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Intraexaminer comparison of applied kinesiology manual muscle testing of varying durations: a pilot study

Katharine M. Conable DC*

Associate Professor, Chiropractic Division, Logan College of Chiropractic, St Louis, MO 63132

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Abstract

Objective: The purpose of this study is to investigate the difference in results (strong/facilitated vs weak/functionally inhibited) between short (1 second) and long (3 seconds) manual muscle tests (MMTs) on the same subject and to pilot the use of thin-film force transducers for characterizing the parameters of MMT and for measuring maximum voluntary isometric contraction (MVIC).

Method: Forty-four healthy chiropractic students were tested. A thin-film force transducer recorded force over time during MVIC of the middle deltoid and 1- and 3-second MMTs of the same subjects. The MMTs were graded as strong (able to resist the testing pressure) or weak (unable to resist testing pressure, breaking away).

Results: Forty-two short tests were strong, and 2 were weak. Thirty-nine long tests were strong, and 5 were weak. κ (0.54) showed fair agreement for results between short and long tests. Peak force in both short and long weak tests was higher than that in strong tests when expressed as a proportion of maximum contraction. All manual tests used less force than MVICs.

Conclusions: This study demonstrated that a study of this nature is feasible. Longer test durations demonstrate some muscle weaknesses that are not evident on 1-second MMTs. Thin-film transducers show promise for recording MMT parameters for research purposes.

Introduction

Applied kinesiologists test muscles before and after challenges and treatments, and may make clinical judgments based on immediate changes in muscle tests.[1] Muscles are tested according to similar methods described by Kendall et al[2] from a contracted position with pressure toward lengthening. If the subject can maintain the position against gradually increasing pressure, it is graded as "facilitated" or "strong" (grade 5). If the muscle weakens during the procedure, the muscle is rated as "inhibited" or "weak" (grade 4 or less). Applied kinesiology (AK) authors suggest that manual muscle testing (MMT) measures a complex proprioceptive response to changing pressure, rather than strength of the muscle itself.[1,3] The range of parameters that yield similar results on this binary evaluation is not currently known. This information is important in training accurate muscle testers and in evaluating the reliability and

* Corresponding author. Chiropractic Division, Logan College of Chiropractic, 608 No. McKnight Rd, St Louis, MO 63132. Tel.: +1 314 991 5655; fax: +1 314 991 4872.
E-mail address: katharine.conable@logan.edu.

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validity of other AK procedures based on muscle responses to various stimuli and challenges.

The physiotherapy literature distinguishes between "make" or "active strength" and "break" or "passive strength" testing both in MMT and in handheld dynamometry. In both styles, the muscle is tested relatively isometrically, either near its most shortened position or in the middle of its range of motion. In break testing, there is also eccentric lengthening as the muscle breaks away. Both differ from isokinetic testing, such as the Cybex,[4] which tests the muscle through an entire range of motion at a constant speed.

Active or "make" tests are similar to maximum isometric voluntary contraction tests—the subject presses against a fixed dynamometer, a strap with a force transducer is used, or the examiner acts as a fixed point.[4,5] Given intact neurologic control, the subject's own initiative and muscle size determine the maximum force generated. In contrast, in break tests, the subject resists the examiner's increasing pressure until the muscle breaks away. This requires more complex proprioception than simply pressing against a fixed resistance. The subject must continually adjust muscular output to match the examiner's pressure. Breaking strength testing is frequently cited as yielding higher peak force measurements than make tests. If the breaking force of a muscle is to be measured with a dynamometer on each test, the examiner must be stronger than the subject.[5] The key distinction between "make" and "break" in the physiotherapy literature is whether the resistance the tested muscle contracts against is constant at a fixed location or gradually increasing and mobile. This distinction might be purely academic except for the likelihood that the 2 styles to some degree monitor different aspects of neuromuscular control.

