Reliability and Measurement Error of Active Knee Extension Range of Motion in a Modified Slump Test Position: A Pilot Study

Neil Tucker, PT, MHSc (Hons)
Duncan Reid, PT, MHSc (Hons)
Peter McNair, PhD

Abstract: The slump test is a tool to assess the mechanosensitivity of the neuromeningeal structures within the vertebral canal. While some studies have investigated the reliability of aspects of this test within the same day, few have assessed the reliability across days. Therefore, the purpose of this pilot study was to investigate reliability when measuring active knee extension range of motion (AROM) in a modified slump test position within trials on a single day and across days. Ten male and ten female asymptomatic subjects, ages 20–49 (mean age 30.1, SD 6.4) participated in the study. Knee extension AROM in a modified slump position with the cervical spine in a flexed position and then in an extended position was measured via three trials on two separate days. Across three trials, knee extension AROM increased significantly with a mean magnitude of 2° within days for both cervical spine positions ($P>0.05$). The findings showed that there was no statistically significant difference in knee extension AROM measurements across days ($P>0.05$). The intraclass correlation coefficients for the mean of the three trials across days were 0.96 (lower limit 95% CI: 0.90) with the cervical spine flexed and 0.93 (lower limit 95% CI: 0.83) with cervical extension. Measurement error was calculated by way of the typical error and 95% limits of agreement, and visually represented in Bland and Altman plots. The typical error for the cervical flexed and extended positions averaged across trials was 2.6° and 3.3°, respectively. The limits of agreement were narrow, and the Bland and Altman plots also showed minimal bias in the joint angles across days with a random distribution of errors across the range of measured angles. This study demonstrated that knee extension AROM could be reliably measured across days in subjects without pathology and that the measurement error was acceptable. Implications of variability over multiple trials are discussed. The modified set-up for the test using the Kincom dynamometer and elevated thigh position may be useful to clinical researchers in determining the mechanosensitivity of the nervous system.

Key Words: Modified Slump Test, Knee Extension, Within-Trial Reliability, Reliability across Days, Measurement Error

Address all correspondence and requests for reprints to:
Duncan Reid
Health Rehabilitation Research Centre
School of Rehabilitation and Occupation Studies
Faculty of Health and Environmental Science
Auckland University of Technology,
Akoranga Drive, North Shore, Auckland
New Zealand
E-mail: duncan.reid@aut.ac.nz

Maitland[1] proposed the slump test as a tool to assess the mechanosensitivity of the neuromeningeal structures within the vertebral canal. This test and other tests of neuromeningeal structures, such as the upper limb tension tests have been described as "neurodynamic" or "neural provocation" tests[2-4]. A neural provocation test is a sequence of movements designed to assess the mechanics and physiology of that part of the nervous system by elongation of the nerve[4]. Physical therapists have found the slump test both a useful test and intervention in patients who present with spinal or lower limb pain[3,5,6]. However, in these neurodynamic tests, a number of structures may be responsible for the pain elicited during the test sequence. Many of these nerve tissues interface or run alongside various mono- and poly-articular joint structures that may be mechanically stressed with neural provocation tests, so the sequence and order of the loading components needs to be well controlled in order to differentiate between these structures[4].

While trying to control all the elements of this test or treatment procedure, clinicians may ask the patient to actively extend the knee to increase tension to the neural components[5]. Knee extension range of motion (ROM) has been used as a dependent variable to quantify the slump test[1,8-12]. Values of 16–35.4° short of full knee extension have been observed in the slump position[7-9,11,12]; these restrictions in knee extension ROM decreased when the neck was extended. From a treatment perspective, some authors have modified the slump position and have placed the patient in long sitting in order to control the knee extension range of motion and have then used cervical flexion as the variable to be altered[6]. It could be argued that this position places significant stress through the neural components of the test and is more useful as a progression towards the end stages of treatment. However, patients who cannot tolerate this position may require an alternative position. One possible alternative position might be to increase the amount of hip flexion and combine this with knee extension. Whereas some patients might be unable to even assume the long sitting position due to other bi-articular influences, using knee extension in a modified slump sitting position with increased hip flexion as described above would reduce the influence that the other poly-articular structures (most notably limitations in hamstring muscle length) have on the outcomes of the test sequence. With those subjects unable to attain full knee extension, this position also eliminates the effect that mono-articular (mainly capsuloligamentous) restraints might have on the amount of knee extension.

