier Saunders; 2005.
25. Atkinson G, Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med*. 1998;26(4):217–38. <http://dx.doi.org/10.2165/00007256-199826040-00002>. Medline:9820922
26. Corriveau H, Hébert R, Prince F, et al. Intrasession reliability of the “center of pressure minus center of mass” variable of postural control in the healthy elderly. *Arch Phys Med Rehabil*. 2000;81(1):45–8. Medline:10638875
27. Charter RA. Effect on measurement error on tests of statistical significance. *J Clin Exp Neuropsychol*. 1997;19(3):458–62. <http://dx.doi.org/10.1080/01688639708403872>. Medline:9268818
28. Sherafat S, Salavati M, Ebrahimi Takamjani I, et al. Intrasession and inter-session reliability of postural control in participants with and without nonspecific low back pain using the Biodex Balance System. *J Manipulative Physiol Ther*. 2013;36(2):111–8. <http://dx.doi.org/10.1016/j.jmpt.2012.12.005>. Medline:23499146
29. Mohammadirad S, Salavati M, Takamjani IE, et al. Intra and inter-session 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):627–36. Medline:23316426
30. Pincivero DM, Lephart SM, Henry TJ. Learning effects and reliability of the Biodex Stability System. *J Athl Train*. 1995;30:S35.
31. Carter R, Lubinsky J. Rehabilitation research: principles and applications. 4th ed. St. Louis (MO): Elsevier Saunders; 2005.
32. Hinman M. Factors affecting reliability of the Biodex Balance System: a summary of four studies. *J Sport Rehabil*. 2000;9(3):240–52.
33. Parraca JA, Olivares PR, Carbonell-Baeza A, et al. Test-retest reliability of Biodex Balance SD on physically active old people. *J Hum Sport Exerc*. 2011;6(2):444–51. <http://dx.doi.org/10.4100/jhse.2011.62.25>.