Repeatability of Cervical Joint Flexion and Extension Within and Between Days

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Abstract

Objective: The purpose of this study was to investigate within- and between-day repeatability of free and unrestricted healthy cervical flexion and extension motion when assessing dynamic cervical spine motion.

Methods: Fluoroscopy videos of 2 repeated cervical flexion and 2 repeated extension motions were examined for within-day repeatability (20-second interval) for 18 participants (6 females) and between-day repeatability (1-week interval) for 15 participants (6 females). The dynamic cervical motions were free and unrestricted from neutral to end range. The flexion videos and extension videos were evenly divided into 10% epochs of the C0-to-C7 range of motion. Within-day and between-day repeatability of joint motion angles (all 7 joints and epochs, respectively) was tested in a repeated-measures analysis of variance. Joint motion angle differences between repetitions were calculated for each epoch and joint (7 joints), and these joint motion angle differences between within-day and between-day repetitions were tested in mixed-model analysis of variance.

Results: For all joints and epochs, respectively, no significant differences were found in joint motion angle between within-day or between-day repetitions. There were no significant effects of joint motion angle differences between within-day and between-day repetitions. The average within-day joint motion angle differences across all joints and epochs were 0.00° ± 2.98° and 0.00° ± 3.05° for flexion and extension, respectively. The average between-day joint motion angle differences were 0.02° ± 2.56° and 0.05° ± 2.40° for flexion and extension, respectively.

Conclusions: This is the first study to report the within-day and between-day joint motion angle differences of repeated cervical flexion and extension. This study supports the idea that cervical joints repeat their motion accurately.

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Key Indexing Terms: *Spine; Cervical Vertebrae; Range of Motion, Articular; Fluoroscopy*

Introduction

Dynamic cervical joint motion is an important part of cervical biomechanics. Clinical examination of cervical joints and neck motion is an important diagnostic tool in continued diagnostic assessment of intervention and surgery.[1-5] Repeated examination of cervical motion is common in clinical practice[6-10]; however, the repeatability of dynamic cervical motion has not been investigated. Diagnosis presumes a repeatable cervical motion pattern or at least repeatable cervical joint motion. The descriptive evidence for free and unrestricted cervical motion is weak, even though biomechanical assessments of cervical joint motions are important for surgery, treatment, and ergonomics.[11-15] A better understanding of cervical joint motion may provide new methods to assess cervical dysfunctions.[13-17]

Previous normative studies of cervical joint motion have documented cervical joint motion from 3 to 5 static roentgen images,[15,18] which does not allow a detailed understanding of natural dynamic joint motion. Real-time video fluoroscopy studies with analysis of dynamic motion provide the means to a new and detailed understanding of cervical flexion and extension joint motion.[14,16,19]

Healthy cervical motion has previously been described and modeled as a "spring like" structure with continuous

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joint motion contributions.[20] In these models, cervical motor control is exerted through deep and superficial muscles, where the deep muscles contribute to stability of the cervical spine, and the superficial muscles move the head and neck.[21-23] New research suggests that a free and unrestricted cervical joint moves with irregular motion speed.[11,14,17,24] Furthermore, the maximum joint motion has previously been documented before end range; thus cervical joints with maximum motion occurring before end range move, at least in part, antidirectionally or opposite to the intended cervical motion direction from the maximum joint motion to end range.[14,25] Such movement patterns do not support the "spring-like" model, and suggest the motion patterns are more convoluted and require more joint specific muscle activity of the deep muscles compared with the "spring-like" model, as superficial muscles have little capacity for control of specific joint motion.[11,13-17]

The finding of maximum cervical joint motion before end range implies that cervical joints can move in excess of the motion measured at end range.[14] The excess motion capacity is unknown; however, the excess motion opens up the possibility of multiple motion pattern solutions, with varying joint motion contributions to end-range motion or cervical range of motion (ROM). Dynamic joint contributions can be expressed in degrees or in percentages of total cervical ROM,[11,13-15,26] and the contributions have in the past been assessed as free and unrestricted motion or as controlled motion with the head and neck controlled by a pivot arm.[14-17,26,27]

The aim of this study was to assess the within-day and between-day repeatability of free and unrestricted cervical flexion and extension joint motion. Cervical flexion and extension joint motion was hypothesized to be repeatable within day (20-second interval) and between days (1-week interval).