Coppieters et al[4] have commented that high reliability and small measurement error is required to render a test (such as neuromeningeal tests) suitable for clinical practice and experimental studies. Two earlier studies have assessed the reliability of the slump test. Phillips et al[5] studied interrater agreement for the slump test in patients with low back and leg symptoms. These authors reported a κ-value of 0.89 (95% CI: 0.81-0.97) for mean pair-wise interrater agreement on a positive or negative test finding when defining a positive slump test as symptom reproduction and subsequent decrease with cervical extension, whereas adding increased knee extension ROM as a criterion for a positive slump test yielded a mean $\kappa = 0.83$ (95% CI: 0.75–0.91). More similar to the current study, Yeung et al[11] studied the reliability of instrumented goniometric measurement of knee extension AROM limited by symptom response during slump sitting, but they did not clarify if the measures for this pilot reliability study were taken from asymptomatic controls or subjects with post-whiplash syndrome. They reported excellent intrarater ($r = 0.940$) and, for one pair of raters, good interrater agreement ($r = 0.854$). However, neither of these studies undertook testing of the respective slump test parameters across more than one day. Therefore, the purpose of this pilot study was to investigate the measurement error and the reliability of measurements within trials on a single day and across days of knee extension AROM in a modified slump test position involving increased hip flexion. We hypothesized that this position would be reliable as a test procedure in that it would have small measurement error and that it would show little variation within and across days.

Materials and Methods

Subjects

A test-retest cross-sectional experimental study design was undertaken. A convenience sample of 10 male and 10 female asymptomatic subjects (mean age 30.1, SD 6.4) were recruited from the local community and student population. In accordance with the requirements of the Auckland University of Technology (AUT) Ethics Committee (05/104), written and verbal explanations of the experimental procedures were provided to the subjects. Written consent was gained prior to testing. Subjects were excluded from the study if they had a history of low back pain, radiating leg pain, or knee pain or were currently receiving treatment for the same conditions.

Equipment and Procedures

A registered physical therapist with 5 years experience performed the study including the proposal development, the study design, and data collection. Analysis, interpretation, and writing of this paper were done in combination with the other authors.

During the testing procedure, the subjects were positioned in a KinCom® Isokinetic dynamometer chair (Kinetic Communicator, Chattex Corp., Chattanooga, TN, USA) using a methodology similar to the one used by Fidel et al[12] and Laessoe and Voigt[10]. The Kincom seat provides a stable platform for measurement and also allows easy access to the subject. Once the subject is seated, a specially constructed pad that creates a thigh angle of 25° to the horizontal produces the increased hip flexion position as compared to the standard slump position. The height of the pad was used to prevent subjects from reaching full extension at their knee joint. This was done to ensure that knee extension ROM was only limited by hamstring extensibility and the neural structures and not other structures around the knee such as the ligament and capsule as discussed above. Pelvis and hip position was kept constant by a strap around the waist and upper thigh.

While the patient was in this position, two trials of the test procedure were performed to allow the subject to become familiar with the procedure. A subsequent rest period of 10 minutes allowed any possible viscoelastic effects of these maneuvers to resolve[13]. Following the familiarization trials, a Penny and Giles electrogoniometer (Penny and Giles Biometrics Ltd, Gwent, UK) was attached by double-sided tape to the lateral aspect of the thigh and lower leg (Figure 1). To allow the goniometer to be positioned accurately across days, the subjects were marked with ink at the center of the lateral femoral condyle and then 7 (cm) above and below that point on the line connecting the greater trochanter of the hip to the head of the fibula (Figure 1). To control spinal flexion, the subjects were instructed to flex the trunk maximally to a point where they perceived a tolerable stretch sensation in the spine but no pain. Maximal spinal flexion was then maintained with a strap fixing the thoracic and lumbar spine into flexion perpendicular to the seat (Figure 2). To keep the amount of spinal flexion constant across days, the vertical distance from tip of the acromion to the seat was measured and kept constant within and across days.

For each test, the starting position was 90° flexion at the knee joint with the ankle in full dorsiflexion. Knee extension ROM was tested in two positions: in the slump position including full head and cervical flexion (Figure 2) and with the head and upper cervical spine moving into a more neutral head position (relative extension) from this flexed position (Figure 3). The maximum knee extension angle was the variable of interest. The subjects were asked to extend the knee until they reached the point of perceived maximal discomfort due to the stretch. At this point, the knee ROM was recorded. The subject was then instructed to extend the cervical spine back to the neutral position. The subject was then asked to extend the knee further if possible (Figure 3). Knee extension ROM was then recorded with the head and upper cervical spine in relative extension. Subjects repeated this sequence 3 times on each day. The testing sequence was also repeated with a separation of 2 days.