Comparison of the results of measures of muscle force under various conditions is complicated by the wide range in size and fitness between subjects. Therefore, it is useful to normalize results of dynamometry by comparison to maximum contraction for each subject.[6] This has not been done in previous AK studies.

Maximum voluntary isometric contraction (MVIC) is tested, by definition, as a "make" or "active" contraction test. The subject pushes against a relatively stationary force-recording device that offers stable resistance. Methods for measuring MVIC are described in many studies. Some use strain gauges, and others have the subject press directly against some form of force transducer.[7-10]

In a study of normative values for MVIC in healthy subjects, Meldrum et al[11] describe the method for measuring MVIC. They summarize references comparing MVIC and MMT, concluding that, generally, MVIC shows better sensitivity than does MMT for small changes in quantitative muscle strength in the context of monitoring patients with neuromuscular disease. Manual muscle test grading on a 5-point numerical scale does not allow for the fine objective gradations that can be done when measuring units of force. A muscle may fall within one grade at a range of forces, so small interval changes may be missed. These concerns are important for evaluation of progress or deterioration in a patient in rehabilitation or with neuromuscular pathology. Maximum voluntary isometric contraction testing is appropriate to test the size of the muscle itself or the changes in muscle in neurologic disease or recovery. It is equipment intensive and not easily adapted to clinical practice or to measuring rapid changes in muscle function over the short term.

On especially strong muscles and for weaker testers, it is possible that clinicians may miss small short-term changes in strength with AK MMT as well.

Schmitt[12] observed that subtle differences in timing seemed to yield different results in AK MMT. He described a "doctor-initiated" test in which the subject is asked to resist the doctor's gradually increasing force. "Patient-initiated" testing begins in the same position, but the patient is asked to push against the examiner's hand as hard as possible. This test style usually includes verbal encouragement to continue to push. In both tests, the examiner attempts to break the patient's contraction, the difference being timing. Schmitt postulated that the timing differences accessed different neurologic pathways. This model is similar but not identical to the make/break contrast.

Conable et al[13] were unable to demonstrate a consistent difference in whether the patient's or the examiner's muscle contraction began first when 41 experienced AK testers attempted to perform both patient-started and doctor-started muscle tests of the middle deltoid. This study found that the mean duration of AK muscle testing was 1.3 seconds (range, .325-3.5 seconds). There was a suggestion of a bimodal distribution of durations above and below about 1.5 seconds as examiners attempted to execute different styles of muscle tests. This led to the question of whether the difference Schmitt observed was a matter of duration rather than whose contraction began first.

This is important in that at least one study that purports to compare reliability of these 2 styles of muscle testing did not report duration. Hsieh and Phillips[14] did a reliability study with a computerized dynamometer comparing doctor-initiated and patient-initiated testing of 3 muscles by 3 testers over 2 sessions on 2 separate groups of 15 subjects. The authors concluded that patient-initiated testing was more reliable than doctor-initiated testing with this instrument. However, when the details of this study are examined, problems with this conclusion are revealed. Only peak force was recorded, rather than a continuous recording of force over time, making it impossible to determine the actual timing of each method. Because the examiners were free to stop the "doctor-initiated" test whenever they were satisfied that the muscle had "locked" or "broken away," it is unsurprising that these tests demonstrated quite a wide variation in peak force. The "patient-initiated" tests required the examiner to maintain pressure until an apparent maximum was achieved. It seems likely that this point would be more similar tester to tester and test to test. Subjects were tested by one or the other style of testing, not both, making comparison between styles problematic. This illustrates the need to better define the parameters of muscle tests used in AK research.

Manual muscle testing in AK clinical practice uses direct hand contact with the subject. The interposition of an instrument for research alters the quality of the muscle test and the delicacy of the examiner's perception. The present study piloted the use of a thin-film force transducer to record MMT. Similar sensors have been used in research on prosthetics, ergonomics, and physical medicine.[15,16]

This study compared results (strong/weak) between short (1 second) and long (3 seconds) MMTs of the same subject. The null hypothesis was good agreement between long- and short-duration muscle tests, in other words, that the duration of the test would not influence the outcome. The research hypothesis is that the 2 conditions are at least partially independent of each other and so would demonstrate a low κ.