Methods

Participants

Thirty-six healthy participants were recruited in this study. Eighteen participants were examined for within-day repeatability, and 15 participants, for between-day repeatability. The within-day data were extracted and reanalyzed from another data set focusing on morphology of movements and not repeatability.[24] Participants were university colleagues and students (Table 1). The exclusion criteria were neck pain within the last 3 months, pain during the experiment, and possible pregnancy. Participants signed written informed consent forms. The study was executed in accordance with Declaration of Helsinki. The North Denmark Region ethics committee approved the study (N20140004).

Experimental Procedures

In the first experiment, participants conducted 2 cervical flexion motions and 2 extension motions with 20 seconds between repetitions. In the second experiment, participants engaged in 2 sessions with 1 week between sessions.

Participants were asked to sit in a chair with hips, knees, and ankles at 90° fixed by straps. The instruction was to flex/extend the head following a vertical line on wall, ceiling, and floor, and the line was used to control out-of-plane motion. A cross marked at eye height on the line assisted reposition of neutral position. Flexion or extension motions were recorded by fluoroscopy from neutral position to end range, and the motions were free and unrestricted. Participants wore a pair of glasses on which lead balls were attached via steel wires for better identification of the C0 joint. Participants were asked to hold neutral position and end range for 2 seconds. In the second repetition (20 seconds or 1 week later), participants repeated the flexion and extension. Compliance with experimental procedures was practiced several times before acquisition and timed to approximately 16 seconds.

Table 1. *Participant Characteristics*

	Within-Day Group	Between-Day Group	*P* Value
N	18 (6 women)	15 (6 women)	
Age (y)	26.5 ± 5.1	25.1 ± 4.6	.104
Height (cm)	173.9 ± 9.8	173.9 ± 12.1	.941
Weight (kg)	68.3 ± 11.5	70.4 ± 13.3	.889
Body mass index (kg/m^2)	22.4 ± 2.0	23.1 ± 2.4	.396

Except for N, values are expressed as mean ± standard deviation. *P* values are for comparisons between groups made with an unpaired *t* test.

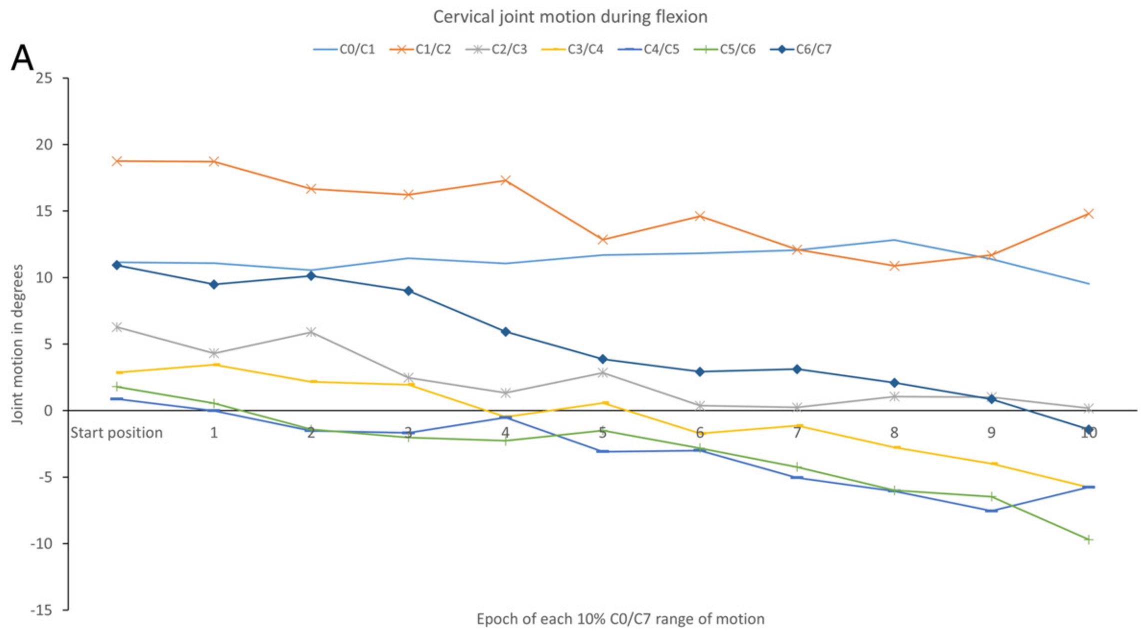
Fluoroscopic Recordings

Fluoroscopy images were acquired at 25 frames per second (BV Libra, Philips, Netherlands) with an average source-to-participant (C7 spinous process) distance of 76 cm. Average exposure of 45-kV, 208-mA, 6.0-ms x-ray pulses during complete cervical motion recordings yielded 0.48 mSv (PCXMC software, STUK, Helsinki, Finland).

