Repeatability of Cervical Joint Flexion and Extension Within and Between Days

Wang, Xu; Lindstroem, René; Plocharski, Maciej; Østergaard, Lasse Riis; Graven-Nielsen, Thomas

Published in:
Journal of Manipulative and Physiological Therapeutics

DOI (link to publication from Publisher):
10.1016/j.jmpt.2017.08.005

Publication date:
2018

Document Version
Accepted author manuscript, peer reviewed version

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Original paper for: Journal of Manipulative and Physiological Therapeutics (JMPT)

Running head: Cervical spine flexion and extension motion repeatability

Key Indexing Terms: Cervical spine, Motion pattern, Neck, Motion repeatability, Video-fluoroscopy

Disclosures: No conflicts of interest declared.

ABSTRACT

Objective: Investigation of within and between-day repeatability of free and unrestricted healthy cervical flexion and extension motion when assessing cervical spine motion.

Methods: Fluoroscopy videos of two repeated cervical flexion and two extension motions were examined for within-day repeatability (20 s interval) for eighteen subjects (6 females) and between-day repeatability (1 week interval) in another group of fifteen subjects (6 females). The 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 (ROM). Within-day and between-day repeatability of joint motion angles (all 7 joints and epochs, respectively) was tested in a repeated-measure ANOVA. Joint motion angle differences between repetitions were calculated for each epoch and joint (7 joints) and these joint motion angle differences within-day and between-day repetitions were tested in mixed-model ANOVA.

Results: For all joints and epochs, respectively, no significant differences were found in joint motion angle 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 demonstrate 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.

Key Indexing Terms: Cervical spine, Motion pattern, Neck, Motion repeatability, Video-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 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 anti-directionally or opposite to the intended cervical motion direction from the maximum joint motion to end-range. [14] Such movement pattern 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 joint can move in excess of the motion measure 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, [11,13-15,25] 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. [14-17,25,26]

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 s interval) and between-day (1 week interval).

Methods

Subjects

Thirty-six healthy subjects were included in this study. Eighteen subjects were examined for within-day repeatability and fifteen subjects for between-day repeatability. The within-day data was extracted and re-analyzed from another data set focusing on morphology of movements and not repeatability. [24] Subjects were university colleagues and students (Table 1). The exclusion criteria were: Neck pain within the last 3 months, pain during the experiment or possible pregnancy. Subjects signed written informed consent. The study was executed in accordance with Declaration of Helsinki. The local research ethics committee approved the study (N20140004).

Experimental procedures

In the first experiment subjects conducted two cervical flexion motions and two extension motions with 20 s between repetitions. In the second experiment subjects participated in 2 sessions with 1 week between sessions.

Subjects 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. Subjects wore glasses where lead balls were mounted for better identification of the C0 joint. Subjects were asked to hold neutral position and end-range for 2 seconds. In the second repetition (20 s or 1 week later) subjects repeated the flexion and extension. Compliance to experimental procedures were practiced several times before acquisition and timed to approximately 16 s.

Fluoroscopic recordings

Fluoroscopy images were acquired at 25 frames per second (Philips BV Libra, 2006, Netherland) with average source-to-subject (C7 spinous process) distance of 76 cm. Average exposure of 45 KV, 208 mA, 6.0 ms X-ray pulses during the whole 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) 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.

[15,16,27] The 4 external markers improved analysis of C0, they were lead balls attached to glasses with steel wires.

The marking points were 2 anterior and 2 posterior external markers for occiput (C0), two points at the centers of the medullary cavities of anterior and posterior arcs of atlas (C1), two inferior corners of axis (C2), two 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 vertebra (C3-C6). An analysis program was developed from previous radiographic studies [12,27-29] 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. [15,27] For C2 and C7, the midplanes are the lines through the 2 marking points. [27] Positive numbers indicate the joint opens anteriorly in the direction of looking forward, whereas negative numbers indicate the joint opens posteriorly in the opposite direction as positive numbers.

The intra-investigator measurement error was assessed by investigator XW marking five images three times to test intra-rater reliability (upright, mid-range flexion and extension, end-range flexion and 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 two images on either side of the precise 10% C0/C7 ROM. Thus, nine interpolated flexion or extension images, one image of upright position and one image of end-range position were analyzed for joint motion in degrees of the 7 joints between C0 to C7. For each joint the analysis yielded 10 joint motion angles for flexion or extension by subtractions between two 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 show the joint moves in the direction opposed with the intended direction (anti-directional joint motion).

Repeatability differences were derived by subtractions of joint motion angle in corresponding epochs and joint between two 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 was tested for normality with Shapiro-Wilk test and a QQ plot. Data was presented as mean and standard deviation (SD). Difference of age and BMI between within-day and between-day groups was tested with unpaired t-tests. The joint motion angles for the first and second repetition were assessed with two-way repeated measure (RM) analysis of variance (ANOVA) with within-subject factors as epoch (10) and repetition (1^{st}, 2^{nd}), followed by Tukey post-hoc test for pair-wise comparisons. The joint motion angle differences over time of repeated flexions or extensions were compared with a mixed-model ANOVA with epoch as within-subject factor and with time (20-interval, 1 week interval) and joint as between-subject factors. Sphericity was tested with Mauchly's test and the Greenhouse-Geisser and correction was applied if violated. Effect size was indicated by Partial Eta Squared (η^2_p). Intra-investigator measurement errors were analyzed with intra-class correlation coefficient (ICC 3, 1). Significant level was set at $P<0.05$. Statistical analysis was performed in SPSS (version 22, IBM).

