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Variation in the Cervical Range of Motion Over Time Measured by the "Flock of Birds" Electromagnetic Tracking System

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Study Design. Observational longitudinal study.

Objective. To establish the normal variation over time for active and passive cervical range of motion (ROM) measured with the Flock of Birds electromagnetic tracking system (FOB).

Summary of Background Data. Data about normal variation of cervical ROM over time are scarce but important for the interpretation of study results.

Methods. Forty-eight subjects without a manifest dysfunction in neck and shoulder region (asymptomatic group) and 58 subjects with a dysfunction in the neck and shoulder region (symptomatic group) participated in this study. Cervical active and passive ROM was assessed in three different sessions 6 weeks apart. The following movements were measured: flexion-extension, lateral bending, and axial rotation in neutral, flexed, and extended position.

Results. A wide range of variation of active and passive cervical ROM was found at the 6- and 12-week measurement in the asymptomatic group as well as in the symptomatic group. Highest variation was found during passive ROM testing as compared with active ROM testing. The symptomatic group showed larger variation than the asymptomatic group.

Conclusions. Cervical range of motion varies considerably over time. This variation should be taken into account when results of therapeutic trials with respect to cervical ROM are interpreted.

Key words: cervical range of motion, variation, longitudinal study, symptomatic and asymptomatic subjects
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Measurement of cervical range of motion (ROM) is used for diagnostic purposes as well as for the evaluation of clinical effectiveness of therapeutic interventions, both in patient care and in scientific research. Accurate measurement of cervical ROM is considered difficult because of the anatomic structure of the cervical spine, which consists of multiple segments with multiple joints.[1] Small differences in mobility of individual cervical segments can add up to considerable differences in total cervical ROM as was already described by Bogduk.[2] Various measurement techniques have been described, but there is little agreement among researchers and clinicians about which method should be used for assessing cervical ROM.[3–5] Most studies concerning cervical ROM measurement have focused on the reliability and validity of the various measurement techniques, which is essential for the analysis and interpretation of measurement results.

The Flock of Birds (FOB), a six-degrees-of-freedom electromagnetic tracking device, is a relatively new technique. Recently, the accuracy and reliability of this measurement technique was evaluated for measuring the cervical ROM at the Center for Rehabilitation of the University Hospital Groningen, the Netherlands. In a dummy setup, the reproducibility of axial rotation, forward flexion, and lateral bending was within 0.85° and was within 1.7° for combined movements such as axial rotation in flexed or extended position.[6] However, the authors found a small within-session variation (2°-4°) and a considerable variation between two measurement sessions (5°-15°).[7]

Accurate information concerning normal variation of the cervical ROM is necessary for interpretation of scientific research but also in daily medical practice when evaluating cervical function. Unfortunately, scientific research about normal variation of cervical ROM over time remains scarce. Therefore, the aim of this study was to quantify the variation of cervical ROM over time in subjects without a dysfunction of the neck or shoulder region as well as in subjects with a dysfunction in either region measured with the FOB.

Materials and Methods

Subjects An asymptomatic group and a symptomatic group were examined. The asymptomatic group, without known dysfunctions in neck and shoulder region, consisted of 48 subjects, mostly employees of the Center for Rehabilitation of the University Hospital Groningen. The symptomatic group, with shoulder complaints and concomitant neck complaints, consisted of 58 subjects. This symptomatic group was recruited from participants in a randomized controlled trial, which evaluated the effects of manipulative treatment of the cervicothoracic spine and adjacent ribs in treatment of shoulder complaints.[8] The selected subjects allocated to the control group did not receive and active treatment of the cericothoracic spine but only received usual care for shoulder complaints by their general practitioner. Usual care includes medical treatment of

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Table 1. Mean Scores and Mean Difference Between Measures of Cervical Range of Motion of Asymptomatic Subjects