Image Analysis

After video fluoroscopy acquisition of cervical flexions and extensions, the images (frames) were digitalized, clipped (Honestech VHS to DVD 3.0 SE, Honestech Inc, Austin, Texas), and stored on a computer. On a high-resolution monitor, 26 marking points (4 external points for C0 and 22 bony points) were placed manually for each image in a MATLAB-based program. The anatomical points were based on radiographic analysis.[15,16,28] The 4 external markers improved analysis of C0.

The marking points were 2 anterior and 2 posterior external markers for occiput (C0), 2 points at the centers of



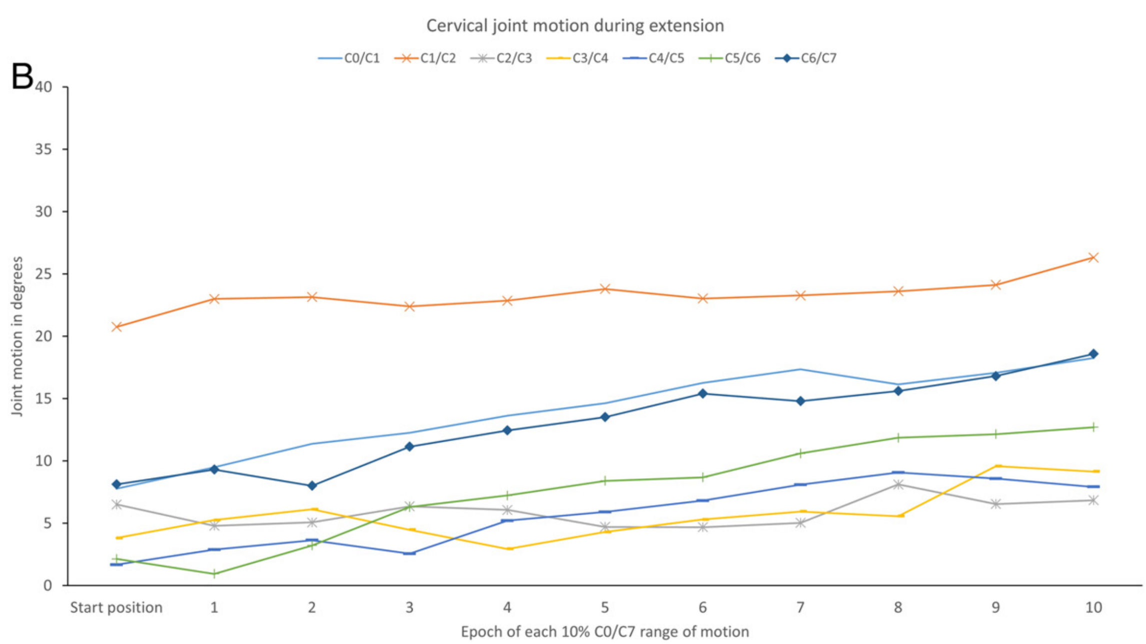


Fig 1. *Representative motion pattern of cervical flexion (A) and extension (B) for 1 participant of the between-day group. The figure's y-axis represents joint motion in degrees, and for the x-axis, 10% epochs of C0/C7 range of motion with the upright position left and accumulated change in each consecutive epoch toward the right. The upright positions are similar for flexion and extension; however, the upright positions are not identical. The maximum joint motion was not at end range in 5 of 14 joint excursions. The largest contribution was from C6/C7 with 12.4° of flexion, and the smallest contribution was from C2/C3 with 0.3° of extension.*

the medullary cavities of anterior and posterior arcs of atlas (C1), 2 inferior corners of axis (C2), 2 superior corners of the seventh vertebra (C7), and the anterior and posterior corners of the superior and inferior endplates of the third to the sixth vertebrae (C3-C6). An analysis program was developed from previous radiographic studies[12,28-30] to calculate midplane angles between 2 adjacent vertebrae defined as a line through the midpoint of the 2 anterior points and the midpoint of the 2 posterior points.[15,28] For C2 and C7, the midplanes are the lines through the 2 marking points.[28] Positive numbers indicate the joint opens anteriorly in the direction of looking forward, whereas