Results

Eighteen subjects were included in the within-day analysis, two subjects were excluded from the analysis, as their shoulder shadows concealed C5/C6 and C6/C7. The between-day analysis included fifteen subjects and one subject was excluded from the between-day analysis as C0 was concealed. All data sets were normally distributed (Shapiro-Wilk test: $P > 0.05$).

The intra-investigator measurement error was normally distributed. The measurement errors are presented as mean ± SD and ICC for 1) neutral, 0.18° ± 0.57° and 0.996; 2) mid-range flexion, 0.32° ± 1.23° and 0.968; 3) mid-range 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 subjects (Fig. 1). The figure shows cervical joint motion with intermittent pro-directional and anti-directional motions. Five out of fourteen joint excursions reached maximum joint motion excursions before end-range, the maximum joint motions were reached in the 8^{th} and 9^{th} epochs (Fig. 1).

Within-day repeatability

There were no significant differences found in joint motion angles for individual joints for cervical flexions or extensions when repeated with 20 s and tested in RM-ANOVA (Supplementary Table 3). However, for flexion there were main effects of epochs for C1/C2 and C6/C7 but no interaction effects on these two joints. For C1/C2, the post-hoc analysis indicated larger motions in the 10^{th} epoch compared with epochs from the 2^{nd} and 7^{th} in flexion (Fig. 2A; Tukey: $P<0.04$), C6/C7 showed smaller motions in 9^{th} epoch compared to epochs of the 2^{nd} and 4^{th} (Fig. 2B; Tukey: $P<0.04$) and smaller motions in 10^{th} epoch in comparison with epochs from 2^{nd} to 5^{th} during flexion (Tukey: $P<0.03$)

Between-day repeatability

Between-day repeated flexions and extensions showed no significant differences in joint motion angles for individual joints in RM-ANOVA (Supplementary Table 4). For between-day repeated flexions, there were significant main epoch effects found for C6/C7 (Supplementary Table 4). Post-hoc analysis showed smaller motions in the 10^{th} epoch compared to the epochs of 1^{st}, 2^{nd} and 7^{th} during flexion (Fig. 2B Tukey: P< 0.04).

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 > 0.05). When reassessed with 20 s 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 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 presented 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 = 1.00, $\eta^2_p < 0.001$), joint (F = 1.27, P = 0.27, $\eta^2_p = 0.04$), time (F = 0.12, P = 0.73, $\eta^2_p = 0.001$), interaction for epoch and joint (F = 1.04, P = 0.41, $\eta^2_p = 0.03$), or for epoch & joint & time (F = 1.22, P = 0.17, $\eta^2_p = 0.04$).

Discussions

Unrestricted cervical flexion and extension motion repeated within and between-day and demonstrated small average differences between -0.16° to 0.19° for joint levels. The average differences across joints and epochs between repeated flexion and extension motion were between 0.00° to 0.05°. In contrast, the within subject 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°, while 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 approximate 0.5° smaller than the within-day difference. These results suggest that the normal variations of cervical motion are comparable when repeated within 20 s and 1 week.

The large variation in joint ROM poses a problem when applying these results in diagnosis. Interestingly, figure 2 demonstrated 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-day. The hypothesis was confirmed with some constraint of variance and a between-day of 1 week. Additional studies are required to investigate between-day repetitions over longer timeframes. The differences between the repeated measures within-day and between-day were of similar magnitude, thus the results suggest that time does not influence the cervical motion pattern.

Clinical implications

This study is the first study to support of the clinical assumption that healthy cervical joint motion repeats in similar motion patterns, which includes anti-directional cervical joint motions. The results indicate large within subject variations when compared to 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, in order to evaluate if the large biologic variations or 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 in an attempt 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, which can control the motions of individual intervertebral joints. [21-23] The activity of deep cervical muscles reduced by neck pain is interesting; however, it is unknown if neck pain alters the cervical joint motion patterns. [30-32]

Limitations Subsection

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 subjects were asked to follow a line in order 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 subjects from university students and colleagues without neck pain within the last 3 months and the study may not represent all age groups of healthy subjects. Future studies are required to investigate cervical joint motion differences between sex, age, postures and occupations.

Conclusion

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

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TABLES

Table 1. Participant characteristics

	Within-day group	Between-day group	*P* -value
N	18 (6 women)	15 (6 women)	
Age (years)	26.5 ± 5.1	25.1 ± 4.6	0.104
Height (cm)	173.9 ± 9.8	173.9 ± 12.1	0.941
Weight (kg)	68.3 ± 11.5	70.4 ± 13.3	0.889
BMI (kg/m^2)	22.4 ± 2.0	23.1 ± 2.4	0.396

Number of participants and mean characteristics (± standard deviation). BMI: body mass index. P-value is comparisons between groups with unpaired t test.