Secondarily, this study compared peak force of the MVIC tests between strong and weak tests and peak force of MMTs between strong and weak tests in absolute terms and as a percentage of estimated maximum voluntary contraction to further define the objective differences between the states applied kinesiologists refer to as "strong" and "weak."

Methods

The author, an applied kinesiologist with more than 30 years in the practice and teaching of AK, examined 44 chiropractic students (23 men, 21 women) with a mean age of 26 years (range, 20-54). Subjects were screened for major injuries or physical conditions preventing testing the middle deltoid. No volunteers were excluded. Informed consent was obtained before testing. The study was approved by the Institutional Review Board of Logan College of Chiropractic and the Human Research Ethics Committee of Royal Melbourne Institute of Technology (RMIT) University, Bundoora, Australia.

A 3/8-in–diameter Tekscan (Tekscan, South Boston, MA) Flexiforce 1-lb sensor was connected to a BioPac MP150 (BioPac Systems, Inc, Goleta, CA) modular physiology recording system with a DA100B amplifier (BioPac Systems, Inc) via a custom interface manufactured by BioPac Systems, Inc. The amplifier was set to load the sensor with .2 V, allowing the reading of a wide range of forces. The sensor was calibrated using a 5-lb weight and the BioPac system's calibration function. The sensor was attached to the subject's arm approximately 2 in proximal to the elbow over the humerus (Figs 1 and 2).

All subjects were tested in 3 ways, including MVIC against a strap, MMT for 1 second, and MMT for 3 seconds. All subjects performed the MVIC contractions and then were manually tested. Subjects were assigned randomly by toss of a die to have the long manual test or the short manual test first. Die toss was done in advance for each subject number. Subject numbers where the toss was even had the short test first. Where the toss was odd, the long test was first.

Estimation of MVIC

The seated subject's arm was held at 90° abduction with the elbow at 90° of flexion and forearm parallel to the floor. A strap attached to the subject's chair was adjusted to allow the subject to abduct the shoulder to 90° (Fig 3). Neither subject nor examiner could see the computer tracing during tests. The subject was asked to push up against the strap as hard as possible until told to stop (5-10 seconds). Verbal encouragement was given throughout. The subject rested for 10 seconds, and the MVIC was repeated. The greatest force recorded was used as an estimate of the MVIC.

Manual muscle tests

After a 10-second rest, the examiner manually tested the middle deltoid (Fig 4). Short (1 second) and long (3 seconds) conditions were each tested 3 times in a row. Half the subjects had the short manual test first and half had the long manual test first according to randomization of subject numbers. Tests

Fig 1. Sensor placement.

Fig 2. Sensor and strap for measurement of MVIC.

were timed visually with the clock positioned so the subject could not see it. A 5-second rest was given between tests. The examiner recorded the result (strong/facilitated or weak/inhibited). No warm-up was used to approximate the manner in which MMT is done in clinical practice.

The .44-in^2 sensor covered only a fraction of the area of contact between the examiner's hand and the subject's arm (approximately 1 in^2) and the area of contact of the strap during MVIC, (2-3 in^2). No precise comparison of these measures is possible. Relative areas covered were similar for different subjects, enabling relative comparisons.

The following parameters were recorded: estimate of MVIC (pound), result of the MMT (strong/facilitated vs weak/inhibited), duration of manual test, peak force of manual test (pound), and peak force as a percentage of MVIC. Data tracings were marked using AcqKnowledge software (BioPac Systems, Inc) supplied with the BioPac system. Results were analyzed with Statview 5.0 (SAS Institute Inc, Cary, NC).