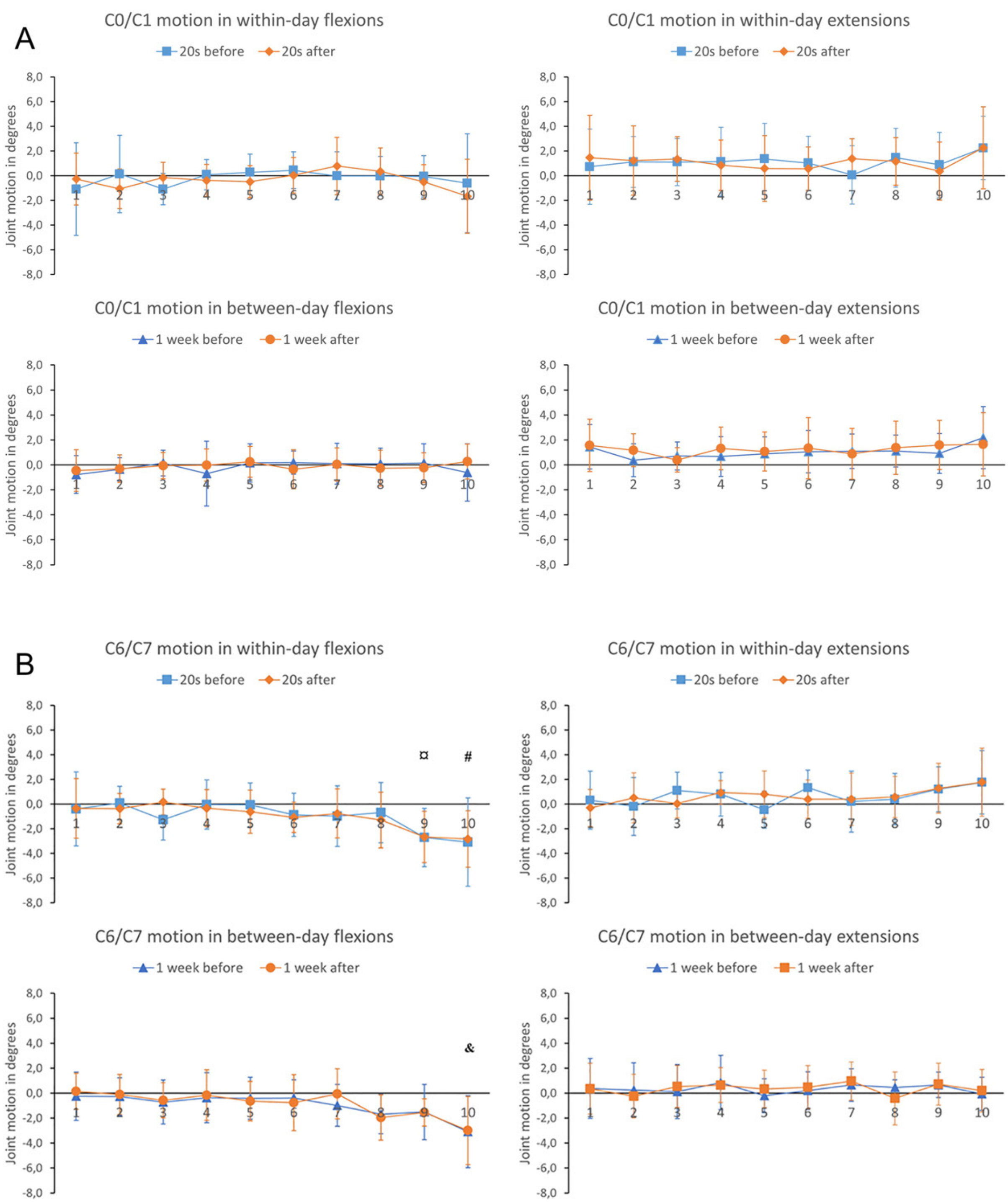


Fig 2. *Flexion and extension motions within day and between days for C0/C1 (A) and C6/C7 (B). Depicted here is the average joint motion across epochs of each repeated flexion or extension with standard deviations indicated by error bars. (The remaining joints are included in supplementary material.) The first to last epochs (1 to 10) are indicated on the horizontal axis, whereas the vertical axis indicates the joint motion in degrees. The motion within epochs was extracted as 10% of C0 to C7 range of motion. ¤, Smaller motion compared with the second and fourth epochs. #, Smaller motion compared with the second and fifth epochs. &, smaller motion compared with the first, second, and seventh epochs.*

