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Variability of Active Cervical Range of Motion Within and Between Days in Healthy Participants: A Prospective Observational Study

Martijn S. Stenneberg, PhD,[a, b, c] Herman ten Berge, MSc,[a, c] Bart de Leeuw, MSc,[a, c] Erik Cattrysse, PhD,[c] Rob de Bie, PhD,[d] Henrica de Vet, PhD,[e] and Gwendolijne G.M. Scholten-Peeters, PhD[a, f]

Abstract

Objective: The purpose of this study was to determine the intraday and interday variability and systematic change over the day of active cervical range of motion (aCROM) measurements in asymptomatic persons using a clinically applicable measurement device.

Methods: A prospective observational study was performed. Sixteen adults (8 men and 8 women, median age 51 years) without neck pain in the last 3 months were recruited in 2 physiotherapy practices. Active cervical range of motion was estimated using the Apple iPhone application "3D Range of Motion." Measurements were performed 3 times a day for 7 days and spread over a period of 3 weeks. Mean values of aCROM were calculated. Intraday and interday variability was estimated by calculating limits of agreement.

Results: The limits of agreement for intraday variability ranged from ±12.1° for left rotation to ±15.5° for total rotation. For interday variability, the limits of agreement ranged from ±14.2° for right rotation to ±20.1° for total rotation. No systematic change over the day was found.

Conclusion: This study showed substantial intraday and interday variability of aCROM measurements in asymptomatic people. No trend toward an increased or decreased aCROM was observed during the course of the day. When interpreting aCROM values, clinicians should consider the degree of variation in aCROM measurements over time. (J Manipulative Physiol Ther 2023;46;125-131)

Key Indexing Terms: *Range of Motion, Articular; Neck; Spine; Patient Outcome Assessment; Biological Variation, Individual; Reproducibility of Results*

[a] SOMT University of Physiotherapy, Amersfoort, the Netherlands.

[b] CAPHRI School for Public Health and Primary Care, Maastricht University, Maastricht, the Netherlands.

[c] Experimental Anatomy Research group (EXAN), Department of Physiotherapy, Human Physiology and Anatomy (KIMA), Vrije Universiteit Brussel, Brussel, Belgium.

[d] Department of Epidemiology, CAPHRI Research Institute, Maastricht University, Maastricht, the Netherlands.

[e] Department of Epidemiology and Biostatistics, Amsterdam Public Health Research Institute, Amsterdam University Medical Centers, VU University, Amsterdam, the Netherlands.

[f] Department of Human Movement Sciences, Vrije Universiteit, Amsterdam Movement Sciences, Amsterdam, the Netherlands.

Corresponding author: Martijn S. Stenneberg, PhD, Department of Manual Therapy, SOMT University of Physiotherapy, Softwareweg 5, 3821 BN, Amersfoort, the Netherlands.
(e-mail: *m.stenneberg@somt.nl*).

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Introduction

Active cervical range of motion (aCROM) is an assessment used in practice and research.[1,2] The outcome can be influenced by both the measurement device used as well as the measurement procedures.[3,4] Estimates of aCROM may be influenced by variables such as biologic variation within individuals, the complexity of cervical kinematics, initial head and body position, presence of pain, core temperature, psychological state, and daily activities.[3-8] As several of these factors can vary within the course of the day or between days, it is assumed that aCROM may vary as well. Therefore, it has been recommended to assess aCROM at the same time of day to obtain reliable measurements.[4,9]

Variability in measurement scores over time is commonly assessed in test-retest reliability studies. Differences in scores are due to differences in measurements, different days, or biological variation.[10] The main assumption in test-retest studies is that the participants are assumed to be stable on the construct to be measured. However, this assumption cannot be tested, and the variation in scores may be due to measurement error and or biological variation, and these cannot be disentangled. When examining improvements or deteriorations over time in aCROM and deciding whether the observed change is a real change, it has to be larger than the variation, regardless of whether this is due to measurement error and/or biological variation.