Movement	Baseline (T0) Mean (SD)	6 wk (T1) Mean (SD)	12 wk (T2) Mean (SD)	T0–T1 Δ (95%CI)	T0–T1 valid n	T0–T2 Δ (95%CI)	T0–T2 valid n	ANOVA *P* value
Active Movements								
Rotation in neutral position	135.4 (15.6)	135.1 (16.7)	136 (16.7)	−0.3 (−2.6 to 2)	47	0.7 (−1.6 to 3)	47	0.96
Rotation in extended position	97.6 (18.3)	98.4 (20.8)	103.3 (19.9)	2.7 (−1.5 to 6.8)	44	**6.2 (2 to 10.4)**	44	0.33
Rotation in flexed position	87.5 (12.9)	87.6 (11.1)	91 (14.3)	0.3 (−2.9 to 3.6)	46	2.5 (−1.1 to 6.1)	44	0.33
Flexion-extension	130.8 (16.3)	125.4 (19)	126.5 (17)	**−5.6 (−9.5 to −1.7)**	47	**−4.2 (−7.8 to −0.6)**	47	0.29
Lateral bending	78.1 (14.9)	77.5 (14.4)	77.4 (15.1)	−0.6 (−2.9 to 1.6)	48	0.0 (−2.2 to 2.2)	47	0.97
Passive Movements								
Rotation in neutral position	145.6 (19.0)	148.6 (19.1)	151.7 (19.3)	**3.0 (1.1 to 4.9)**	48	**6.1 (4.4 to 7.8)**	48	0.3
Rotation in extended position	105.6 (21.3)	111.2 (19.5)	119 (20.7)	**7.7 (4.2 to 11.1)**	45	**13.9 (10 to 17.7)**	43	**<0.01**
Rotation in flexed position	85.6 (13.7)	88.3 (14.5)	94.1 (16.8)	3.2 (−0.6 to 6.9)	44	**8.7 (4.1 to 13.4)**	44	**0.03**
Flexion-extension	136.6 (17.8)	135.3 (19.0)	134 (17.7)	−1.5 (−5.7 to 2.7)	46	−2.6 (−6.4 to 1.2)	46	0.79
Lateral bending	82.3 (14.5)	83.5 (14.8)	83.8 (14.8)	1.2 (−0.3 to 2.7)	48	1.5 (−0.4 to 3.4)	48	0.86

ANOVA, one-way ANOVA to analyze differences in range of motion between T0, T1 and T2. Negative differences indicate a reduction of range of motion over time. Figures printed bold indicate a significant change of range of motion.
Δ = mean difference; CI = confidence interval; T0 = baseline measurement; T1 = 6-wk follow-up measurement; T2 = 12-wk follow-up measurement.

the shoulder joint (nonsteroidal anti-inflammatory drugs, injections with corticosteroids, and referral to a physiotherapist).[9] An informed consent was obtained from all subjects.

Measurement System The "Flock of Birds" (Ascension Technology Corporation, Burlington, VT) consists of a standard range transmitter and three receivers. One receiver is mounted on a stylus and is used for palpation of seven bony landmarks on the head and thorax. [10] With the positions of these landmarks, one coordinate system of the head and one coordinate system of the thorax are constructed, defining the posture of the patient. This definition of landmarks makes the measurements less dependent on exact head and thorax positioning of the two receivers and makes follow-up measurements more accurate. [7] The two other receivers are mounted on the forehead and thorax (sternum). These receivers measure the change of position and orientation in the electromagnetic field while moving. Mathematically, mobility is defined as movement of the coordinate system of the thorax. A position calibration procedure was performed before the measurements, because the disturbance produced by metals in the environment (e.g., iron-strengthened concrete) can be quite large.[7,11]

Procedures The subjects were invited to sit in an upright chair with armrests, facing a mirror. They were asked to assume a neutral head-neck position by looking at their reflection in the mirror. No additional fixation techniques were used. Before each measurement the subjects were reminded about the importance of a neutral head-neck position. Each movement was explained and demonstrated by the observer and the subjects were asked to move as far as possible without forcing or movement of the thorax or shoulder girdle. The following movements were measured in a fixed sequence: axial rotation, rotation in flexed position and rotation in extended position, flexion-extension and lateral bending. Each measurement consisted of three repetitions in a continuous motion. Measuring the active ROM of a particular movement was followed by measuring the passive ROM of the same movement. The asymptomatic group was measured by one observer and the symptomatic group by three observers. All observers were extensively trained and experienced in using the FOB. Data were collected in three different sessions: a baseline measurement (T0) and two follow-up measurements, after 6 (T1) and 12 weeks (T2).