Table 2. *Within-Day and Between-Day Joint Motion Angle Differences for Repeated Flexions and Extensions Across All Epochs and for Individual Joints*

	Within Day		Between Days	
Joint	Flexion	Extension	Flexion	Extension
C0/C1	–0.03° ± 2.95°	0.01° ± 2.68°	0.05° ± 1.76°	0.19° ± 1.87°
C1/C2	–0.15° ± 3.79°	–0.16° ± 3.79°	–0.12° ± 2.98°	0.08° ± 2.61°
C2/C3	0.01° ± 3.18°	0.05° ± 3.81°	0.08° ± 3.40°	–0.01° ± 2.78°
C3/C4	0.08° ± 2.59°	0.04° ± 2.76°	0.03° ± 2.52°	0.08° ± 2.09°
C4/C5	0.05° ± 2.93°	0.08° ± 2.95°	–0.13° ± 2.20°	–0.02° ± 2.55°
C5/C6	0.04° ± 2.53°	–0.05° ± 2.65°	0.09° ± 2.38°	0.01° ± 2.45°
C6/C7	0.00° ± 2.93°	–0.01° ± 2.42°	0.10° ± 2.38°	0.03° ± 2.35°
Average	0.00° ± 2.98°	0.00° ± 3.05°	0.01° ± 2.56°	0.05° ± 2.40°

Values are expressed as mean ± standard deviation.

negative numbers indicate the joint opens posteriorly in the opposite direction as positive numbers.

The intra-investigator measurement error was assessed by investigator X.W., who marked 5 images 3 times to test intrarater reliability (upright, mid-range flexion and mid-range extension, end-range flexion and end-range extension).

Analysis of Repeatability

Videos were divided into 10 epochs,[16] and each epoch was 10% of C0/C7 ROM from neutral to end-range positions. When no video image was found at the precise 10% division of C0/C7 ROM, the 10% division was found by linear interpolation of 2 images on either side of the precise 10% C0/C7 ROM. Thus, 9 interpolated flexion or extension images, 1 image of upright position, and 1 image of end-range position were analyzed for joint motion in degrees of the 7 joints between C0 and C7. For each joint, the analysis yielded 10 joint motion angles for flexion or extension by subtractions between 2 adjacent images (first 10% image minus upright and so forth). Positive numbers in a specific epoch indicate the joint moves in the same direction with intended direction (pro-directional joint motion); conversely, negative numbers indicate the joint moves in the direction opposed to the intended direction (anti-directional joint motion).[25]

Repeatability differences were derived by subtractions of joint motion angle in corresponding epochs and joint between 2 repeated flexions or extensions; thus, each repeated within-day or between-day flexion or extension yielded 10 joint motion angle differences for each joint.

Statistical Analysis

Data were tested for normality with the Shapiro-Wilk test and a QQ plot. Data are expressed as the mean and standard deviation (SD). Differences in age and body mass index between within-day and between-day groups were tested with unpaired *t* tests. The joint motion angles for the first and second repetitions were assessed with 2-way repeated measures (RM) analysis of variance (ANOVA), with epoch (10) and repetition (1st, 2nd) as within-participant factors, followed by a Tukey post hoc test for pairwise comparisons. The joint motion angle differences over time of repeated flexions or extensions were compared with a mixed-model ANOVA with epoch as within-participant factor and time (20-second interval, 1-week interval) and joint as between-participant factors. Sphericity was tested with Mauchly's test, and the Greenhouse-Geisser correction was applied if violated. Effect size was indicated by partial eta squared (η^2_p). Intra-investigator measurement errors were analyzed with the intraclass correlation coefficient (ICC 3, 1). The level of significance was set at $P < .05$. Statistical analysis was performed in SPSS (Version 22) (IBM, Armonk, New York).