Information is lacking as to the extent aCROM normally varies between measurement sessions and whether there is a systematic change over the day. Intraday variation of cervical range of motion has not been studied before in contrast to interday variability. Previous studies found an interday variability in aCROM of 12° to 20° in a group of healthy students[11] and an even larger variability in people with and without neck pain.[12] These studies used valid instruments, such as an electromagnetic tracking system[12] or an electrogoniometer[11]; however, these instruments are not suitable for use in clinical practice. Currently, the evidence shows that smartphone-based applications are feasible and reliable options to accurately measure aCROM.[13-15]

Increased knowledge about the amount of interday and intraday variation in aCROM is important to interpret aCROM measurements in clinical practice and research. Moreover, it may have consequences for adequate timing of measurements and comparison of aCROM data. Therefore, the purpose of this study was to determine the intraday and interday variability and systematic change over the day of aCROM measurements in asymptomatic people using a clinically applicable iPhone application.

Methods

Participants

Sixteen healthy adults—8 men and 8 women—with a median (IQR) age of 51.0 years (29-56), weight 74.5 kg (72-82), height 174.5 cm (169-180), without neck pain in the last 3 months were included in the study. All were recruited from 2 physiotherapy practices in the Netherlands. To be included, participants were employees or patients treated for complaints other than neck pain and had to be able to speak and read the Dutch language. People with known dysfunctions in the neck region, previous surgery of the cervical spine, or with neurological, visual, or vestibular disorders, cervical radiculopathy, psychological states, or dizziness were excluded.

Ethics

All participants signed an informed consent form. The Medical Ethics Committee of the Zuyderland Medical Centre, Heerlen, the Netherlands, approved the study protocol (protocol number 15-N-07).

Measurements

All measurements were performed according to a standardized protocol by 2 manual therapists (HB, BL) with more than 10 years practical experience in musculoskeletal physiotherapy. Both examiners attended two 3-hour training sessions to gain experience in the measurement device and standardized examination procedures.

An Apple iPhone 4s (Apple Inc, Cupertino, California) and the "3D Range of Motion" application version 1.1.1 (PMC Helix, Leersum, the Netherlands) were used to measure aCROM. This application uses the iPhone's built-in accelerometer, gyroscope, and magnetometer function and a digital display to show the assessed angles around the x-, y-, and z-axes. Concurrent validity of the application was tested using an electromagnetic tracking device as a reference test on a wooden frame and ranged from 0.02° for flexion-extension to 0.75° for rotation.[16] The intraclass correlation coefficient for concurrent validity and interrater reliability in a sample of neck pain patients ranged from 0.90 to 0.99. Measurement error ranged from about 5° for right lateral bending to 11° for total rotation (left + right).[16] Other studies demonstrated high concurrent validity and intrarater and interrater reliability of iPhone applications to measure aCROM in patients with neck pain, with ICCs above 0.90 and a minimal detectable change for intrarater reliability ranging from 4° to 8° for half-cycle movements.[16,17]

Procedures

Measurements were performed 3 times a day—morning, noon, and evening—on 7 days, determined as per the participant's convenience, spread over a period of 3 weeks. The examiners visited the participants for each measurement occasion.

Prior to the measurements, participants performed all movements to ensure that the movements were executed properly. All participants sat on an upright plastic chair with lumbar support. Their feet rested on the ground, knees and elbows were flexed at 90°, hands on the thighs, with the neck in a neutral position. The iPhone was fixed securely on the participants' forehead by using a customized iPhone running band with a Velcro strap. Glasses and all metal objects (eg, piercings, jewelry) were removed to prevent potential interference with the measurement signal. All measurements were performed under the same conditions with the same equipment.

Participants were asked to move their head fluently until the end of the range of motion without provoking pain and avoiding any movements of the shoulder girdle and thorax. The observers ensured that the movements were correctly performed and followed the relevant axis.

Cervical movements were performed consecutively in a fixed order. Obtained movements were cervical flexion, extension, combined flexion-extension, rotation left, rotation right, and total rotation (left + right). At each measurement occasion, the participants made the movements twice, and the highest score of 2 trials was recorded for each movement direction separately. Participants were blinded to their prior aCROM scores.

During all measurement days, the participants registered possible changes in daily activities, use of medication, and any other relevant factors that might have influenced aCROM during the measurement period to analyze the potential impact of these variables on the variability.

Data Analysis

Statistical analysis was carried out using SPSS for Windows, version 24 (IBM Corp., Armonk, New York). In total, 16 × 7 × 3 measurements were obtained for analysis. For interday variability, 3 aCROM scores per day were used, and for intraday variability, scores of 7 days were used. When performing multiple measurements per participant, a smaller sample size is needed.[10] We considered a sample size of 16 participants as appropriate.