Table 2. Mean (±SD) within-day and between-day joint motion angle differences in degrees for repeated flexions and extensions across all epochs and for individual joints.

Joints	Within day		Between days	
	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°

Figure Legends

Figure 1

Shows a representative motion pattern of cervical flexion (**Figure 1A**) and extension (**Figure 1B**) from one subject of the between-day group. The figure's Y-axis shows joint motion in degrees. The X-axis shows 10% epochs of C0/C7 ROM with the upright position left and accumulated change in each consecutive epoch towards 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 out of 14 joint excursions. The largest contribution was from C6/C7 with 12.4° of flexion, and smallest contribution was from C2/C3 with 0.3° of extension.

Figure 2.

Show flexion and extension motions within-day and between- day for C0/C1 (Figure 2A) and C6/C7 (Figure 2B). The figure shows the average joint motion across epochs of each repeated flexion or extension with SD indicated by error bars joint motion angle (The remaining joints are included in Supplementary materials). The first to the last epochs (1 to 10) are shown on the horizontal axis, while the vertical axis indicates the joint motion in degrees. The motion within epochs was extracted as 10% of C0 to C7 ROM. ¤ indicates smaller motion compared with the 2^{nd} and 4^{th} epochs. # indicates smaller motion compared with the 2^{nd} and 5^{th} epochs. Ω indicates smaller motion compared with the 1^{st}, 2^{nd} and 7^{th} epochs.

Supplementary materials

Tables

Table 3. RM-ANOVA results of the within-day repeated flexions or extensions motions on individual joint levels.

Joints	Effects	Flexion	Extension
C0/C1	Time	F (1.00,17.00)= 0.16, P= 0.69, η^2_p= 0.01	F (1.00,17.00)= 0.01, P= 0.92, η^2_p= 0.001
	Epoch	F (3.60, 54.02)=1.59, P=0.20, η^2_p= 0.10	F (3.91, 62.53)=0.85, P=0.50, η^2_p= 0.05
	Interaction	F (3.26, 48.84)=1.80, P=0.16, η^2_p= 0.11	F (5.39, 86.17)=0.86, P=0.52, η^2_p= 0.05
C1/C2	Time	F (1.00,17.00)= 1.18, P= 0.37, η^2_p= 0.06	F (1.00,17.00)= 1.64, P= 0.22, η^2_p= 0.09
	Epoch	F (3.71, 55.63)=4.38, P<0.001*, η^2_p= 0.23	F (5.75, 92.02)=1.31, P=0.26, η^2_p= 0.08
	Interaction	F (3.81, 57.17)=1.52, P=0.51, η^2_p= 0.09	F (4.15, 66.39)=0.75, P=0.56, η^2_p= 0.05
C2/C3	Time	F (1.00,17.00)= 0.01, P= 0.95, η^2_p< 0.01	F (1.00,17.00)= 0.43, P= 0.52, η^2_p= 0.03
	Epoch	F (4.02, 60.27)=1.05, P=0.39, η^2_p= 0.07	F (5.36, 85.69)=0.81, P=0.56, η^2_p= 0.05
	Interaction	F (5.12, 76.82)=0.78, P=0.57, η^2_p= 0.05	F (3.63, 58.08)=0.93, P=0.45, η^2_p= 0.06
C3/C4	Time	F (1.00,17.00)= 1.58, P= 0.23, η^2_p= 0.10	F (1.00,17.00)= 0.28, P= 0.60, η^2_p= 0.02
	Epoch	F (5.54, 83.02)=2.20, P=0.06, η^2_p= 0.13	F (4.92, 78.79)=0.60, P=0.70, η^2_p= 0.04
	Interaction	F (4.67, 70.08)=0.49, P=0.77, η^2_p= 0.03	F (4.27, 68.30)=1.11, P=0.36, η^2_p= 0.07
C4/C5	Time	F (1.00,17.00)= 0.24, P= 0.63, η^2_p= 0.02	F (1.00,17.00)= 0.99, P= 0.34, η^2_p= 0.06
	Epoch	F (5.89, 88.39)=0.76, P=0.60, η^2_p= 0.05	F (3.85, 61.66)=1.44, P=0.23, η^2_p= 0.08
	Interaction	F (4.24, 63.58)=0.40, P=0.82, η^2_p= 0.03	F (4.34, 69.49)=0.22, P=0.94, η^2_p= 0.01
C5/C6	Time	F (1.00,17.00)= 0.16, P= 0.69, η^2_p= 0.01	F (1.00,17.00)= 0.32, P= 0.58, η^2_p= 0.02
	Epoch	F (5.53, 82.88)=1.35, P=0.28, η^2_p= 0.09	F (4.86, 77.78)=1.27, P=0.29, η^2_p= 0.07
	Interaction	F (4.88, 73.27)=1.10, P=0.37, η^2_p= 0.07	F (5.39, 86.21)=1.23, P=0.30, η^2_p= 0.07
C6/C7	Time	F (1.00,17.00)= 0.01, P= 0.94, η^2_p< 0.01	F (1.00,17.00)= 0.01, P= 0.92, η^2_p= 0.001
	Epoch	F (5.38, 80.63)=6.33, P<0.001*, η^2_p= 0.30	F (5.23, 83.60)=2.21, P=0.06, η^2_p= 0.12
	Interaction	F (5.32, 79.85)=0.69, P=0.64, η^2_p= 0.04	F (4.96, 79.34)=1.37, P=0.25, η^2_p= 0.08