Statistical Analysis Statistical analysis was performed using SPSS software, version 11.0. The mean of three repetitions was calculated for each movement and used for further analysis. Analyses were based on total ROM (for example, flexion plus extension, left plus right rotation). The mean differences and standard deviations were calculated between baseline measurements and the measurements of the first and second session. To analyze systematic differences between different sessions paired samples *t* tests were used. The method of Bland and Altman was used for calculating the range of normal variation, in which plus or minus two standard deviations include 95% of the variation in range of motion.[12] Changes in cervical range of motion have to exceed the upper or lower limit to be clinically relevant. In addition, the percentage of paired observations with a variation within 5°, 10°, and 15° was determined for all ranges of motion. An analysis of variance was performed with all active and all passive motions to analyze the differences between the three sessions.

■ Results

The asymptomatic group consisted of 48 subjects (26 women and 24 men, mean age 44.5 years, SD = 10), and the symptomatic group consisted of 58 subjects (30 women and 28 men, mean age 47.7 years, SD = 10.4). All analyses were based on available data. Because of technical errors of the FOB, noncompliance of patients, and loss to follow-up from the randomized controlled trial, the paired observations T0–T1 and T0–T2, were not available for all subjects. Therefore, the number of subjects included in different analyses varied, as reported in the tables. Tables 1 and 2 summarize the results for the asymptomatic group, and Tables 3 and 4 show the results of the symptomatic group.

Asymptomatic Group, Active ROM

Significant differences in ROM were measured for active flexion-extension for T0–T1 and T0–T2 and for

Table 2. Percentage of Paired Observations With an Agreement in Range of Motion Within 5°, 10° and 15° and Range of Normal Variation Between Measurements of the Neck Mobility of Asymptomatic Subjects

Movement	Agreement Between T0–T1 Within 5°	10°	15°	Agreement Between T0–T2 Within 5°	10°	15°	Range of Normal Variation T0–T1	Range of Normal Variation T0–T2
Active Movements								
Rotation in neutral position	85.1	93.6	97.9	83	91.5	93.6	−15.7 to 16.3	−16.5 to 15.1
Rotation in extended position	61.4	72.7	77.3	52.3	56.8	65.9	−30.3 to 24.9	−21.6 to 34
Rotation in flexed position	65.2	80.4	89.1	56.8	75	95.8	−21.9 to 21.3	−26.1 to 21.1
Flexion-extension	80.9	89.4	91.5	80.9	91.5	95.7	−31.8 to 20.6	−28.6 to 20.2
Lateral bending	79.2	89.6	100	72.3	93.6	97.9	−14.8 to 16	−15 to 15
Passive Movements								
Rotation in neutral position	68.8	85.4	91.7	39.6	77.1	93.8	−10.2 to 16.2	−5.7 to 17.9
Rotation in extended position	37.2	60.5	74.4	27.9	41.9	51.2	−14.7 to 30.1	−11.1 to 38.9
Rotation in flexed position	61.4	72.7	84.1	36.4	52.3	100	−27.8 to 21.4	−22.1 to 39.5
Flexion-extension	65.2	82.6	91.3	82.6	84.8	89.1	−26.7 to 29.7	−23.4 to 28.6
Lateral bending	75	95.8	100	68.8	89.6	100	−11.4 to 9	−14.5 to 11.5

Range of normal variation was calculated as mean difference ± 2 SD. Presented are the lower and upper bound of the ranges. Changes over time in cervical range of motion have to exceed the lower or upper limit to be clinically relevant.
T0 = baseline measurement; T1 = 6-wk follow-up measurement; T2 = 12-wk follow-up measurement.

active rotation in extended position for T0–T2. A substantial variation was measured for T0–T1 as well as T0–T2 (Table 2). For a substantial part of the conducted active movements, the agreement within 5° exceeds 80% and the agreement within 10° exceeds 90%. The least variation was found for rotation in neutral position and lateral bending. The largest amount of variation was found for active rotation in flexed or extended position.

