Evaluating the Reliability of a Novel Neck-Strength Assessment Protocol for Healthy Adults Using Self-Generated Resistance with a Hand-Held Dynamometer

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ABSTRACT

Purpose: To evaluate the intra- and inter-session test–retest agreement of a novel neck-strength assessment protocol using a hand-held dynamometer. **Background:** A literature review found a lack of neck-strength assessment protocols that are both portable and reliable. Hand-held dynamometry is a portable and inexpensive method of assessing muscle strength, but it is not commonly used for neck-strength assessment. **Methods:** A hand-held dynamometer was used to evaluate neck strength in 30 healthy participants. The device measured maximum force in cervical flexion, extension, side flexion, side flexion with rotation, and pure rotation, using the ipsilateral hand to apply isometric resistance over 3 seconds. Three measurements were taken over 6–8 days. **Results:** Test–retest intra-class correlation coefficients (ICCs) showed high reliability, ranging from 0.94 to 0.97 for all tested directions from Trial 1 to Trial 2 (intra-session reliability, ICC [2,1], absolute). ICC values demonstrated good to high inter-session reliability, ranging from 0.87 to 0.95 for all tested directions from Trial 1 to Trial 3 (ICC [2,1], absolute). **Conclusion:** The results suggest that the five test positions of the neck and upper-quadrant strength assessment protocol can be performed using hand-held dynamometry with good to high reliability.

Key Words: muscle strength dynamometer; neck muscles; reproducibility of results.

RÉSUMÉ

Objectif : Évaluer la convergence test-retest intra et intersessionnelle d'un nouveau protocole d'évaluation de la force du cou au moyen d'un dynamomètre portatif. **Contexte :** Une recension des écrits a révélé un manque de protocoles d'évaluation de la force du cou à la fois portables et fiables. La dynamométrie manuelle est une méthode portable et peu coûteuse d'évaluation de la force musculaire, mais elle n'est pas utilisée couramment pour évaluer la force du cou. **Méthodes :** On a utilisé un dynamomètre portatif pour évaluer la force du cou chez 30 participants en bonne santé. On a mesuré la force maximale en flexion cervicale, extension, flexion latérale, flexion latérale avec rotation et rotation pure en utilisant la main ipsilatérale pour appliquer une résistance isométrique pendant 3 secondes. On a pris trois mesures en 6 à 8 jours. **Résultats :** Les coefficients de corrélation intraclasse (CCI) de test-retest ont révélé une grande fiabilité variant de 0,94 à 0,97 dans le cas de toutes les directions vérifiées de l'essai 1 à l'essai 2 (fiabilité intrasessionnelle) [CCI (2,1), absolu]. Les valeurs CCI ont démontré une fiabilité intersessionnelle variant de bonne à élevée, variant de 0,87 à 0,95 dans le cas de toutes les directions mises à l'épreuve de l'essai 1 à l'essai 3 [CCI (2,1), absolu]. **Conclusion :** Les résultats indiquent qu'il est possible d'appliquer le protocole d'évaluation de la force du cou et du quadrant supérieur par les cinq positions d'essai en utilisant la dynamométrie manuelle, et qu'il produit une fiabilité variant de bonne à élevée.

Assessing muscle strength is a fundamental part of patient care for physiotherapists. The value of a reliable tool to assess muscle strength has been emphasized, both to determine functional impairment and to develop appropriate therapeutic interventions. A review of the literature has shown a lack of neck-strength assessment protocols that evaluate side flexion and rotation along with flexion and extension and that are both portable and reliable.¹ Currently, fixed-frame dynamometry is the most widely recognized method of reliably assessing isometric neck strength. This method uses a large wall-

or frame-mounted machine with a fixed base, which are expensive and generally impractical for most clinical settings.² In contrast, hand-held dynamometers are portable, relatively inexpensive, and easy to use. Hand-held dynamometry has been shown to be an objective and reliable measure of strength for several different movements of the extremities in healthy adults.^{3–6} Normative reference values have also been determined for these various movements. Although previous research has used hand-held dynamometry to assess neck strength, a review article¹ noted a lack of consistency in the methodology and

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description of the testing procedure and a lack of normative values. The number of articles reporting comprehensive strength measurements in all planes of the neck is also limited. Of particular note is the difficulty in clinical assessment of neck rotation strength,⁷ which has traditionally been limited to clinically inaccessible lab-based measurement equipment.