Variability between measurement occasions was defined as the range of variation due to measurement error and biological variation. Limits of agreement (LoA) were used to indicate intraday and interday variability. The larger the variation of aCROM between measurement occasions, the larger the width of the LoA. The standard error of measurement (SEM) is a measure of how far apart the outcomes of repeated measurements are.[10] The LoA were based on $SEM_{agreement}$ and calculated as LoA = $\pm 1.96 \times \sqrt{2} \times SEM_{agreement}$. The $SEM_{agreement}$ was derived from generalizability analyses (G-theory) where intraday variance and interday variance were split as follows: $SEM_{agreement} = \sqrt{(\sigma^2_{intraday} + \sigma^2_{residual})}$ or $SEM_{agreement} = \sqrt{(\sigma^2_{interday} + \sigma^2_{residual})}$.[10] The LoA correspond to the smallest detectable change, in that the change in scores that can be detected beyond measurement error and/or biological variation.

To analyze systematic differences between mean scores collected during the morning, noon, and evening measurements, separate 1-way repeated-measures analyses of variance with Greenhouse-Geisser corrections were conducted after a check for assumptions (normal distribution of the dependent variable, outliers, and sphericity). The level of significance was set at $\alpha = 0.05$, and Bonferroni correction was applied for multiple comparisons.

Results

Active cervical range of motion data was normally distributed across the within-day and between-day measurements based on the Shapiro-Wilk test ($P > .05$) and by casually looking at the data. Overall mean scores and SDs for each axis are presented in Table 1.

Table 1. *Overall Mean and SD for Each Axis*

Axis	aCROM (degrees)—Mean (SD)
Flexion	58.7 (8.5)
Extension	63.4 (9.5)
Flexion-extension	122.0 (11.6)
Rotation left	75.0 (7.7)
Rotation right	69.4 (8.1)
Total rotation	144.3 (12.2)

aCROM, active cervical range of motion.

Table 2. *Intraday and Interday Variability*

Axis	Intraday Variability LoA (degrees)	Interday Variability LoA (degrees)
Flexion	±14.0	±14.2
Extension	±14.9	±16.9
Flexion-extension	±15.4	±19.0
Rotation left	±12.1	±14.2
Rotation right	±12.3	±14.2
Total rotation	±15.5	±20.1

LoA, limits of agreement.

The LoA for intraday variability ranged from ±12.1° for left rotation to ±15.5° for total rotation. For interday variability, the LoA ranged from ±14.2° for right rotation to ±20.1° for total rotation (Table 2). Mean differences were constant for the magnitude of measurement.

Changes in scores outside the LoA are identified as real changes. For example, when measuring left rotation twice within a day, a score of more than 12.1° would represent a real difference. When measuring left rotation twice within a 3-week period, a score more than 14.2° would represent a meaningful difference.

The results of the analyses of variance showed no statistically significant differences in aCROM between the morning, noon, and evening measurements, except for flexion on Day 2 (Table 3). However, the average scores of the other 6 days showed no systematic, clinically relevant differences during the day. The total rotation in the morning is consistently less than in the middle of the day, yet this does not seem to be of clinical relevance given the size of the differences (mean 2.6°).

No time effect on aCROM between the 7 measurement days was observed.

Participants did not report any changes in day-to-day activities, presence of pain, or change in medication use in

Table 3. *Mean (SD) Values of 16 Participants for All Active Cervical Range of Motion Assessments at the 3 Occasions on 7 Days*