Asymptomatic Group, Passive ROM

Significant differences are measured for passive rotation in neutral and extended position for T0–T1 and for passive rotation in neutral and extended and flexed position for T0–T2. Again the normal variation is substantial, and the percentage of paired observations within 5° and 10° is generally less than for the active range of motion. The ANOVA analysis revealed significant differences for passive rotation in flexed and extended position between the three sessions. Generally, passive ROM exceeded active ROM with 5° to 10° except for rotation in flexed position. Also, the measured variation over time in this group is lower in passive mobility than in active mobility.

Symptomatic Group, Active ROM

Significant differences were measured for rotation in neutral position and flexion-extension for T0–T1 and for T0–T2. Again, a substantial normal variation was observed for T0–T1 as well as for T0–T2 (Table 4). The percentage of paired observations within 5°, 10°, and 15° was less than those for the asymptomatic group. The analysis of variance revealed significant differences for passive rotation in maximal flexion and extension between the three sessions.

Table 3. Mean Scores and Mean Difference Between Measures of Cervical Range of Motion of Symptomatic Subjects

Movement	Baseline (T0) Mean (SD)	6 weeks (T1) Mean (SD)	12 weeks (T2) Mean (SD)	T0–T1 Δ (95%CI)	T0–T1 valid n	T0–T2 Δ (95%CI)	T0–T2 valid n	ANOVA *P* value
Active Movements								
Rotation in neutral position	134.1 (16.1)	131.0 (14.1)	129.8 (17.1)	**−3.5 (−0.6 to −6.3)**	48	**−5 (−7.7 to −2.1)**	43	0.58
Rotation in extended position	101.4 (16.5)	102.0 (16.2)	102.3 (19.2)	−1.2 (−6.5 to 4.1)	46	−0.3 (−4.8 to 4.2)	43	0.62
Rotation in flexed position	102.7 (16.3)	99.8 (18.3)	102.2 (19.3)	−1.8 (−7.1 to 3.6)	47	−1.2 (−6.4 to 3.9)	43	0.82
Flexion-extension	105.6 (14.9)	110.5 (15.4)	110.5 (16)	**4.5 (1.3 to 7.6)**	48	**5.3 (1.8 to 8.9)**	44	0.09
Lateral bending	65.2 (13.7)	61.7 (13.5)	67.4 (17.1)	−3.1 (−6.4 to 0.2)	49	3.7 (−0.9 to 8.3)	43	0.20
Passive Movements								
Rotation in neutral position	132.5 (15.7)	141.7 (20.0)	137.3 (21.4)	**8.7 (4 to 13.5)**	48	4.3 (0.8 to 9.6)	44	**0.02**
Rotation in extended position	106.7 (18.6)	113.2 (22.6)	110.6 (26.1)	6.0 (−0.4 to 12.4)	45	2.1 (−4.3 to 8.7)	41	0.14
Rotation in flexed position	97.1 (19.2)	99.3 (21.5)	100.6 (21.5)	3.3 (−3.7 to 10.4)	44	2.8 (−4.8 to 10.5)	39	0.56
Flexion-extension	106.4 (18.5)	112.2 (20.3)	112.5 (21)	5.9 (−0.2 to 11.9)	59	**6.7 (0.6 to 12.8)**	44	0.14
Lateral bending	67.5 (11.8)	71.7 (14.8)	69.9 (13.1)	3.5 (−0.5 to 7.6)	45	**3.0 (0.3 to 5.7)**	40	0.14

ANOVA, one-way ANOVA to analyze differences in range of motion between T0, T1, and T2. Negative differences indicate a reduction of range of motion over time. Figures printed bold indicate a significant change of range of motion.
Δ = mean difference; CI = confidence interval; T0 = baseline measurement; T1 = 6-wk follow-up measurement; T2 = 12-wk follow-up measurement.

Table 4. Percentage of Paired Observations with an Agreement in Range of Motion within 5°, 10° and 15° Normal Variation between Measurements of the Cervical Range of Motion Symptomatic Subjects