RM-ANOVAs were applied to compare within-day joint motion angles for the two repetitions. Within-subject factors were time (first repetition and second repetition with 20 seconds interval) and epochs (10% C0/C7 ROM of cervical flexion or extension). F indicates the F value of ANOVA. η^2_p indicates partial eta squared effect size. * indicates P value < 0.05.

Table 4. RM-ANOVA results of the between-day repeated flexions or extensions motions on individual joint levels.

Joints	Effects	Flexion	Extension
C0/C1	Time	F (1.00,14.00)= 0.54, P= 0.47, η^2_p= 0.04	F (1.00,14.00)= 4.00, P= 0.06, η^2_p= 0.21
	Epoch	F (3.05, 45.73)=0.66, P=0.59, η^2_p= 0.04	F (4.12, 61.76)=0.74, P=0.57, η^2_p= 0.05
	Interaction	F (4.63, 69.48)=1.02, P=0.41, η^2_p= 0.06	F (5.23, 78.38)=0.51, P=0.78, η^2_p= 0.03
C1/C2	Time	F (1.00,14.00)= 1.74, P= 0.21, η^2_p= 0.10	F (1.00,14.00)= 0.60, P= 0.45, η^2_p= 0.04
	Epoch	F (3.61, 54.09)=1.81, P=0.15, η^2_p= 0.11	F (4.42, 66.36)=1.23, P=0.31, η^2_p= 0.08
	Interaction	F (4.67, 70.10)=1.81, P=0.13, η^2_p= 0.11	F (4.68, 70.25)=2.15, P=0.07, η^2_p= 0.13
C2/C3	Time	F (1.00,14.00)= 0.44, P= 0.52, η^2_p= 0.03	F (1.00,14.00)= 0.03, P= 0.86, η^2_p= 0.002
	Epoch	F (5.05, 75.80)=2.12, P=0.07, η^2_p= 0.12	F (4.72, 70.85)=1.31, P=0.27, η^2_p= 0.08
	Interaction	F (4.64, 69.52)=0.64, P=0.66, η^2_p= 0.04	F (5.05, 75.70)=1.15, P=0.34, η^2_p= 0.07
C3/C4	Time	F (1.00,14.00)= 0.05, P= 0.83, η^2_p= 0.003	F (1.00,14.00)= 0.71, P= 0.41, η^2_p= 0.05
	Epoch	F (4.82, 72.27)=0.71, P=0.61, η^2_p= 0.05	F (4.92, 73.86)=1.22, P=0.31, η^2_p= 0.08
	Interaction	F (4.87, 73.10)=1.29, P=0.28, η^2_p= 0.08	F (5.20, 78.02)=0.27, P=0.94, η^2_p= 0.02
C4/C5	Time	F (1.00,14.00)= 3.54, P= 0.08, η^2_p= 0.19	F (1.00,14.00)= 0.19, P= 0.67, η^2_p= 0.01
	Epoch	F (4.47, 66.99)=2.01, P=0.10, η^2_p= 0.12	F (4.95, 74.27)=2.31, P=0.053, η^2_p= 0.13
	Interaction	F (4.07, 61.01)=0.56, P=0.70, η^2_p= 0.04	F (4.59, 68.88)=0.15, P=0.97, η^2_p= 0.01
C5/C6	Time	F (1.00,14.00)= 1.27, P= 0.28, η^2_p= 0.08	F (1.00,14.00)= 0.002, P= 0.97, η^2_p< 0.001
	Epoch	F (5.32, 79.80)=1.12, P=0.36, η^2_p= 0.07	F (4.88, 73.15)=1.48, P=0.21, η^2_p= 0.09
	Interaction	F (4.90, 73.43)=0.74, P=0.59, η^2_p= 0.05	F (3.98, 59.63)=1.37, P=0.26, η^2_p= 0.08
C6/C7	Time	F (1.00,14.00)= 0.91, P= 0.36, η^2_p= 0.06	F (1.00,14.00)= 0.11, P= 0.75, η^2_p= 0.007
	Epoch	F (5.12, 76.85)=6.61, P<0.001*, η^2_p= 0.31	F (4.90, 73.49)=0.96, P=0.45, η^2_p= 0.06
	Interaction	F (4.77, 71.55)=0.29, P=0.91, η^2_p= 0.02	F (4.51, 67.62)=0.53, P=0.73, η^2_p= 0.03

RM-ANOVA (repeated measured analysis of variance) was performed to compare joint motion angles with within-subject factors as time (first repetition and second repetition with 1 week interval) and epochs (10% C0/C7 ROM of cervical flexion or extension). F indicates the F value of ANOVA. η^2_p indicates partial eta squared effect size. * indicates P value < 0.05.