Axis	aCROM Morning (degrees)—Mean (SD)	aCROM Noon (degrees)—Mean (SD)	aCROM Evening (degrees)—Mean (SD)	Intraday Differences (*P* Value[a])
Day 1				
Flexion	54.6 (9.5)	57.3 (9.8)	57.4 (9.8)	.13
Extension	62.5 (9.4)	63.4 (8.5)	61.9 (9.9)	.69
Flexion-extension	117.2 (12.4)	120.7 (12.3)	119.4 (13.0)	.12
Rotation left	73.8 (10.7)	75.8 (8.8)	74.6 (9.3)	.39
Rotation right	67.7 (7.4)	67.5 (7.5)	67.9 (8.3)	.95
Total rotation	141.5 (14.1)	143.3 (11.0)	142.5 (12.4)	.61
Day 2				
Flexion	54.9 (7.9)	59.4 (7.4)	58.5 (6.6)	.04[b]
Extension	64.7 (10.2)	63.6 (8.7)	64.4 (10.1)	.84
Flexion-extension	119.5 (12.0)	123.0 (12.7)	122.9 (11.7)	.14
Rotation left	73.0 (7.7)	74.9 (6.2)	75.9 (8.0)	.16
Rotation right	70.7 (8.4)	70.2 (7.9)	71.6 (6.9)	.56
Total rotation	143.6 (12.6)	145.1 (11.0)	147.5 (11.6)	.14
Day 3				
Flexion	60.0 (8.8)	59.8 (9.1)	60.3 (8.8)	.93
Extension	63.6 (9.8)	63.8 (10.6)	63.9 (9.5)	.99
Flexion-extension	123.8 (13.2)	123.6 (13.2)	124.1 (12.2)	.06
Rotation left	73.4 (7.5)	74.4 (8.4)	76.3 (8.1)	.24
Rotation right	69.7 (8.7)	69.8 (8.0)	70.6 (7.9)	.73
Total rotation	143.0 (11.9)	144.2 (11.7)	146.9 (12.6)	.09
Day 4				
Flexion	62.7 (7.5)	60.6 (6.3)	59.5 (6.2)	.15
Extension	61.6 (10.8)	62.7 (7.8)	61.3 (10.3)	.66
Flexion-extension	122.6 (10.0)	122.1 (9.9)	119.8 (12.2)	.20
Rotation left	73.3 (7.5)	76.6 (8.0)	72.7 (8.8)	.06
Rotation right	68.9 (8.1)	68.1 (8.1)	68.9 (8.9)	.68
Total rotation	142.2 (12.5)	144.7 (14.4)	141.6 (12.4)	.25

(*continued*)

Table 3. (*Continued*)

Axis	aCROM Morning (degrees)—Mean (SD)	aCROM Noon (degrees)—Mean (SD)	aCROM Evening (degrees)—Mean (SD)	Intraday Differences (*P* Value[a])
Day 5				
Flexion	58.9 (8.8)	57.9 (6.6)	57.0 (8.4)	.36
Extension	63.9 (8.4)	65.0 (9.8)	63.8 (8.8)	.79
Flexion-extension	122.9 (9.9)	122.9 (10.2)	120.8 (9.1)	.55
Rotation left	75.1 (5.6)	75.6 (7.1)	73.3 (5.9)	.16
Rotation right	67.7 (10.3)	70.4 (9.6)	68.8 (8.8)	.26
Total rotation	142.9 (12.9)	146.0 (12.6)	142.0 (11.7)	.07
Day 6				
Flexion	57.7 (9.4)	58.6 (12.4)	58.4 (10.6)	.90
Extension	64.0 (11.2)	64.6 (12.3)	62.9 (11.3)	.66
Flexion-extension	121.7 (11.2)	123.2 (13.4)	121.3 (12.0)	.51
Rotation left	75.1 (8.5)	77.7 (9.7)	76.1 (7.4)	.26
Rotation right	69.1 (9.4)	69.1 (7.5)	68.4 (8.0)	.81
Total rotation	144.2 (14.2)	146.8 (16.0)	144.5 (12.6)	.30
Day 7				
Flexion	60.6 (9.6)	60.4 (7.6)	58.9 (8.8)	.58
Extension	62.8 (9.1)	64.0 (7.8)	63.0 (8.9)	.70
Flexion-extension	123.4 (12.6)	124.5 (11.6)	121.9 (12.0)	.11
Rotation left	75.4 (6.2)	75.9 (7.0)	75.7 (6.4)	.82
Rotation right	69.2 (8.4)	71.9 (6.9)	70.3 (6.9)	.05
Total rotation	144.7 (11.2)	147.9 (10.5)	146.1 (10.4)	.05

aCROM, active cervical range of motion.
[a] Differences between the morning, noon, and evening measurements (1-way repeated-measures analysis of variance).
[b] Statistical significance at the $P < 0.05$ level.

their diaries. As a result, no additional analysis has been carried out for the possible influence of other factors on variability.

Discussion

The findings of this study have both research and clinical implications. Intraday and interday variability analyses of aCROM measurements in asymptomatic people showed substantial variation in aCROM scores. Comparing intraday and interday variability in all 6 movement directions, the LoA for interday variability appeared to be slightly larger than for intraday variability. No obvious systematic change over the day was found.