One of the challenges of using hand-held dynamometry to assess muscle strength is that results are influenced by the strength of the tester, which may compromise reliability.⁸ If the tester is significantly weaker than the person being tested, the results will only be as high as the force the tester is capable of generating; even if the tester is able to generate sufficient resistance, the stronger the person being tested, the more difficult it becomes for the tester to generate this resistance along the proper vector in a consistent and safe manner, which further decreases the reliability of the results. A person may also be apprehensive about providing full resistance against someone pushing on the side of his or her head.

Our study therefore provides a standardized and functional isometric strength-testing protocol that allows assessment of strength in all planes of the neck, including rotation, using self-generated resistance and a hand-held dynamometer. Given that the resistance is self-generated through the upper kinetic chain (including the shoulder, elbow, wrist, and hand), the test inherently assesses the neck up to the strength limit of the upper kinetic chain. We believe that simultaneous functional assessment of strength about the neck and upper kinetic chain could function as a useful clinical evaluation for people with neck pain and may have potential as a prognostic tool after neck injuries.

The purpose of this study is to evaluate the within-session (10 min) and between-session (6–8 days) test-retest agreement of a novel neck-strength and upper kinetic chain assessment protocol using a hand-held dynamometer in a healthy adult population.

METHODS

Participants

Participants were recruited for this study from the Health and Rehabilitation Sciences programme and the Master of Physical Therapy programme at Western University, as well as from the university community through word of mouth and electronic recruitment (letter of information posting on a Facebook class page; class group email). Volunteers were eligible for inclusion if they were healthy adults aged between 18 and 60 years; able to speak and understand English at a conversational level; free of neck, shoulder, elbow, and wrist pain (self-reported); and able to pass the cervical screening protocol (see Appendix 1 online) with no positive results.

Potential participants were excluded if they had reports of neck pain in the past 3 months for which they

Table 1 Participant Characteristics

Sex	No.	Mean (SD) age, y	Age range, y
Men	14	25.29 (5.41)	19–37
Women	16	23.94 (1.29)	23–28

had sought treatment; any history of previous neck surgeries or rheumatoid conditions; known neck instabilities; any current neck pain, whether actively receiving treatment or not; or any current report of injury or pain in the shoulder, elbow, wrist, or temporomandibular joints. After screening, 30 of 32 consecutive participants were included in the study, for a total of 14 men and 16 women aged 19 to 37 years (see Table 1). Informed and documented consent was obtained from all participants. The project was approved by the Western University Research Ethics Board for Health Sciences Research Involving Human Subjects.

Testing protocol

After providing written informed consent, potentially eligible participants were screened by a group of four physiotherapy student examiners (in their 2nd year of the MPT programme), who used a screening protocol to identify any gross cervical dysfunction (decreased active range of motion in any of the three planes of movement, pain during the four quadrants combined planes test, pain with Spurling's cervical compression test).⁹ Participants with a negative screening protocol—that is, those who had grossly good neck health and no exclusion criteria reported—proceeded to perform a standardized strength-testing protocol under the guidance of one of the physiotherapy student examiners (see Appendix 2 online). Because each participant provided his or her own resistance to produce the test values recorded, the four physiotherapy student examiners who administered the protocol were considered to be interchangeable. A standardized, calibrated digital hand-held dynamometer (MicroFET 2 force gauge, Hoggan Health Industries, Salt Lake City, Utah) was used to evaluate maximum force generated in kilogram-force (kgf) for each plane. The MicroFET 2 is a common instrument in physiotherapy clinics and ergonomic assessments and has been shown to be valid for muscle force measurement in other joints, including the shoulder, hip, and knee.^{3–6} It consists of a plastic unit housing a force gauge and a soft, cushioned pad that is applied to the long bone of the joint to be tested, as shown in Figure 1.

To measure neck strength, participants were seated comfortably on a stool with their feet flat on the floor. They sat with no back or arm rests to prevent bracing the trunk against a chair. One of the four physiotherapy students then guided each participant through the testing procedure. For calibration purposes, the isometric peak force voluntarily and maximally generated with

Figure 1 MicroFET 2 dynamometer.

hands in front of the body and palms together during horizontal adduction was recorded (see Figure 2A); this value was used to determine the maximum force the participant could generate with the upper extremities and to ensure that he or she had the ability to generate sufficient force to overcome the tested neck movements. After a 3-minute rest, isometric neck strength was tested in eight positions: forward flexion (with resistance applied to the forehead with both hands); extension (with resistance applied with both hands to the occiput); right and left side flexion (with resistance applied with the ipsilateral hand just above the ear); right and left side flexion and rotation (with resistance applied with the ipsilateral hand to the temple); and right and left pure rotation (with resistance applied with the ipsilateral hand along the jaw near the chin with jaw clenched), as shown in Figures 2B–2F (see also Appendix 2 online).