Figure Legends

Figure 3 C1/C2 joint motion in cervical flexion and extension repetitions

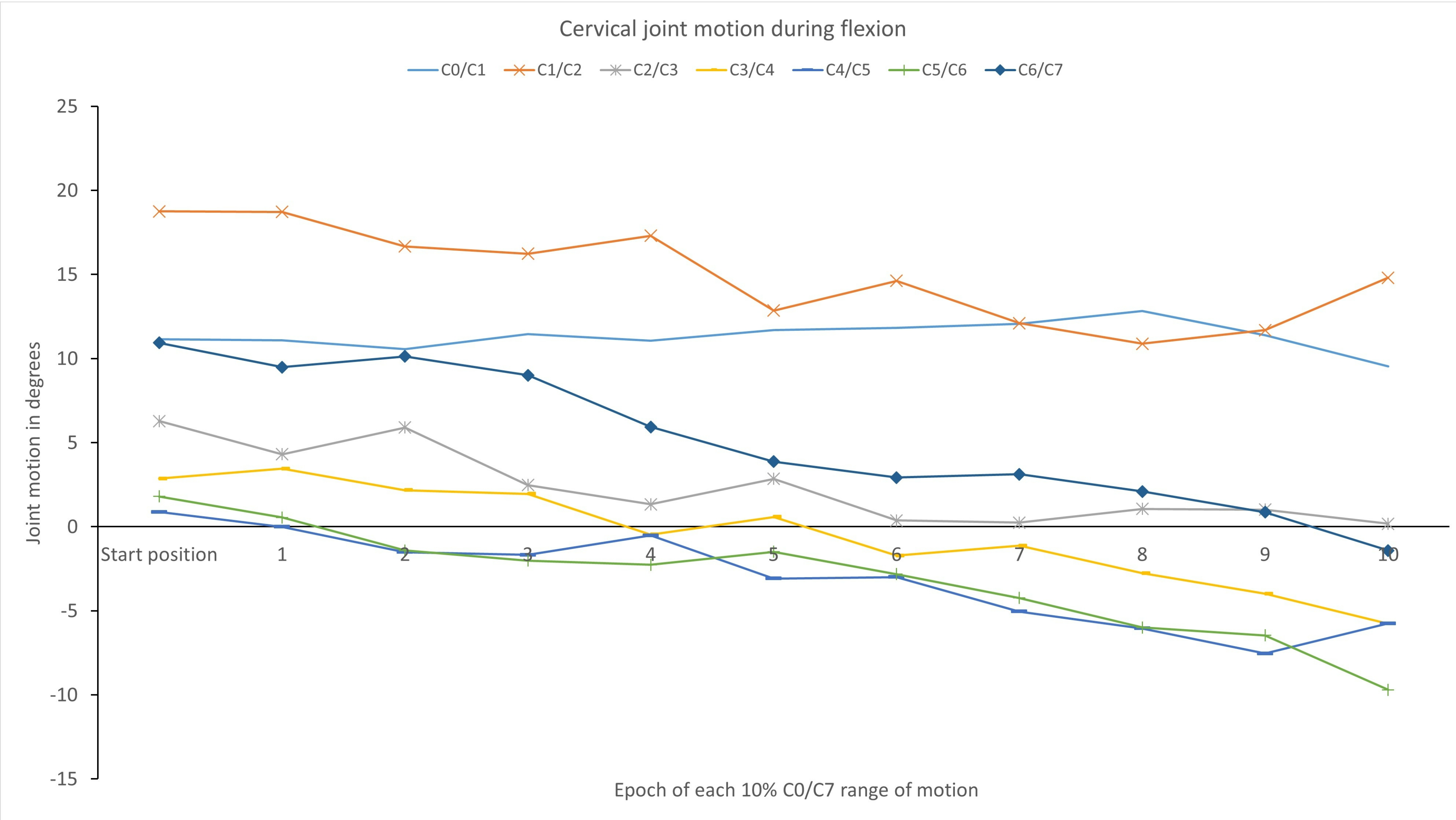
* indicates larger motion compared to the 2^{nd} and 7^{th} epochs