Results

Eighteen participants were included in the within-day analysis; 2 participants were excluded from the analysis, as their shoulder shadows concealed C5/C6 and C6/C7. The between-day analysis included 15 participants; 1 participant was excluded from the between-day analysis as C0 was concealed. All data sets were normally distributed (Shapiro-Wilk test: $P > .05$).

The intra-investigator measurement error was normally distributed. Measurement errors are expressed as means ± SD and ICC for (1) neutral, 0.18° ± 0.57° and 0.996; (2) midrange flexion, 0.32° ± 1.23° and 0.968; (3) midrange extension, 0.21° ± 1.08° and 0.974; (4) end-range flexion, 0.03° ± 0.91° and 0.985; and (5) end-range extension, 0.02° ± 0.85° and 0.992.

Cervical Motion Pattern

The results did not indicate a uniform cervical motion pattern across participant (Fig 1). The figure depicts cervical joint motion with intermittent pro-directional and anti-directional motions.[25] Five of 14 joint excursions reached maximum joint motion excursions before end range; the maximum joint motions were reached in the eighth and ninth epochs (Fig 1).

Within-Day Repeatability

No significant differences were found in joint motion angles for individual joints for cervical flexions or extensions when repeated at 20-second intervals and tested in a RM-ANOVA (Supplementary Table S3, online only, available at https://doi.org/10.1016/j.jmpt.2017.08.005). However, for flexion, there were main effects of epochs for C1/C2 and C6/C7, but no interaction effects on these 2 joints. For C1/C2, the post hoc analysis indicated larger motions in the 10th epoch compared with the second and seventh epochs in flexion (Fig 2A; Tukey: $P < .04$), C6/C7 showed smaller motions in the ninth epoch compared with the second and fourth epochs (Fig 2B; Tukey: $P < .04$) and smaller motions in the 10th epoch in comparison with the second to fifth epochs during flexion (Tukey: $P < .03$).

Between-Day Repeatability

Between-day repeated flexions and extensions exhibited no significant differences in joint motion angles for individual joints in the RM-ANOVA (Supplementary Table S4, online only, available at https://doi.org/10.1016/j.jmpt.2017.08.005). For between-day repeated flexions, significant main epoch effects were found for C6/C7 (Supplementary Table S4). Post hoc analysis revealed smaller motions in the 10th epoch compared with the first, second, and seventh epochs during flexion (Fig 2B Tukey: $P < .04$). Figures for joint motion in cervical flexion and extension repetitions for other segments can be found in the Supplementary Figures S1 through S5 (online only, available at https://doi.org/10.1016/j.jmpt.2017.08.005).

Joint Motion Angle Differences When Repeated Within or Between Days

The joint motion angle differences between the repeated flexions or extensions were normally distributed (Shapiro-Wilk test: $P > .05$). When reassessed with a 20-second interval, the average joint motion angle differences across all joints and epochs were 0.00° ± 2.98° and 0.00° ± 3.05° for flexion and extension, respectively. Likewise, the average joint motion angle difference when reassessed with a 1-week interval were 0.02° ± 2.56° and 0.05° ± 2.40° for flexion and extension, respectively. The within-day and between-day joint motion angle differences for each joint are summarized in Table 2.

No significant differences were found between within-day and between-day joint motion angle differences when compared with a mixed-model ANOVA. There were no main effects of epoch ($F = 0.00$, $P = .99$, $\eta^2_p < 0.001$), joint ($F = 1.27$, $P = .27$, $\eta^2_p = 0.04$), time ($F = 0.12$, $P = .73$, $\eta^2_p = .001$), or epoch × joint ($F = 1.04$, $P = .41$, $\eta^2_p = 0.03$) or epoch × joint × time ($F = 1.22$, $P = .17$, $\eta^2_p = 0.04$) interactions.

Discussion

Unrestricted cervical flexion and extension motion repeated within day and between days revealed small average differences between –0.16° and 0.19° for joint levels. The average differences across joints and epochs between repeated flexion and extension motions were between 0.00° and 0.05°. In contrast, the within-participant variation was larger, as reflected in the SD ranging from 1.76° to 3.79°; however, no significant differences were found between repeated joint motions or repeated flexion and extensions motions.

Repeatability of Cervical Motions

The small average differences between unrestricted repeated flexions or extensions were normally distributed, and the differences contained the natural variation of cervical motions in addition to methodological errors, both of which were normally distributed. The standard deviation of marking errors ranged from 0.57° to 1.23°, whereas standard deviations between repetitions ranged between 1.76° and 3.81°. The differences between methodological and normal variability suggest that the normal variations were considerably larger than the methodological variations.