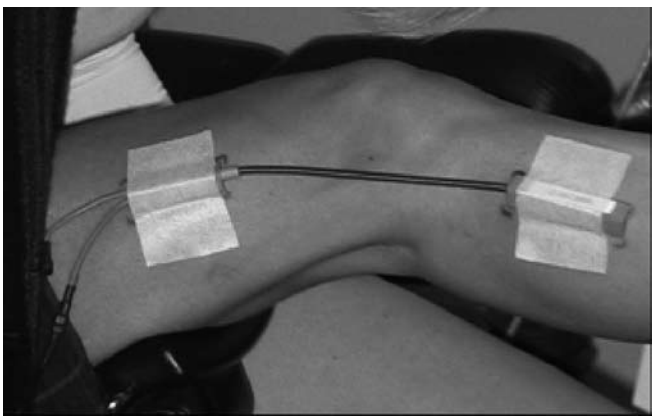


Fig. 1. Electrogoniometer placement.

Fig. 2. The slump position for a typical subject in the fixed seat with the cervical spine in flexion.

Fig. 3. The slump position for a typical subject in the fixed seat with the cervical spine in extension.

Statistical Analysis

Descriptive statistics were calculated and the normal distribution of the dependent variables was assessed. To compare the data within and across days, we used a two-factor (trials and days) repeated-measures analysis of variance (ANOVA) model. Assumptions associated with sphericity were tested and corrections (Greenhouse-Geisser) were made where appropriate. Pair-wise contrasts of Trial 1 with the other trials were undertaken with Bonferroni tests. Typical error[14] was calculated using the standard deviation of the difference in scores (Day 2–Day 1 data). This was divided by the square root of 2. The intraclass correlation coefficients (ICC) for Trial 1 and for the average of three trials across days were also calculated. For this test, a two-way mixed model was used with the mode of assessment (days) as the fixed variable, and the subjects as the random variable[15]. As an additional indication of measurement error in the form of within-subject variation but closely related to the typical error calculated above, we also calculated Bland and Altman 95% limits of agreement. Data were plotted using Bland and Altman graphs[16] to demonstrate the distribution of error across days for Trial 1 and for the average of three trials. The statistical analysis was undertaken using Statistical Package for Social Sciences (SPSS) Version 13.0 (Chicago, Illinois). The alpha-level was set at 0.05.

Results

Subjects

All of the subjects completed the study. The demographic data are presented in Table 1 and include means and standard deviation for subject age, height, and mass. On analyzing the ROM data, there was one outlier. On further questioning, it was revealed that this subject took part in a significant cycling session one day prior to his second test and failed to inform the researchers, and this event may have subsequently affected his data. His data were, therefore, discarded.

Comparison across Trials and Days

Descriptive statistics for knee flexion angle in the slump position with cervical flexion and cervical extension position are presented in Table 2. The findings of the two-factor repeated measures ANOVA for both cervical flexion and extension conditions showed a significant difference with a mean magnitude of 2° across trials for both conditions ($P<0.05$). Pair-wise contrasts showed that the knee extension angle was significantly less in the first trial compared to later trials for both flexed and extended cervical spine conditions, showing a clear positive effect of repetition on our dependent variable of knee extension ROM. However, supporting our hypothesis of reliability across days, there was no significant difference across days ($P>0.05$). There was no interaction effect ($P>0.05$) across day and trial factors.

With regard to the reliability testing, for the cervical flexion position, the ICC for the mean of the three trials across days was 0.96 (lower limit of 95%CI: 0.90). Taking into account the demonstrated increase in knee extension AROM with successive trials, we also calculated the ICC for the first trial only. The ICC for trial 1 across days was 0.95 (lower limit of 95%CI: 0.86) (Table 3). For the cervical extension position, the ICC for the mean of the three trials across days was 0.93 (lower limit of 95%CI: 0.83) and for Trial 1 only, across days it was 0.95 (lower limit of 95%CI: 0.87) (Table 3).

With regard to measurement error, the typical error for the flexed and extended positions averaged across trials was 2.6° and 3.3°, respectively. For Trial 1 only, the typical errors were 2.4° and 2.7°, respectively. Bland and Altman limits of agreement are provided in Table 4; Bland and Altman plots are presented in Figure 4.1–4.4. They show that there is no systematic pattern in the differences between days.