Fig 3. Measurement of MVIC.

Fig 4. Manual muscle test.

Results

Force results represent a fraction of the total force exerted by the patient, as the sensor only registered a part of the contact area of the strap for MVIC and a part of the examiner's hand contact for muscle testing.

As seen in Table 1, maximum contraction tests averaged 7.16 seconds. Short tests averaged 1.09 seconds. The intended duration for the long condition was 3 seconds; however, long tests averaged only 2.34 seconds. Long tests averaged significantly higher peak force than short tests in absolute terms and as a proportion of MVIC (Tables 2 and 3).

Strong vs weak tests

Weak and strong tests were of similar durations in both the long and short conditions. Forty-two short tests were strong, and 2 were weak. Although peak force in strong and weak short tests appeared similar in terms of pounds, weak short tests used a higher proportion of MVIC than strong short tests. Thirty-nine long tests were strong, and 5 were weak. The 5 weak long tests demonstrated significantly higher peak force than the 39 strong ones in both absolute terms and relative to MVIC. In other words, weak tests engaged a higher proportion of available force than strong tests at both durations (Table 4).

One might expect that muscles that test weak manually would also test weaker on MVIC than those that test strong manually. Although subjects with weak tests in both the long and short conditions had lower mean force on MVICs, by 7 and 12 pounds, respectively, than those who tested strong, this difference was not statistically significant. Because there were so few weak tests, it is unlikely that there was adequate power to show a difference not due to chance and variation in subject body size.

Difference in MMT result—short vs long tests

Both subjects who were weak on short tests were also weak in the long tests. Three subjects were weak on all 3 repeats of the long test, but strong on the short tests. Two other subjects had a single weak test in the long condition, both with the short condition strong.

The κ statistic for agreement of results between the short and long conditions was .54, indicating only fair agreement between the 2 conditions. The null hypothesis was good agreement or better ($\kappa \geq .61$)[17] if the length of the muscle test did not affect the outcome. The null hypothesis is rejected—duration of MMTs does appear to matter.

Discussion

Some muscles that can hold an isometric contraction in an MMT for a short time cannot maintain the

Table 1 Durations of tests

	Mean	SD	Minimum	Maximum
Duration MVIC	7.156	.944	5.530	10.310
Duration Short MMT	1.092	.242	.713	1.927
Duration Long MMT	2.337	.489	1.710	3.640

Short MMT, short manual test (1 second); *Long MMT*, long manual test (3 seconds).

Table 2 Peak forces in pounds

	Mean	SD	Minimum	Maximum
Peak Force MVIC	29.319	11.276	9.760	49.885
Peak Force Short MMT	2.233	1.451	.610	7.210
Peak Force Long MMT	3.037	1.658	.937	8.240
Peak Force Short/ MVIC	.085	.057	.021	.240
Peak Force Long/ MVIC	.117	.074	.024	.362

Short/MVIC, Peak force of short manual test divided by peak force of MVIC; *Long/MVIC*, peak force of long manual test divided by peak force of MVIC.

Table 3 Paired *t* tests for force and duration differences in short vs long MMTs

Comparison	Mean Difference	DF	*t* Value	*P* Value
Mean Duration Short − Long MMT	−1.245	43	−17.875	<.0001
Mean Force Short − Long MMT	−.804	43	−.4023	.0002
Normalized Force Difference: Short MMT/MVIC − Long MMT/MVIC	−.032	43	−4.276	.0001

Force in pounds, duration in seconds. Short tests, approximately 1 second; long tests, approximately 3 seconds. *MVIC*, Peak force during MVIC.

contraction for the 2.5 to 3 seconds of a longer test. Short and long MMTs sometimes yield different results. Because many AK examiners use tests of 1 second or less in practice,[18] muscle weaknesses that develop later may be missed.