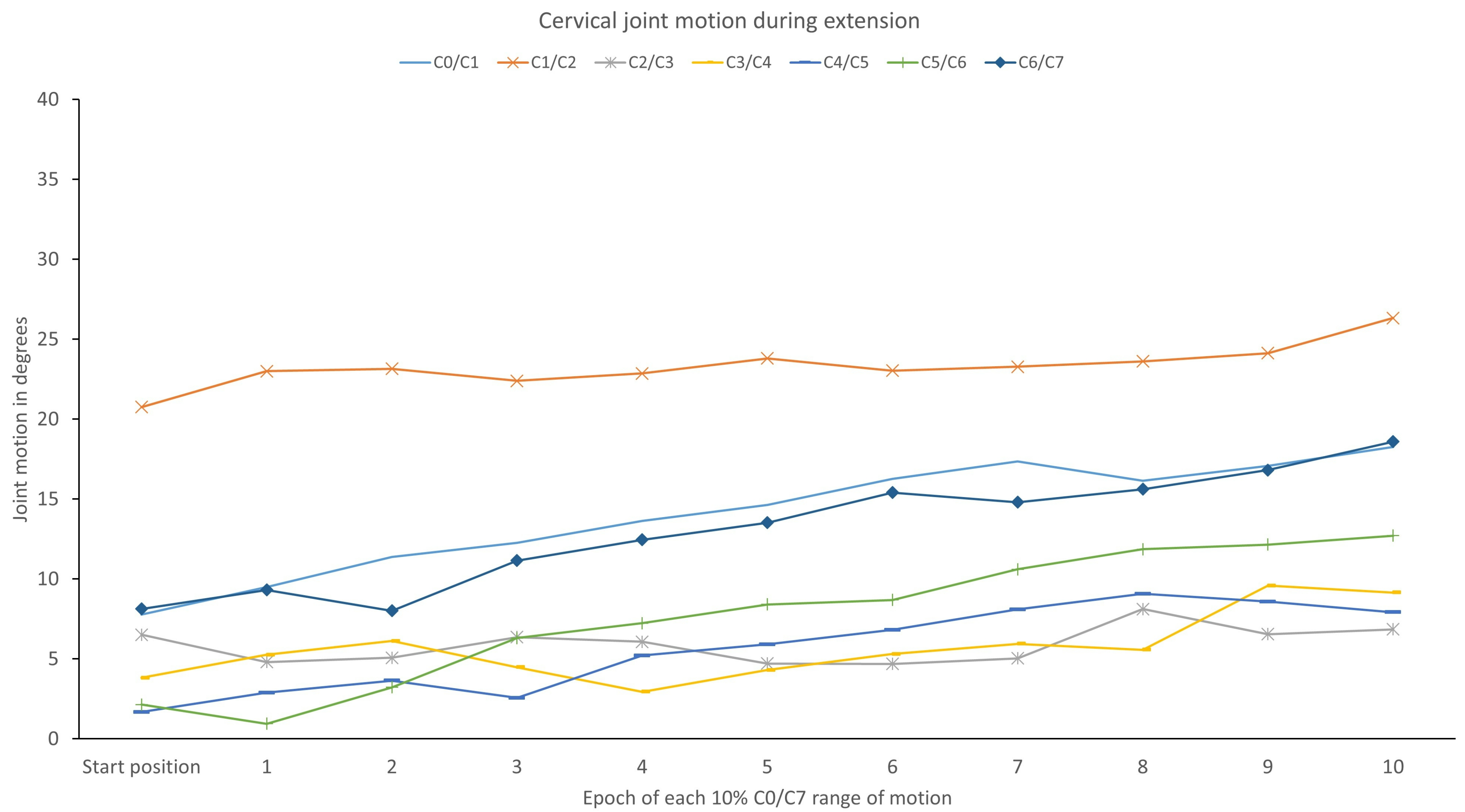
Figure 4 C2/C3 joint motion in cervical flexion and extension repetitions

Figure 5 C3/C4 joint motion in cervical flexion and extension repetitions

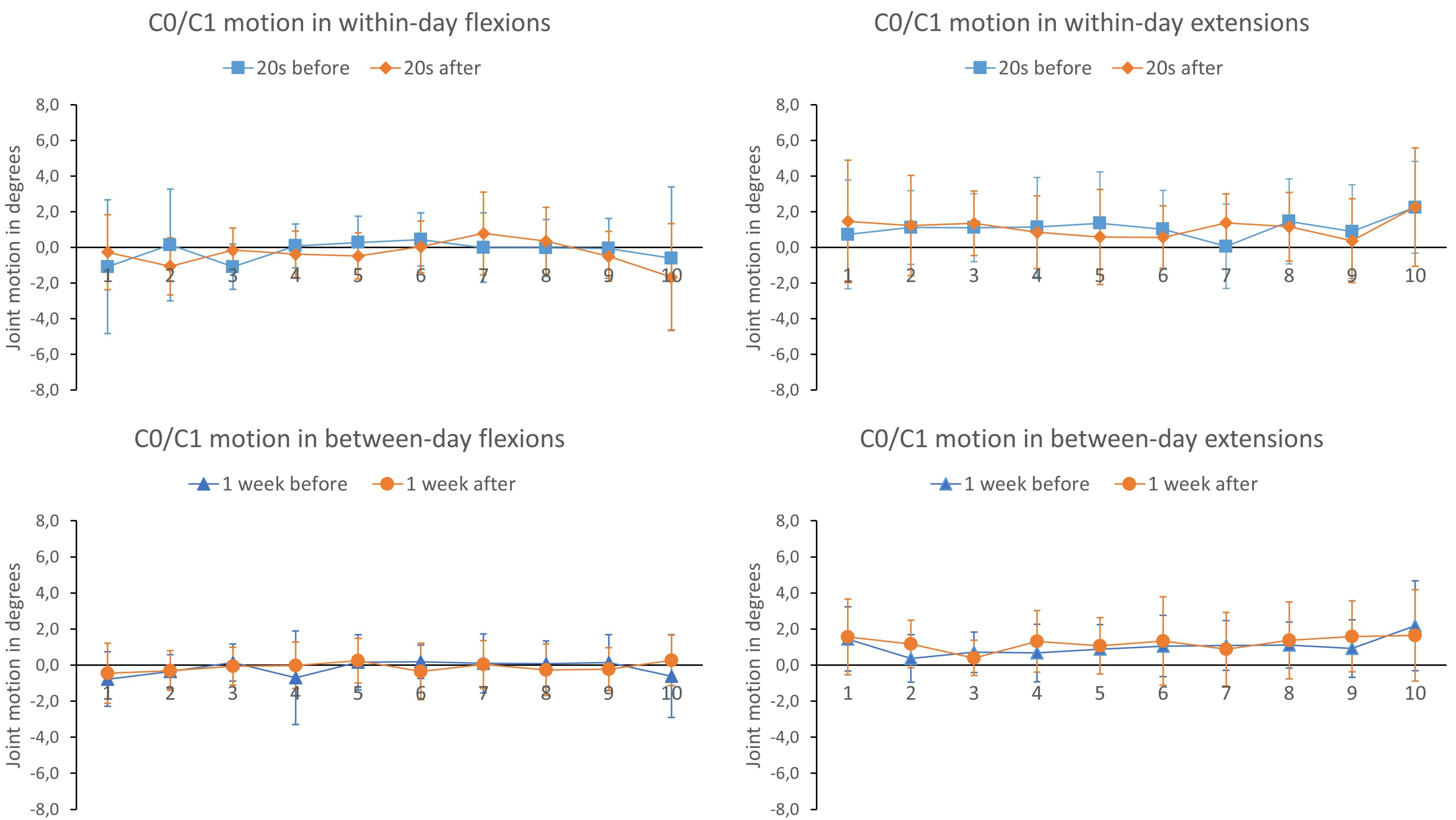
Figure 6 C4/C5 joint motion in cervical flexion and extension repetitions