Movement	Agreement Between T0–T1 Within 5°	10°	15°	Agreement Between T0–T2 Within 5°	10°	15°	Range of ROM Variation T0–T1	Range of ROM Variation T0–T2
Active Movements								
Rotation in neutral position	85.4	89.6	93.8	88.4	95.3	100	−23.1 to 16.1	−22.8 to 12.8
Rotation in extended position	65.2	78.3	87	67.4	81.4	83.7	−34.4 to 36.8	−29.1 to 29.7
Rotation in flexed position	68.1	83	87.2	65.1	76.7	79.5	−34.4 to 38	−32.0 to 34.4
Flexion-extension	58.3	75	81.3	38.6	63.6	79.5	−17.1 to 26.1	−18.1 to 28.7
Lateral bending	75.5	91.8	93.9	69.8	74.4	81.4	−19.7 to 25.9	−33.5 to 26.2
Passive Movements								
Rotation in neutral position	39.6	50	62.5	52.3	68.2	77.3	−23.7 to 41.1	−38.7 to 30.1
Rotation in extended position	48.9	62.2	73.3	61.0	63.4	70.7	−48.6 to 36.6	−43.7 to 39.5
Rotation in flexed position	43.2	56.8	63.6	51.3	59	90.9	−29.5 to 22.9	−50.0 to 44.4
Flexion-extension	51	67.3	75.5	38.6	59.1	72.7	−47.9 to 36.1	−33.3 to 46.7
Lateral bending	57.8	75.6	75.6	55	82.5	95	−30.3 to 23.3	−13.8 to 19.8

Normal variation was calculated as mean difference ± 2 SD. Presented are the lower and upper bound of the ranges. Changes over time in cervical range of motion have to exceed the lower or upper limit to be clinically relevant.
T0 = baseline measurement; T1 = 6-wk follow-up measurement; T2 = 12-wk follow-up measurement.

Symptomatic Group, Passive ROM

Significant differences were measured for passive rotation in neutral position for T0–T1 and for passive flexion-extension and passive lateral bending for T0–T2. The ANOVA-analysis revealed significant differences between the three sessions for passive rotation in neutral position. The variation in the symptomatic group is on average 10° to 20° larger than the variation in the asymptomatic group. This larger variation is most obvious in the passive ROM. The percentage of paired observation within 5°, 10°, and 15° is lowest for the passive ROM of the symptomatic group.

Both subject groups have a similar ROM for active rotation in neutral, flexed, and extended position The ROM of the groups differ for active flexion-extension and active lateral bending. The passive ROM is less in the symptomatic group than in the asymptomatic group, except for passive rotation in extended position. Generally, passive ROM exceeded active ROM with 5° to 10° except for rotation in maximal flexion. The variation over time in this group is larger in passive mobility than in active mobility. Looking at the ranges of normal variation, at best a decrease of <11.4° and an increase of <9.0° must be considered as normal variation (see Table 2, T0–T1 passive lateral bending in asymptomatic subjects). These ranges can reach a lower bound of 48.6° and an upper bound of 36.6° (see Table 4, T0–T1 rotation in extended position in symptomatic subjects).

■ Discussion

Cervical range of motion varies considerably over time. Using the Flock of Birds system, a highly sophisticated measurement method with a high degree of precision,[6] it appeared that the cervical mobility changed considerably over the course of time. The normal variation over time ranged from 20.4° for passive lateral bending in the asymptomatic group up to 85.2° for passive rotation in extended position in the symptomatic group. The amount of normal variation was not expected because the asymptomatic group reported no neck complaints and the symptomatic group did not receive an active treatment of the neck region.

However, we cannot assume that all the variation found can be attributed to the normal variation in the course of time. Other sources, such as different observers and several measurement sessions may have made a contribution. To reduce interobserver variation, the measurements were highly standardized using a minimum of observers. Only one observer measured the asymptomatic group, but the symptomatic group was measured by three observers, because of organizational reasons. As a consequence, most subjects in this group were examined by two observers in three measurement sessions. This situation, however, reflects the normal situation in health care in which patients are evaluated by different physicians and physical therapists. An additional analysis did not show significant difference in variation between the individual observers (no data reported). To reduce variation, the mean of the three measurements per session was used for further analysis. A previous study demonstrated that the Flock of Birds system has a very small measurement error (2° to 4° within one session), but the measurement error between sessions was substantially larger (varying from 5° to 15°).[7]

It is possible that this variation between sessions reflects the normal variation of cervical ROM, but part of this variation might as well be explained by other sources of measurement. According to the review of normal kinematics of the cervical spine,[2] there is a substantial amount of variation in the ROM of individual segments of the cervical spine, which adds up to a variation of ROM of the total cervical spine. The question regarding the proportion of normal cervical mobility variation, between session variation and random variation might be clarified in another research design.