It is possible that the differences observed by Schmitt[12] between “patient-started” and “examiner-started” tests may well be differences in duration of tests. Schmitt states that if an “examiner-started” test is weak, then a “patient-started” test of that muscle will be weak, but not vice versa. We observed that if a short test was weak, the long test would be weak, but not vice versa. This is consistent with the theory that “examiner-started” tests are generally shorter tests and “patient-started” tests are longer tests.

Different durations of testing may measure different aspects of neuromuscular function—the initial rapid response to external pressure and the ability to sustain a contraction against increasing pressure. Vasilyeva et al[19] describe 2 stages of muscle contraction. In phasic contraction, the length of the muscle changes concentrically or eccentrically; but its tonus remains the same. The balance between agonists and antagonists determines the length of the muscle. This is the initial type of contraction in voluntary movement, regulated by the cerebral cortex. Tonic contraction involves no change in length of the muscle (isometric) but a change in tone. Vasilyeva et al cite NA Bernstein’s 1929 and 1947 work stating that these 2 phases are also seen in an isometric contraction. The initial contraction is phasic/voluntary. Tonic contraction appears after 3 seconds of an isometric contraction, fatigues slowly, and is involuntary. It is regulated at the striatopallidar level. A large-amplitude pallidar tremor can be seen to develop in the second 3 seconds after passive stretch in a dysfunctional muscle with a hypoactive stretch reflex.

Table 4 Unpaired *t* tests for differences in force between facilitated (strong) and inhibited (weak) MMTs

	Mean Difference	DF	*t* Value	*P* Value
1-s Tests				
Mean Force Short MMT Strong vs Weak	−.755	42	−.714	.4789
Mean Force of MVIC Strong vs Weak on Short Tests	12.390	42	1.542	.1305
Mean Force Short MMT/ MVIC Strong vs Weak	−.103	42	−2.646	.0114
3-s Tests				
Mean Force Long MMT Strong vs Weak	−2.131	42	−2.936	.0054
Mean Force of MVIC Strong vs Weak on Long Tests	7.059	42	1.330	.1908
Mean Force Long MMT/ MVIC Strong vs Weak	−.116	42	−3.772	.0005

Force in pounds. *Short MMT/MVIC*, Peak force of short manual test divided by peak force of MVIC; *Long MMT/MVIC*, peak force of long manual test divided by peak force of MVIC.

Vasilyeva[18] et al[19] demonstrated differences between normal and dysfunctional muscles by testing in two or three 3-second increments with force and surface electromyographic (EMG) recordings. The EMG findings paralleled the perception of the manual muscle tester. In normal muscles, after 3 seconds of an isometric contraction, if the subject is asked to push harder, an increase in force output is seen. In dysfunctional muscles, there is either no rise or a decline. They also found that, in normal muscles, after rapid stretching, the force of the muscle contraction increased, but in a dysfunctional muscle, force decreased after stretching, indicating abnormal proprioception.

Muscles that break away exhibit higher peak forces during MMT than muscles that can hold. This may reflect a tendency of the examiner to allow the force to plateau when it is apparent that the muscle is holding, or it may reflect a recruitment of more fibers in a dysfunctional muscle to try to avoid failure. This is consistent with the observations of Nicholas et al[20] that break tests generate higher peak forces than make tests and that the peak force occurs after the breaking point. It is consistent with the observations of Leisman et al[21] that muscles that test weak exhibit higher EMG output and less efficient contractions than muscles that test strong.

Leisman et al compared AK MMT results to force/integrated EMG data showing effects of fatigue and task repetition.[21] Several muscles for each subject were manually tested and rated as "strong" or "weak." Electrophysiologic testing was then conducted by examiners blind to the previous MMT results. Maximum voluntary contraction (MVC) was determined by having the subject contract each muscle as hard as possible for 3 seconds against a force transducer. Subjects then did a series of short (5 seconds) and long (as long as possible) isometric contractions at a series of increasing percentages of MVC while EMG data were recorded.