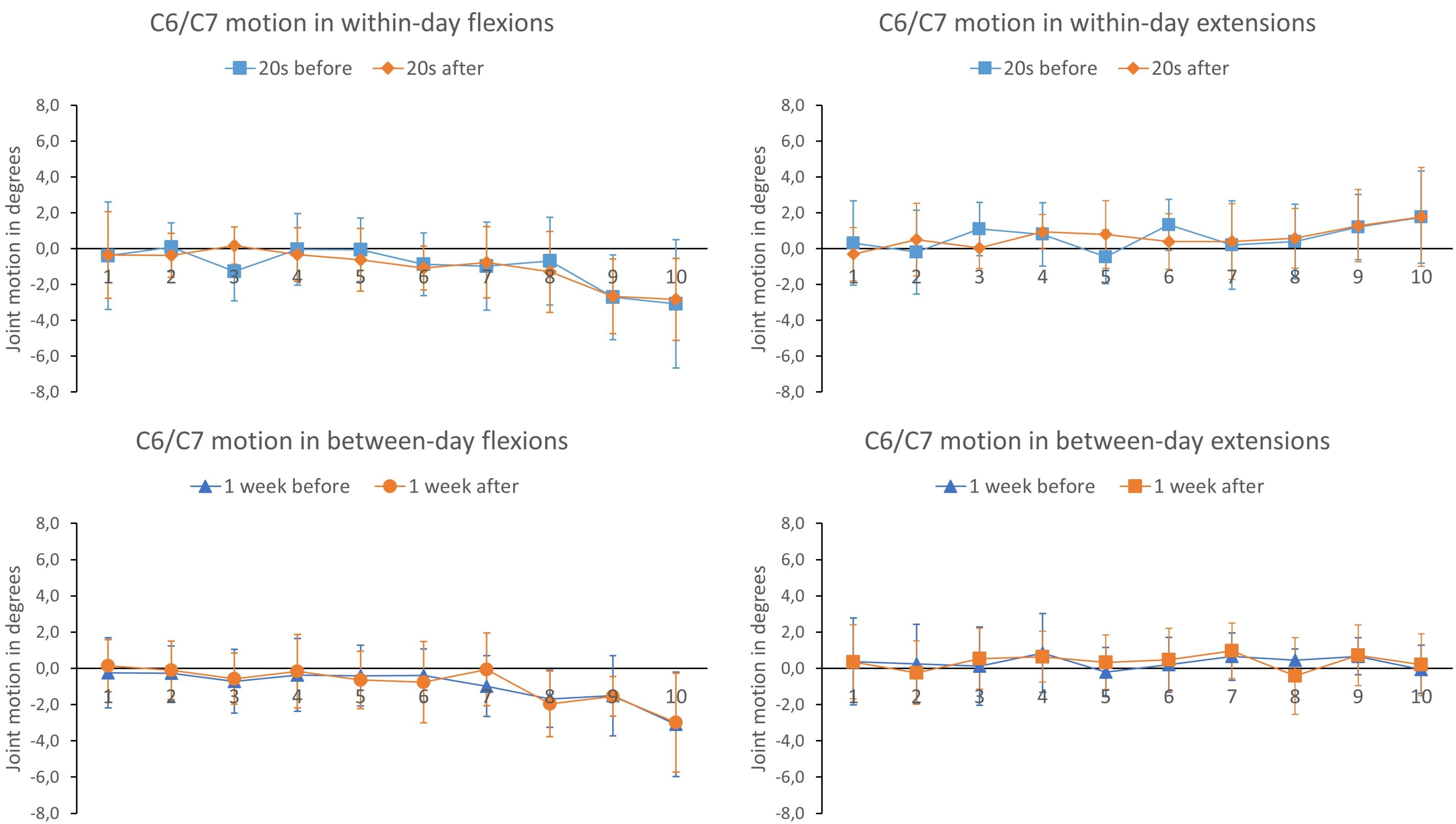
Figure 7 C5/C6 joint motion in cervical flexion and extension repetitions