All test positions were performed with the neck in neutral; proper positioning was augmented by the use of a mirror. In each “make” test position, the participants were instructed to build up to their maximum cervical muscle force over 3 seconds, maintaining the static neck position (a “make” test is an isometric strength test in which the tester matches the maximum resistance produced by the testee, maintaining the length of the muscle, and a “break” test is an eccentric test in which the tester exceeds the maximum resistance produced by the testee and causes lengthening of the muscle). The peak force produced in Trial 1 for each test position was recorded. Participants could stop the test at any point during the assessment and were instructed to stop should any pain or dizziness arise.

On completing the protocol, participants rested comfortably in a supportive chair for 10 minutes. The neck–upper-quadrant protocol was then repeated in all test positions (Trial 2) to evaluate intra-session reliability. This initial visit took approximately 25–30 minutes to complete, including screening and two trials of the strength-testing protocol. Finally, participants returned to the lab after 6–8 days for a second visit to determine inter-session reliability. This second visit was no longer than 10 minutes and consisted of a single trial using the same data-collection process as in the first testing session (Trial 3).

Data analysis

The statistic of interest was the intra-class correlation coefficient type 2,1 (ICC [2,1], absolute). We chose this statistic because it assumes the same group of raters (participants themselves) randomly sampled from the population of possible raters (random effects) and allows for generalizability beyond this study for other participants using themselves as raters. For clinical and research purposes, we expected an ICC (2,1), absolute, of at least 0.8, with 95% confidence that the true value is greater than 0.4.¹⁰ Using these values and a formula presented by Walter and colleagues,¹¹ we calculated that a sample size of 27 would provide 80% power for detecting a true difference between 0.8 and 0.4 where one exists. Therefore, we set a target sample size of 30 to ensure sufficient power for our study. To determine the level of reliability, we adapted the scheme previously reported by Meyers and Blesh,¹² who defined the degrees of reliability based on ICC (2,1), absolute, values as follows: 0.90–0.99, high reliability; 0.80–0.89, good reliability; 0.70–0.79, fair reliability; and ≤ 0.69 , poor reliability.

We also calculated the standard error of measurement (SEM) and the minimal detectable change (MDC). The SEM is used to determine the confidence level around an observed score within which the true score lies; a 95% CI around an observed score is ± 2 SEM. The MDC is the minimum change in score that must be observed before one can be 95% confident that a true change has occurred. Bland–Altman plots with 95% limits of agreement were produced for the various test positions across trials.

RESULTS

All participants completed the full test procedure; none reported experiencing any discomfort during or after testing.

As reported in Tables 2 and 3, the SEM with 95% CI for the various test positions ranged from 0.96 to 1.71 kgf for Trial 1 and Trial 2 (intra-session reliability) and from 1.29 to 2.04 kgf for Trial 1 and Trial 3 (inter-session reliability). The MDC ranged from 2.66 to 4.72 kgf between Trial 1 and Trial 2 and from 3.38 to 5.64 kgf between Trial 2 and Trial 3.

Figure 2 Test positions: Calibration (A), forward flexion (B), extension (C), side flexion (D), side flexion with rotation (E), pure rotation (F).

Table 2 Intra-session Retest Reliability of Neck Strength Using a Hand-Held Dynamometer in a Healthy Population

Test position	Trial 1 test score, kgf, mean (SD)	Trial 2 test score, kgf, mean (SD)	Mean difference, kgf*	SEM	MDC	ICC (95% CI)
Forward flexion	14.20 (6.52)	14.71 (5.91)	0.51	1.13	3.13	0.97 (0.93–0.98)
Extension	23.72 (9.10)	24.02 (9.83)	0.30	1.71	4.72	0.97 (0.93–0.98)
Pure side flexion, left	14.86 (6.39)	14.91 (6.25)	0.05	1.11	3.07	0.97 (0.93–0.99)
Pure side flexion, right	14.84 (6.58)	15.03 (6.47)	0.19	1.32	3.65	0.96 (0.91–0.98)
Side flexion with rotation, left	10.75 (4.32)	11.54 (4.67)	0.79	1.14	3.17	0.94 (0.83–0.97)
Side flexion with rotation, right	11.39 (4.80)	11.60 (4.76)	0.20	0.96	2.66	0.96 (0.92–0.98)
Pure rotation, left	12.60 (5.22)	12.92 (5.15)	0.32	1.28	3.54	0.94 (0.87–0.97)
Pure rotation, right	12.60 (5.87)	12.99 (5.46)	0.39	1.31	3.64	0.95 (0.89–0.97)

*Mean difference = Trial 2 – Trial 1 strength score.

kgf = kilogram-force; MDC = minimal detectable change; ICC = intra-class coefficient.