Even at 75% of MVC, "weak" muscles did not give out until 20 seconds, much longer than the MMT in their study (maximum of 2.5 seconds) or in any other studies reporting AK muscle tests.[18,19] The EMG findings for "weak" muscles differed from the effects of fatigue and from "strong" muscles.

In the present study, each subject was able to maintain the MVIC contraction against the fixed strap at higher forces and for a longer time than any of the manual tests. The breaking away that occurs in AK MMT at the durations commonly used (1-3.5 seconds) is unlikely to be due to fatigue.

Applied kinesiology MMT does not involve the full force that a muscle can generate, even when the muscle tests "weak." This may seem paradoxical, but supports applied kinesiologists' contention that MMT tests the ability of the neuromuscular system to adapt to changing pressure, not the total or peak force the muscle can produce.

The thin-film force sensor was very comfortable to use and did not interfere with testing. It is flexible and would allow testing in many positions for a variety of muscles, especially if attached to the tester's hand rather than to the subject's limb. It will also allow accurate measurement of forces for controlled studies of a variety of AK challenge procedures in a manner approximating what is actually done in a clinical setting without the interposition of a bulky dynamometer.

Limitations

Testing done by a single examiner may not be representative of other AK muscle testers. The small group of subjects and use of one examiner demonstrated feasibility that this study can be done on a larger scale. Another weakness of this study is the use of healthy subjects. Future studies should be designed to increase the yield of dysfunctional muscles by testing symptomatic subjects or more muscles per subject. Although the long manual tests were intended to be 3 seconds, the range actually achieved was 1.7 to 3.6 seconds, averaging 2.3 seconds. This appeared to be due to mistakes in visual timing of the long tests by the examiner. Long tests were clearly longer than the "short" tests, but not consistently as long as the 3-second mark that Vasilyeva cites as distinguishing different phases of neuromuscular control. Future studies in which duration is a variable should consider an audible or other standardized time signal to ensure that long tests are sustained for the full time intended.

The small sensor captured only a fraction of the force used and could not show any changes in hand contact by the examiner. In future studies, a full-hand array of sensors would better capture the full force used in testing and could document any variations in tester contact during repeated testing. In addition, during MVIC testing, if the strap shifted, the sensor could slip off the most solid contact over bone. Although the examiner watched for this, it may have occurred, reducing the relative percentage of force captured on some tests. Another weakness of this study is that the subjects were chiropractic students, so they may have been biased or unintentionally performed differently than laypeople or patients.

Future studies including MVIC should include better stabilization of the subjects. Despite cautions by the examiner, some of the subjects in this study leaned away from the strap during the MVIC test, potentially increasing the recorded force beyond what was being generated by the deltoid muscle. This may have obscured differences between strong and weak muscles on MVIC. Strapping the subject to a chair or table is described in norming studies of MVIC[7-10] and should be considered.

Conclusion

Applied kinesiology muscle testing uses submaximal forces and measures neuromuscular response to gradually increasing pressure, rather than total force that the muscle is capable of generating. Longer tests may demonstrate weakness that is not evident when the muscle is tested for 1 second. Duration of tests should be controlled for and specified in future AK research, particularly when testing before and after diagnostic or therapeutic interventions and challenges. Thin-film Flexiforce force sensors show promise to record AK muscle testing and other manual techniques under conditions similar to clinical practice.