This is the first study that assessed intraday variability in aCROM measurement. One previous study found similar ranges for interday variation in flexion-extension, and slightly smaller variation for total rotation than we found.[12] Another study found slightly larger interday variation with LoA around ±16.0° for total rotation and ±26.2° for flexion-extension.[11] The results of these previous studies, however, are difficult to compare with our study because of differences in measurement devices, and associated measurement error, study population, and methods of data analysis are likely to influence the results considerably.[3,11,12]

Measurements were taken under controlled conditions, which reduces random errors.[18] Despite the use of a standardized protocol and the effort that was made to control the movement, it remains unclear to what extent the variability scores of aCROM found were the result of variation within the participants who differed in aCROM at the different measurement occasions or were the result of variability of the application used, or were caused by observer variability.[3] Given the high accuracy of the device[16] and the rigor of our assessment method, we assume, however, that most of the observed variation is attributable to true variation in aCROM in the participant.[16]

Under the influence of time, the variation of aCROM appears to be larger than the measurement error of commonly used instruments.[16,19,20] This is explicable if we consider that the measurement error is often based on measurements carried out with a relatively small time interval between repeated measurements to ensure the stability of the variable being measured. Clinicians, however, usually assess aCROM over a longer timeframe, such as when evaluating the effect of interventions, and it is therefore recommended not only to consider the measurement error but also to consider the variability of aCROM measurements when interpreting the results. Only a change larger than the LoA can be considered a real change.

To ensure the stability of range of motion measurements of the spine in practice and research, it is recommended to perform measurements at the same time of the day to reduce the influence of diurnal changes.[4,8,9] In this study, however, at group level, no clinically relevant trend was observed in decreasing or increasing aCROM during the day. Nevertheless, individuals or patients with neck complaints may become more or less mobile during the day or over time, for example, as a result of altered activity levels or varying pain intensity.

Limitations

In this study, primary planar movements were assessed. However, this does not seem to reflect the complexity of 3-dimensional cervical kinematics.[21,22] A reduction of the primary movement can be accompanied by an increase in a coupled cervical movement.[23] Moreover, small changes in the test position of the participant between the measurement occasions can increase the variation in aCROM since the anatomical reference frame changes in relation to the absolute reference frame used by the measurement instrument. It might be interesting to evaluate the amount of variability including all 3 movement components together in future research.

The highest score of 2 trials for each movement was used for the analysis. Using the highest score could potentially have resulted in an overestimation of variability. Nevertheless, in clinical practice, one can assume that there will be less standardization and fewer trained observers, implying even more variation than was presented in this study.

We arbitrarily considered the sample size as appropriate, taking into account multiple measurements per participant. However, the relatively small sample may limit the precision of the results. Further, as aCROM is also influenced by age,[24] and our sample consisted of a relatively wide age range, we cannot exclude the influence of age on the variability of aCROM.

Finally, in clinical settings, aCROM measurements mostly involve patients with neck pain. It is recommended to perform a study on aCROM variability in subgroups of patients with neck pain to gain more insight into potential intraday and interday variability in patients and the interpretation of aCROM scores found in clinical practice and research.

Conclusion

This study showed substantial intraday and interday variability of aCROM in asymptomatic people. No trend toward an increased or decreased aCROM during the course of the day was observed. These findings suggest that clinicians should take the variation in aCROM into account when interpreting changes in aCROM scores over time in their patients.

Funding Sources and Conflicts of Interest

No funding sources or conflicts of interest were reported for this study.

Contributorship Information

Concept development (provided idea for the research): M.S.S., H.t.B., B.d.L., R.d.B., G.G.S.
Design (planned the methods to generate the results): M.S.S., H.t.B., B.d.L., E.C., G.G.S.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): M.S.S., E.C., R.d.B., G.G.S.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): M.S.S., H.t.B., B.d.L., G.G.S.
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): M.S.S., E.C., R.d.B., H.d.V., G.G.S.
Literature search (performed the literature search): M.S.S., H.t.B., B.d.L.
Writing (responsible for writing a substantive part of the manuscript): M.S.S., H.t.B., R.d.B., H.d.V., G.G.S.

Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): E.C., R.d.B., H.d.V., G.G.S.
Other (list other specific novel contributions) Statistical analysis: M.S.S., H.d.V.

Practical Applications

- Cervical range of motion measurements are subject to substantial intraday and interday variability.
- No trend toward an increased or decreased active cervical range of motion was observed during the course of the day.
- Variation in cervical range of motion must be taken into account when interpreting cervical range of motion scores.

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