TABLE 1. Patient demographics (means and standard deviations)

	Number	Age (yrs)	Height (cm)	Mass (kgs)
Subjects	20	30.1 (6.4)	174.1 (9.0)	74.5 (15.0)

TABLE 2. Descriptive statistics for the knee flexion angle across trials and days in the slumped and extended positions

	n		Mean	Std. Deviation
Cx Flexion Day 1	19	*Trial 1*	34.1	12.5
		Trial 2	33.6	13.1
		Trial 3	32.3	13.3
Cx Flexion Day 2	19	*Trial 1*	33.2	11.4
		Trial 2	31.3	12.0
		Trial 3	30.3	12.7
Cx Extension Day 1	19	*Trial 1*	27.6	11.8
		Trial 2	27.0	12.5
		Trial 3	26.1	12.7
Cx Extension Day 2	19	*Trial 1*	26.8	11.4
		Trial 2	25.7	12.2
		Trial 3	25.2	13.1

Cx = cervical

TABLE 3. Intraclass correlation coefficient for cervical flexion and extension positions

	Averaged across days *ICC (lower limit 95% CI)*	**Trial 1 only across days** *ICC (lower limit 95% CI)*
Cx Flexion	0.96 (.90)	0.95 (.86)
Cx Extension	0.93 (.83)	0.95 (.87)

ICC = intraclass correlation coefficient; Cx = cervical

TABLE 4. Bland and Altman analysis—bias and limits of agreement for knee flexion angle in the slump and extended positions

			95% limits of agreement	
	Bias	**SD of bias**	**From**	**To**
Cx Flexion	–1.7	3.6	-8.8	5.4
Cx Flexion (*Trial 1)*	–0.9	3.4	–7.6	5.8
Cx Extension	–0.9	4.6	–10.0	8.2
Cx Extension (*Trial 1)*	–0.7	3.8	–8.2	6.8

Cx = cervical, SD = standard deviation

Fig. 4. Bland and Altman graphs of knee flexion angle difference from day 1-2 across the average angle for:

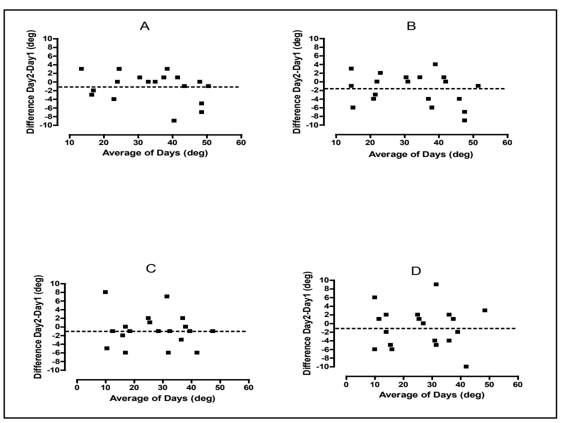
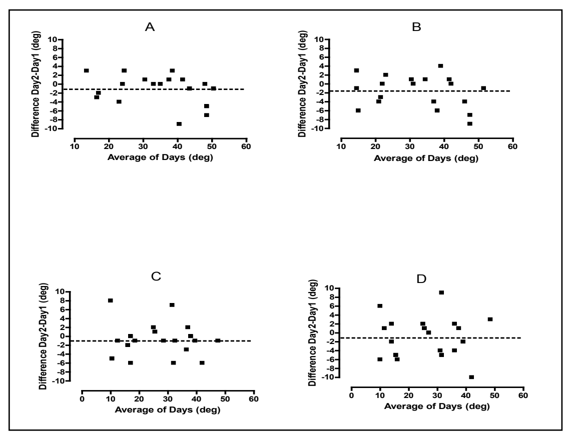


Fig 4.1 (A). (top left) Trial 1 in the cervical flexion position.

Fig. 4.2 (B). (bottom left) The average of the three trials in the cervical flexion position.