Until now, only scarce figures existed regarding the variation of ROM in the course of time.[13] In the study of Christensen et al, the normal variation in asymptomatic subjects was found to be in the order of ±20° for flexion-extension, ±12° for lateral bending, and ±14° for axial rotation using the CA-6000 Spine Motion Analyzer. Our data confirm that a substantial variation of cervical mobility in the course of time exists and shows a larger variation compared with the study of Christensen. This variation is more obvious for the symptomatic group. Furthermore, passive ROM showed larger variation in the course of time than active ROM in both groups.

Given the substantial amount of variation in passive ROM measurement, it can be questioned whether passive ROM should be used as an outcome measure in intervention studies. The same yields for the use of "complex" cervical motions like rotation in flexed and extended position. Considering these results, the interpretation of outcome measurements of cervical spine mobility in therapy trials should be done with utmost care and is best reflected in the following quote:[2] "A lower range today, a higher range tomorrow, or *vice versa*, could be only the normal, diurnal variation and not something attributable to a disease or a therapeutic intervention."

■ Key Points

- Measurement of cervical range of motion is often used for diagnostic purposes as well as in the evaluation of clinical effectiveness.
- Data on normal variation over time of cervical range of motion are scarce.
- In symptomatic and asymptomatic subjects a substantial variation over time was demonstrated.
- Given this large variation, it is to be questioned whether measurement of crevical range of motion should be used in both diagnosis and research.

References

1. Antonaci F, Ghirmai S, Bono G, et al. Current methods for cervical spine movement evaluation: a review. *Clin Exp Rheumatol* 2000;18:S45–52.
2. Bogduk N, Mercer S. Biomechanics of the cervical spine. I: normal kinematics. *Clin Biomech (Bristol, Avon)* 2000;15:633–48.
3. Chen J, Solinger AB, Poncet JF, et al. Meta-analysis of normative cervical motion. *Spine* 1999;24:1571–8.
4. Dvorak J, Vajda EG, Grob D, et al. Normal motion of the lumbar spine as related to age and gender. *Eur Spine J* 1995;4:18–23.
5. Lantz CA, Chen J, Buch D. Clinical validity and stability of active and passive cervical range of motion with regard to total and unilateral uniplanar motion. *Spine* 1999;24:1082–9.
6. Hof AL, Koerhuis CL, Winters JC. "Coupled motions" in cervical spine rotation can be misleading. Comment on V. Feipel, B. Rondelet, J.-P. Le Pallec and M. Rooze. Normal global motion of the cervical spine: an electrogoniometric study. *Clin Biomech (Bristol, Avon)* 2001;16:455–8.
7. Koerhuis CL, Winters JC, van der Helm FC, et al. Neck mobility measurement by means of the "Flock of Birds" electromagnetic tracking system. *Clin Biomech (Bristol, Avon)* 2003;18:14–8.
8. Bergman GJ, Winters JC, van der Heijden GJ, et al. Groningen Manipulation Study. The effect of manipulation of the structures of the shoulder girdle as additional treatment for symptom relief and for prevention of chronicity or recurrence of shoulder symptoms. Design of a randomized controlled trial within a comprehensive prognostic cohort study. *J Manipulative Physiol Ther* 2002;25:543–9.
9. Winters JC, De Jong AC, van der Windt DAWM, et al. NHG-Standaard Schouderklachten (versie 1999) [Guidelines for Shoulder Complaints of the Dutch College of General Practitioners (version 1999)]. *Huisarts Wet* 1999;42:222–31.
10. Meskers CG, Fraterman H, van der Helm FC, et al. Calibration of the "Flock of Birds" electromagnetic tracking device and its application in shoulder motion studies. *J Biomech* 1999;32:629–33.
11. Meskers CG, Vermeulen HM, de Groot JH, et al. 3D shoulder position measurements using a six-degree-of-freedom electromagnetic tracking device. *Clin Biomech (Bristol, Avon)* 1998;13:280–92.
12. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;1:307–10.
13. Christensen HW, Nilsson N. Natural variation of cervical range of motion: a one-way repeated-measures design. *J Manipulative Physiol Ther* 1998;21:383–7.