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References

1. Walther D.S. Applied kinesiology synopsis. 2nd ed. Pueblo, CO: Systems DC; 2000. pp. 37,71,2.
2. Kendall FP, Kendall McCreary E, Provance PG. Muscles—testing and function. 4th ed. Baltimore: Williams and Wilkins; 1993. p. 179-90.
3. Blaich RM, Mendenhall EI. Manual muscle testing and Cybex machine muscle testing, a search for a correlation. 1984 Selected papers of the International College of Applied Kinesiology; 1984.
4. Rarick L, Gross K, Mohns M. Comparison of two methods of measuring strength of selected muscle groups in children. Res Q 1955;26:76-9.
5. Wilkhom JB, Bohannon RW. Hand-held dynamometer measurements: tester strength makes a difference. J Orthop Sports Phys Ther 1991;13(4):191-7.
6. Laprade J, Culham E, Brouwer B. Comparison of five isometric exercises in the recruitment of the vastus medialis oblique in persons with and without patellofemoral pain syndrome. J Orthop Sports Phys Ther 1998;27:197-204.
7. National Isometric Muscle Strength Database Consortium. Muscular weakness assessment: use of normal isometric strength data. Arch Phys Med Rehabil 1996;77:1251-5.
8. Colombo R, Mazzini L, Mora G, Parenzan R, Creola G, Pirali I, et al. Measurement of isometric muscle strength: a reproducibility study of maximal voluntary contraction in normal subjects and amyotrophic lateral sclerosis patients. Med Eng Phys 2000;22(3):167-74.
9. Great Lakes ALS Study Group. A comparison of muscle strength testing techniques in amyotrophic lateral sclerosis. Neurology 2003;61(11):1503-7.
10. Stoll T, Huber E, Seifert B, Michel BA, Stucki G. Maximal isometric strength: normative values and gender-specific relation to age. Clin Rheumatol 2000;19(2):105-13.
11. Meldrum D, Cahalane E, Conroy R, Fitzgerald D, Hardiman O. Maximum voluntary isometric contraction: reference values and clinical application. Amyotroph Lateral Scler 2007;8:47-55.
12. Schmitt WH. Muscle testing as functional neurology: differentiating functional upper motor-neuron and functional lower motor-neuron problems. Selected papers of the International College of Applied Kinesiology: Shawnee Mission, KS:ICAK; 1986. p. 21-32.
13. Conable K, Corneal J, Hambrick T, Marquina N, Zhang Q. Electromyogram and force patterns in variably timed manual muscle testing of the middle deltoid muscle. J Manipulative Physiol Ther 2006;29(4):305-14.
14. Hsieh C, Phillips R. Reliability of manual muscle testing with a computerized dynamometer. J Manipulative Physiol Ther 1990;13:72-82.
15. Smit E, Conradie M, Wessels J, Witbooi I, Otto R. Measurement of the magnitude of force applied by students when learning a mobilization technique. SA J Physiother 2003;59(4):3-8.
16. Conradie M, Smit E, Louw M, Prinsloo M, Loubser L, Wilsdorf A. Do experienced physiotherapists apply equal magnitude of force during a grade I central PA on the cervical spine? SA J Physiother 2004;60(4):18-25.
17. Dawson B, Trapp R. Basic and clinical biostatistics. 4th ed. New York: Lang Medical Books/McGraw-Hill; 2004. p. 119.
18. Vasilyeva LF. Clinical and experimental substantiation of the functional muscle weakness phenomenon. Proceedings of the International College of Applied Kinesiology Annual Meeting [CD-ROM], 2004. Rome, Italy [CD-ROM]-Shawnee Mission, KS:ICAK; 2004.
19. Vasilyeva LF, Chernysheva TN, Korenbaum VI, Aukhtina TO. About peculiarities of the effect of muscle functional weakness. Proceedings of the Annual Meeting of the International College of Applied Kinesiology-USA, Volume 1, 2001-2002. Kansas City: International College of Applied Kinesiology; 2001. p. 63-6.
20. Nicholas J, Sapega B, Kraus H, Webb J. Factors influencing manual muscle tests in physical therapy. J Bone Joint Surg 1978;60-A(2):186-90.
21. Leisman G, Zenhausern R, Ferentz A, Tefera T, Zemcov A. Electromyographic effects of fatigue and task repetition on the validity of estimates of strong and weak muscles in applied kinesiological muscle-testing procedures. Percept Mot Skills 1995;80:963-77.