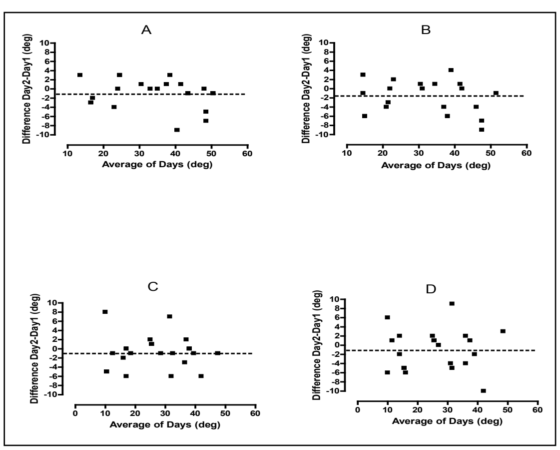
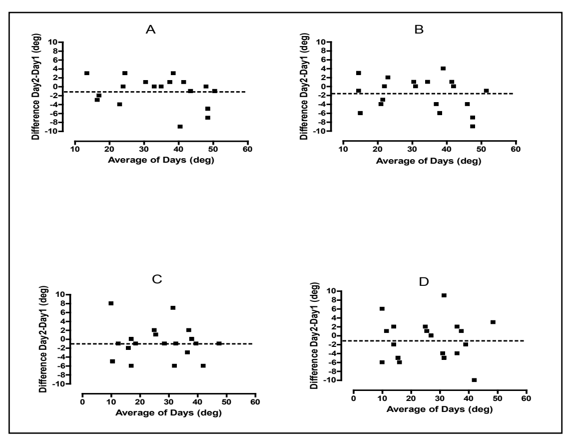


Fig. 4.3 (C). (top right) Trial 1 in the cervical extension position.

Fig. 4.4 (D). (bottom right) The average of the three trials in the cervical extension position.



Discussion

The goal of the study was to investigate whether knee extension AROM during a modified slump testing could be reliably measured across trials within one day and across days. The results indicated that this parameter was indeed reliable across days. This study showed that there was no significant difference ($P<0.05$) for knee extension AROM across days in this modified slump test position both with the neck flexed and extended. The ICC value both for the first trial and the mean of three trials across days for both test conditions exceeded 0.90 and was thereby above the recommended level for clinical tests[17]. These ICC values are comparable to those reported for the active knee extension test and KinCom® studies measuring knee extension ROM[18-20].

While these ICC values provide a measure of reliability, they do not allow the researcher or clinician to appreciate the magnitude of error in the units of measurement, in this case ROM. For this purpose, we also calculated the typical error and the limits of agreement and also provided the Bland and Altman plots. For the fully slumped and neck-extended positions averaged across trials, the typical error was 2.6° and 3.3°, respectively. For Trial 1 only, the typical errors were 2.4° and 2.7°, respectively. The Bland and Altman plots also showed that there was minimal bias in the joint angles across days and that the distribution of errors was random across the range of measured angles. Together with the narrow 95% limits of agreement, these findings provide further indication of a high degree of reliability in the measurement of knee angle in the modified slump test position.

It is worth noting that the current study showed an increase in knee extension AROM with a mean magnitude of 2° occurring during the course of the three trials of slump testing. Fidel et al[9] also observed an increase in ROM during repeated slump trials: they reported increases of 5.6° and 3.1° with the cervical spine in flexion and extension, respectively, following 10 repetitive knee extension movements. No other studies investigating knee extension ROM during the slump test[1,7-11] have reported on this phenomenon. Although there was a significant difference across trials, the mean magnitude of 2° was small and did not exceed the typical error calculated; therefore, its clinical importance is debatable. The mechanism behind the difference across trials probably reflects changes in viscoelasticity and stretch tolerance[21,22]. If anything, this finding indicates that researchers/clinicians should be consistent. If they do only one trial at day one, they should only do one trial at day two of testing; similarly if they do three trials on day one, then they should do three trials on subsequent days.

The methodology described in this study may be particularly useful for those clinicians with access to a dynamometer such as a Kincom. Its use allowed good fixation of the participants and enabled controlled knee extension to occur. Although not used in the current study, it would be possible for the clinician to use the dynamometer readings of knee angle rather than the electrogoniometer used here. Furthermore, from a clinical perspective, if the patient reaches full knee extension without the reproduction of symptoms or cannot tolerate the long sitting position, elevating the thigh while in the sitting position may be an additional or alternate way to increase the tension within the nervous system. Consistent with a treatment option suggested by George[23], Cleland et al[6] treated subjects with non-radicular low back pain with slump stretches in the long sitting position. Subjects then had neck flexion applied by the therapist. For patients who cannot tolerate this position, increasing hip flexion might be an intermediary step and these patients could then progress to the long sitting position as symptoms improve. For clinical researchers, this modified set-up for the test using the Kincom dynamometer and elevated thigh position may be useful in determining the mechanosensitivity of the nervous system.