Table 3 Inter-session Retest Reliability of Neck Strength Using a Hand-Held Dynamometer in a Healthy Population

Test position	Trial 1 test score, kgf, mean (SD)	Trial 3 test score, kgf, mean (SD)	Mean difference, kgf*	SEM	MDC	ICC (2, 1)	
						Absolute	95% CI
Forward flexion	14.20 (6.52)	15.63 (6.60)	1.43	1.86	5.17	.92	.77–.97
Extension	23.72 (9.10)	24.81 (8.76)	1.08	2.04	5.64	.95	.88–.97
Pure side flexion, left	14.86 (6.39)	15.66 (6.21)	0.80	1.43	3.38	.95	.89–.98
Pure side flexion, right	14.84 (6.58)	15.54 (6.28)	0.70	1.47	4.08	.95	.90–.98
Side flexion with rotation, left	10.75 (4.32)	12.07 (4.89)	1.32	1.55	4.29	.90	.61–.97
Side flexion with rotation, right	11.39 (4.80)	12.16 (4.86)	0.77	1.29	3.57	.93	.85–.97
Pure rotation, left	12.60 (5.22)	13.56 (5.48)	0.97	1.98	5.48	.87	.74–.94
Pure rotation, right	12.60 (5.87)	13.67 (5.39)	1.08	1.76	4.88	.91	.79–.96

*Mean difference equals Trial 3 – Trial 1 strength score.

kgf = kilogram-force; MDC = minimal detectable change; ICC = intra-class coefficient.

Table 4 Mean Strength Values by Gender for Trial 1

Test positions	Strength, kgf, mean (95% CI)		Strength values for women as % of strength values for men
	Men	Women	
Forward flexion	42.6 (35.3–49.9)	21.4 (18.1–24.7)	50.2
Extension	67.7 (56.8–78.6)	38.9 (34.9–42.8)	57.5
Side flexion, left	44.4 (38.1–50.7)	22.5 (19.1–25.9)	50.7
Side flexion, right	44.1 (36.4–51.9)	22.7 (20.2–25.3)	51.5
Side flexion/rotation, left	31.4 (27.0–35.8)	17.0 (14.5–19.4)	54.1
Side flexion/rotation, right	33.0 (27.3–38.8)	18.2 (15.7–20.6)	55.2
Pure rotation, left	35.0 (28.3–41.7)	21.4 (17.7–25.1)	61.1
Pure rotation, right	36.1 (28.4–41.7)	20.5 (16.9–24.0)	56.8
Ratio of flexion to extension strength	0.64 (0.55–0.73)	0.55 (0.48–0.62)	

L = left; R = right.

ICCs and 95% CIs for all isometric neck strength measurements (five test positions) for intra-session and inter-session are presented in Tables 2 and 3, respectively. In this study, ICCs ranged from 0.94 to 0.97 for all tested directions for Trial 1 to Trial 2 (ICC [2,1], absolute), demonstrating that intra-session test–retest reliability was high. The ICC values ranged from 0.87 to 0.95 for all tested directions for Trial 1 to Trial 3 (ICC [2,1], absolute), indicating that inter-session reliability was good to high. These results suggest a good to high level

of both intra- and inter-session reliability for the isometric neck strength protocol used in our study.

Average neck strength in Trial 1 ranged from 31.4 to 67.7 kgf for men and from 17.0 to 38.9 kgf for women; women's mean strength ranged from 50.2% to 61.1% of men's. The mean flexion–extension ratio in Trial 1 was 0.64 for men and 0.55 for women (see Table 4). Although Bland–Altman plots are best used to compare different measurement tools, they can also serve to provide a visual description of the error and variability existing in the

same measurement tool at different assessment times (see Appendix 3 online).