The between-day average repetition difference for neck motion was 0.02° larger for flexion and 0.05° larger for extension compared with the within-day average difference; however, the SD is approximately 0.5° smaller than the within-day difference. These results suggest that the normal variations of cervical motion are comparable when repeated with 20-second and 1-week intervals.

The large variation in joint ROM poses a problem when applying these results in diagnosis. Interestingly, Figure 2 depicts SDs of similar size regardless of the magnitude of the joint ROM. This indicates that the normal variation is not dependent on the size of the motion excursions. The normal variations of the applied movements appear, to some extent, to be of equal size regardless of the resultant joint motions. This finding decreases the scientific value of small joint ROM results, as the normal variation is so large that small results are diluted.

The results confirmed the hypothesis that cervical flexion and extension joint motions were repeatable within day and between days. The hypothesis was confirmed with some constraint of variance and a between-day interval of 1 week. Additional studies are required to investigate between-day repetitions over longer time frames. The differences between the repeated measures within day and between days were of similar magnitude; thus, the results suggest that time does not influence the cervical motion pattern.

Clinical Implications

To the best of our knowledge, this is the first study to support the clinical assumption that healthy cervical joint motion repeats in similar motion patterns, which include anti-directional cervical joint motions. The results indicate large within-participant variations compared with the resultant joint motions, especially if the resultant joint ROMs are small. However, when the variance in joint motion is viewed in context of the resultant neck motion, the variance within joint motion becomes small and of little diagnostic consequence. The finding of repeated cervical motion after 1 week is important for diagnosis and clinical practice; however, new studies of repeated cervical motion in patients with neck disorders are warranted to evaluate if the large variation in cervical joint motion is altered in pain conditions.

Motion Control and Function of the Deep Cervical Muscles

The study results suggest a repetitive cervical motor control strategy with intermittent pro-directional and anti-directional joint motion. The pro-directional and anti-directional motions may be interconnected to track a predefined motor control strategy by overshooting with pro-directional motions and undershooting with anti-directional motions, and vice versa.

The repeated motor control strategy may in future studies underline the importance of the deep cervical muscles, as these muscles are the only muscles that can control the motions of individual intervertebral joints.[21-23] The muscle activity of deep cervical muscles is reduced by neck pain; however, it is unknown if neck pain alters cervical joint motion patterns.[31-33]

Limitations

Measurement errors were the largest source of errors; however, the measurement errors were normally distributed, and the measurement errors appear to confound joint motion without altering the group average. Out-of-sagittal-plane motion influences the results; however, in this study participants were asked to follow a line to reduce out-of-plane motions. Free and unrestricted neck movements were investigated in this study; the strapping of shoulders, elbows, and hips may, however, confound free and unrestricted motion. Finally, this study only recruited a sample of university students and colleagues without neck pain within the last 3 months, and the study may not represent all age groups of healthy participants. Future studies are required to investigate cervical joint motion differences between sexes, ages, postures, and occupations.

Conclusions

This is the first study to investigate repeatability of cervical flexion and extension joint motion. The study indicates that the cervical flexion and extension joint motions were repeatable and provides background for further clinical and experimental investigation of the cervical motion pattern.

Practical Applications

- Cervical flexion and extension joint motion repeated within day and between days show a small average difference between –0.16° and 0.19°.
- Cervical spine repeats its motion accurately but with a variation in SD of 1.76° to 3.79°.
- Repeatability of cervical flexion and extension motion provides background for further clinical and experimental investigation of the cervical motion pattern.

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Funding Sources and Conflicts of Interest

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Contributorship Information

Concept development (provided idea for the research): X.W., R.L., T.G.-N., M.P., L.R.Ø.
Design (planned the methods to generate the results): X.W., R.L., T.G.-N., M.P., L.R.Ø.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): T.G.-N.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): X.W., R.L., T.G.-N.
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): X.W., R.L., T.G.-N., M.P., L.R.Ø.
Literature search (performed the literature search): X.W.
Writing (responsible for writing a substantive part of the manuscript): X.W., R.L.
Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): R.L., T.G.-N., M.P., L.R.Ø.

Appendix A. Supplementary Data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jmpt.2017.08.005.

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