Conclusion

This study examined the measurement error and the reliability of measurements within trials on a single day and across days of knee extension AROM in a modified slump test position involving increased hip flexion in asymptomatic subjects. The findings showed that there were no significant differences across a two-day interval for the full or neck-extended slump positions. The ICC values calculated for agreement in both positions tested across days were high and sufficient for clinical use. Typical error values were low and limits of agreement were narrow, indicating minimal measurement error. Across trials within the same day, a statistically significant difference was noted, but its implications seem limited, as its magnitude did not exceed the calculated typical error values. Further research into this test variation in symptomatic subjects is required, but this modified slump test holds potential value for clinical researchers interested in quantifying the mechanosensitivity of the nervous system. ■

REFERENCES

1. Maitland G. The slump test: Examination and treatment. *Aust J Physiother* 1985;31:215–219.
2. Elvey RL. Physical evaluation of the peripheral nervous system in disorders of pain and dysfunction. *J Hand Ther* 1997;10:122–129.
3. Butler DS. *The Sensitive Nervous System*. Adelaide, Australia: Noigroup Publications, 2000.
4. Coppieters M, Stappaerts K, Janssens K, Jull G. Reliability of detecting "onset of pain" and "submaximal pain" during neural provocation testing of the upper quadrant. *Physiother Res Int* 2002;7:146–156.
5. Phillip K, Lew P, Matyas T. The inter-tester reliability of the slump test. *Aust J Physiother* 1989;35:89–94.
6. Cleland J, Childs J, Palmer J, Eberhart S. Slump stretching in the management of non-radicular low back pain: A pilot clinical trial. *Man Ther* 2006;11:279–286.
7. Coppieters M, Kurz K, Mortensen TE, Richards NL, et al. The impact of neurodynamic testing on the perception of experimentally induced muscle pain. *Man Ther* 2005;10:52–60.
8. Herrington L. What is a normal neurogenic response to the slump test? In: *Conference Proceedings. International Federation of Orthopedic Manipulative Therapists' Conference.* Cape Town, South Africa: IFOMT, 2004.
9. Johnson E, Chiarello C. The slump test: The effects of head and lower extremity position on knee extension. *J Orthop Sports Phys Ther* 1997;26:310–317.
10. Laessoe U, Voigt M. Modification of stretch tolerance in a stooping position. *Scand J Med Sci Sports* 2004;14:239–244.
11. Yeung E, Jones M, Hall B. The response to the slump test in a group of female whiplash patients. *Aust J Physiother* 1997;43:245–252.
12. Fidel C, Martin E, Dankaerts W, Allison G, Hall T. Cervical spine sensitizing manoeuvres during the slump test. *J Manual Manipulative Ther* 1996;4:16–21.
13. Magnusson S, Simonsen E, Aagaard P, Gleim G, McHugh M, Kjaer M. Viscoelastic response to repeated static stretching in the human hamstring muscle. *Scand J Med Sci Sports*1995;5:342–347.
14. Hopkins W. Measures of reliability in sports medicine and science. *Sports Med* 2000;30:1–15.
15. Muller R, Buttner P. A critical discussion of intraclass correlation coefficients. *Stat Med* 1994;13:2465–2467.
16. Bland J, Altman D. Statistical methods for assessing agreement between two methods of clinical measurements. *Lancet* 1986;8:307–310.
17. Fleiss J. *Design and Analysis of Clinical Experiments*. New York, NY: John Wiley and Sons, 1986.
18. Gajdosik R. Effects of static stretching on the maximal length and resistance to passive stretch of short hamstring muscles. *J Orthop Sports Phys Ther* 1991;16:250–255.
19. Reid DA, McNair PJ. Passive force, angle and stiffness changes after stretching of hamstring muscles. *Med Sci Sports Exer* 2004;36:1944–1948.
20. Webright WG, Randolph BJ, Perrin DH. Comparison of non-ballistic active knee extension in neural slump position and static stretch techniques on hamstring flexibility. *J Orthop Sports Phys Ther* 1997;26:7–13.
21. Halbertsma, J, Ludwig N, Goeken M. Stretching exercises: Effect on passive extensibility and stiffness in short hamstrings of healthy subjects. *Arch Phys Med Rehabil* 1994;75:976–981.
22. McNair P, Dombroski E, Hewson D, Stanley S. Stretching at the ankle joint: Viscoelastic responses to holds and continuous passive motion. *Med Sci Sports Exer* 2001;33:354–358.
23. George S. Characteristics of patients with lower extremity symptoms treated with slump stretching: A case series. *J Orthop Sports Phys Ther* 2002;32:391–393.