DISCUSSION

Our results are consistent with reliability findings from studies using large fixed-frame dynamometers to assess isometric neck strength.^{13–17} For instance, Peolsson and Öberg¹³ examined the intra- and inter-tester reliability of isometric neck strength in 30 healthy participants using a David Back Clinic (DBC 140), a large fixed-frame dynamometer, and found high ICCs (ranging from 0.85 to 0.97) for the tested movements of flexion, extension, and lateral flexion. Chiu and Lo¹⁴ also studied the reliability of isometric neck strength using another large fixed-frame dynamometer, the Multi Cervical Rehabilitation Unit. Their results demonstrated that intra-session test–retest reliability was high for all tested positions of neck flexion (ICC = 0.98), neck extension (ICC = 0.98), left side flexion (ICC = 0.97), and right side flexion (ICC = 0.95), all values very similar to those found in our study (flexion = 0.97, extension = 0.97, left side flexion = 0.97, right side flexion = 0.96). Comparing our findings with those of Peolsson and Öberg¹³ and Chiu and Lo¹⁴ illustrates that the same level of reliability achieved with large, expensive fixed-frame dynamometry can be achieved using the protocol presented here and the more cost-effective MicroFET 2.

Although evaluating validity was not a goal of our study, it is notable that we found ratios of flexion to extension strength and comparative strength of men and women that are in line with those found in studies using fixed-frame dynamometry. Using various fixed-frame dynamometry systems, prior studies have found women to be 40%–70%^{7,13,15–17} as strong as men; our study found a range of 50.2%–57.5% for the same movements. In those fixed-frame dynamometry studies that reported the flexion-to-extension ratio, values ranged from 0.42 to 0.78;^{7,13,15–17} our study found ratios of 0.55 for women and 0.64 for men. Although the values in our study are consistent with those of fixed-frame dynamometry, further studies are needed to formally test the validity of the protocol presented here.

Our protocol avoids a known shortfall of using hand-held dynamometry—the influence of the tester’s strength on the reliability of the test⁸—by having the person being tested provide the resistance. It has also been suggested that measuring neck strength using a break test in people with neck pain is difficult because participants fear evoking pain during the assessment.¹ Our study suggests that assessing neck strength using a closed-kinetic-chain make test is likely to reduce participants’ fears during maximal strength testing because the participant’s own hand is providing the resistance to neck movement. This consideration will be especially important when assessing individuals with neck dysfunction. Our protocol allows participants to stop quickly at any time if they experience

pain or discomfort without first informing the therapist, which makes this test inherently safer and easier to administer.

Our study has several limitations. First, our convenience sample of 30 participants had a very narrow age range (19–37 years for men, and only 23–28 years for women); future studies should include a sample with a larger age range. Second, the study assessed a healthy cohort of participants, which limits its applicability to a population with pathology. We intend to continue collecting normative values for comparison purposes in future clinical studies. Furthermore, future directions will investigate this protocol as a meaningful evaluation procedure for people with neck pain and as a prognostic tool after neck injuries.

The proposed assessment protocol also has some limitations. To perform the test, the participant must have sufficient range of motion of the shoulder, elbow, and wrist; the protocol cannot be used effectively if any of these are lacking. The participant must also be able to generate sufficient force to overcome the tested neck movement. This limitation is addressed by having participants perform a calibration test consisting of compressing the dynamometer between their two hands, without interlocking their fingers, in front of their head. For example, if the participant is able to generate 50 kgf for the calibration test and only 18 kgf as a maximum for the side flexion and rotation components, then it is arguably safe to say that the strength of the side flexion or rotation movement is the value found with that test. If, however, the calibration value is 18 kgf and the side flexion and or rotation test also measures approximately 18 kgf, then it is possible that the maximum force of those movements was not determined because the participant may not have been able to generate enough force to overcome his or her own neck strength.

CONCLUSION

Our study provides a standardized protocol for assessing neck strength in all planes using a MicroFET 2. The results suggest that all five test positions of the neck and upper-quadrant strength assessment procedure can be performed using hand-held dynamometry with good to high reliability. Moreover, self-generated resistance using a MicroFET 2 to measure neck strength could be a reliable evaluation procedure for a healthy population.

KEY MESSAGES

What is already known on this topic

Reliable methods of assessing neck strength currently exist, but these methods have several limitations. Many of them require large, expensive fixed-frame dynamometry systems that are not practical for use in most clinics. Protocols that use portable hand-held dynamometry lack standardization and depend on the therapist’s being stronger than the patient. They also commonly rely on

break tests that can cause apprehension, pain, and safety concerns for the participant or patient.

What this study adds

This study describes a novel method for assessing neck strength that is safe, reliable, cost effective, and independent of therapist strength. It also provides a standardized method for assessing all neck movements, including flexion, extension, side flexion, and rotation.

REFERENCES

1. de Koning CH, van den Heuvel SP, Staal JB, et al. Clinimetric evaluation of methods to measure muscle functioning in patients with non-specific neck pain: a systematic review. *BMC Musculoskelet Disord.* 2008;9(1):142. <http://dx.doi.org/10.1186/1471-2474-9-142>. Medline:18928568
2. Dvir Z, Prushansky T. Cervical muscles strength testing: methods and clinical implications. *J Manipulative Physiol Ther.* 2008;31(7):518–24. <http://dx.doi.org/10.1016/j.jmpt.2008.08.008>. Medline:18804002
3. Kelln BM, McKeon PO, Gontkof LM, et al. Hand-held dynamometry: reliability of lower extremity muscle testing in healthy, physically active, young adults. *J Sport Rehabil.* 2008;17(2):160–70. Medline:18515915
4. Kolber MJ, Beekhuizen K, Cheng M-SS, et al. The reliability of hand-held dynamometry in measuring isometric strength of the shoulder internal and external rotator musculature using a stabilization device. *Physiother Theory Pract.* 2007;23(2):119–24. <http://dx.doi.org/10.1080/09593980701213032>. Medline:17530541
5. Van Meeteren J, Mens J, Stam HJ. Reliability of strength measurement of the hip with a hand-held dynamometer in healthy women. *European J Phys Med Rehabil.* 1997;7(1):17–20.
6. Schaubert KL, Bohannon RW. Reliability and validity of three strength measures obtained from community-dwelling elderly persons. *J Strength Cond Res.* 2005;19(3):717–20. Medline:16095431
7. Strimpakos N, Sakellari V, Giotfos G, et al. Intratester and intertester reliability of neck isometric dynamometry. *Arch Phys Med Rehabil.* 2004;85(8):1309–16. <http://dx.doi.org/10.1016/j.apmr.2003.08.104>. Medline:15295758
8. Wikholm JB, Bohannon RW. Hand-held dynamometer measurements: tester strength makes a difference. *J Orthop Sports Phys Ther.* 1991;13(4):191–8. <http://dx.doi.org/10.2519/jospt.1991.13.4.191>. Medline:18796845
9. Tong HC, Haig AJ, Yamakawa K. The Spurling test and cervical radiculopathy. *Spine.* 2002;27(2):156–9. <http://dx.doi.org/10.1097/00007632-200201150-00007>. Medline:11805661
10. 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
11. Walter SD, Eliasziw M, Donner A. Sample size and optimal designs for reliability studies. *Stat Med.* 1998;17(1):101–10. [http://dx.doi.org/10.1002/\(SICI\)1097-0258\(19980115\)17:1<101::AID-SIM727>3.0.CO;2-E](http://dx.doi.org/10.1002/(SICI)1097-0258(19980115)17:1<101::AID-SIM727>3.0.CO;2-E). Medline:9463853
12. Meyers CR, Blesh TE. Measurement in physical education. New York: Ronald Press; 1974.
13. Peolsson A, Oberg B, Hedlund R. Intra- and inter-tester reliability and reference values for isometric neck strength. *Physiother Res Int.* 2001;6(1):15–26. <http://dx.doi.org/10.1002/pri.210>. Medline:11379253
14. Chiu TTW, Lo SK. Evaluation of cervical range of motion and isometric neck muscle strength: reliability and validity. *Clin Rehabil.* 2002;16(8):851–8. <http://dx.doi.org/10.1191/0269215502cr550oa>. Medline:12501947
15. Garcés GL, Medina D, Milutinovic L, et al. Normative database of isometric cervical strength in a healthy population. *Med Sci Sports Exerc.* 2002;34(3):464–70. <http://dx.doi.org/10.1097/00005768-200203000-00013>. Medline:11880811
16. Vasavada AN, Li S, Delp SL. Three-dimensional isometric strength of neck muscles in humans. *Spine.* 2001;26(17):1904–9. <http://dx.doi.org/10.1097/00007632-200109010-00018>. Medline:11568704
17. Cagnie B, Cools A, De Loose V, et al. Differences in isometric neck muscle strength between healthy controls and women with chronic neck pain: the use of a reliable measurement. *Arch Phys Med Rehabil.* 2007;88(11):1441–5. <http://dx.doi.org/10.1016/j.apmr.2007.06.776>. Medline:17964885