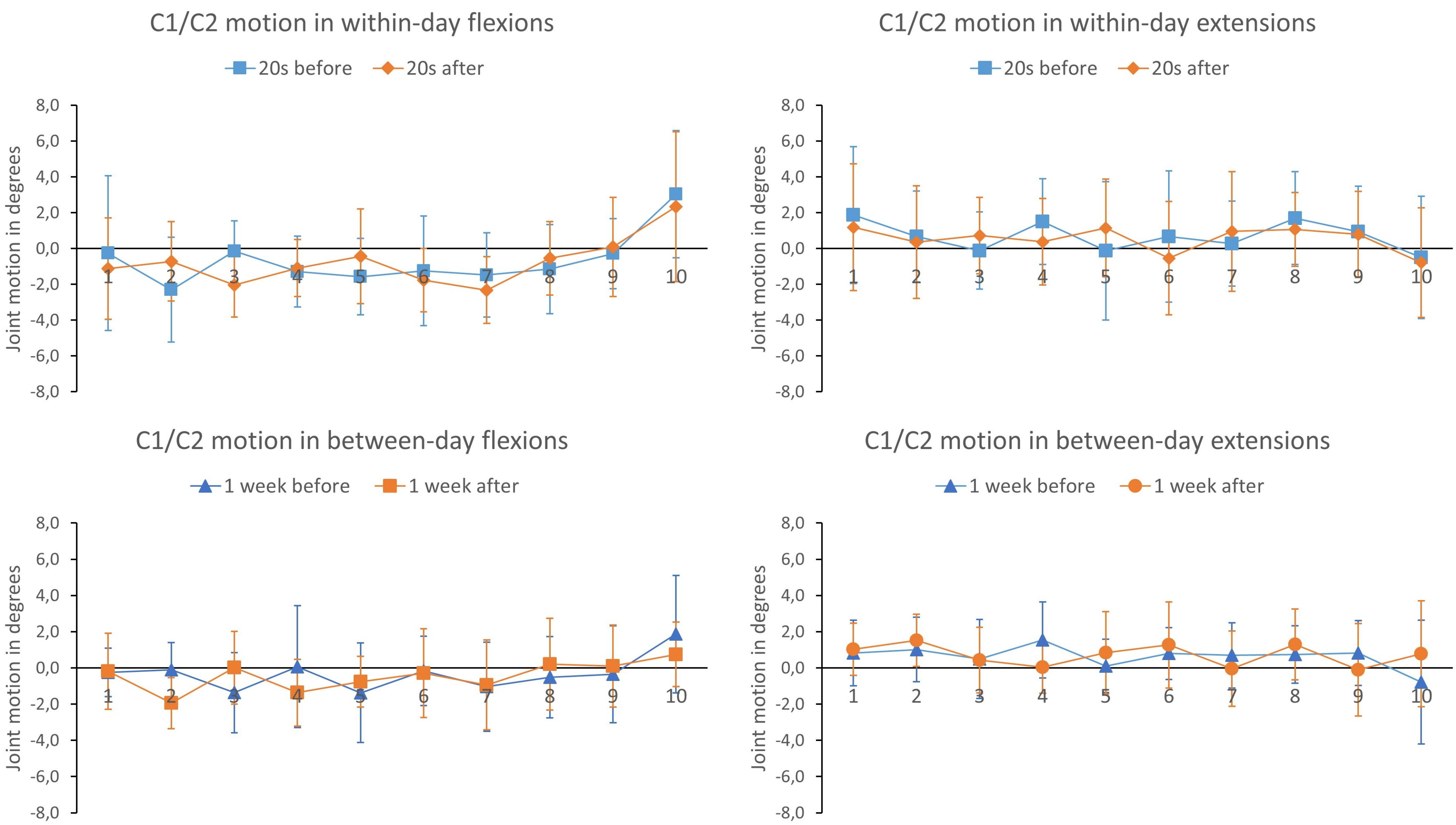

Cervical joint motion during flexion
C0/C1
C1/C2
C2/C3
C3/C4
C4/C5
C5/C6
C6/C7
Joint motion in degrees
25
20
15
10
5
0
-5
-10
-15
Start position
1
2
3
4
5
6
7
8
9
10
Epoch of each 10% C0/C7 range of motion

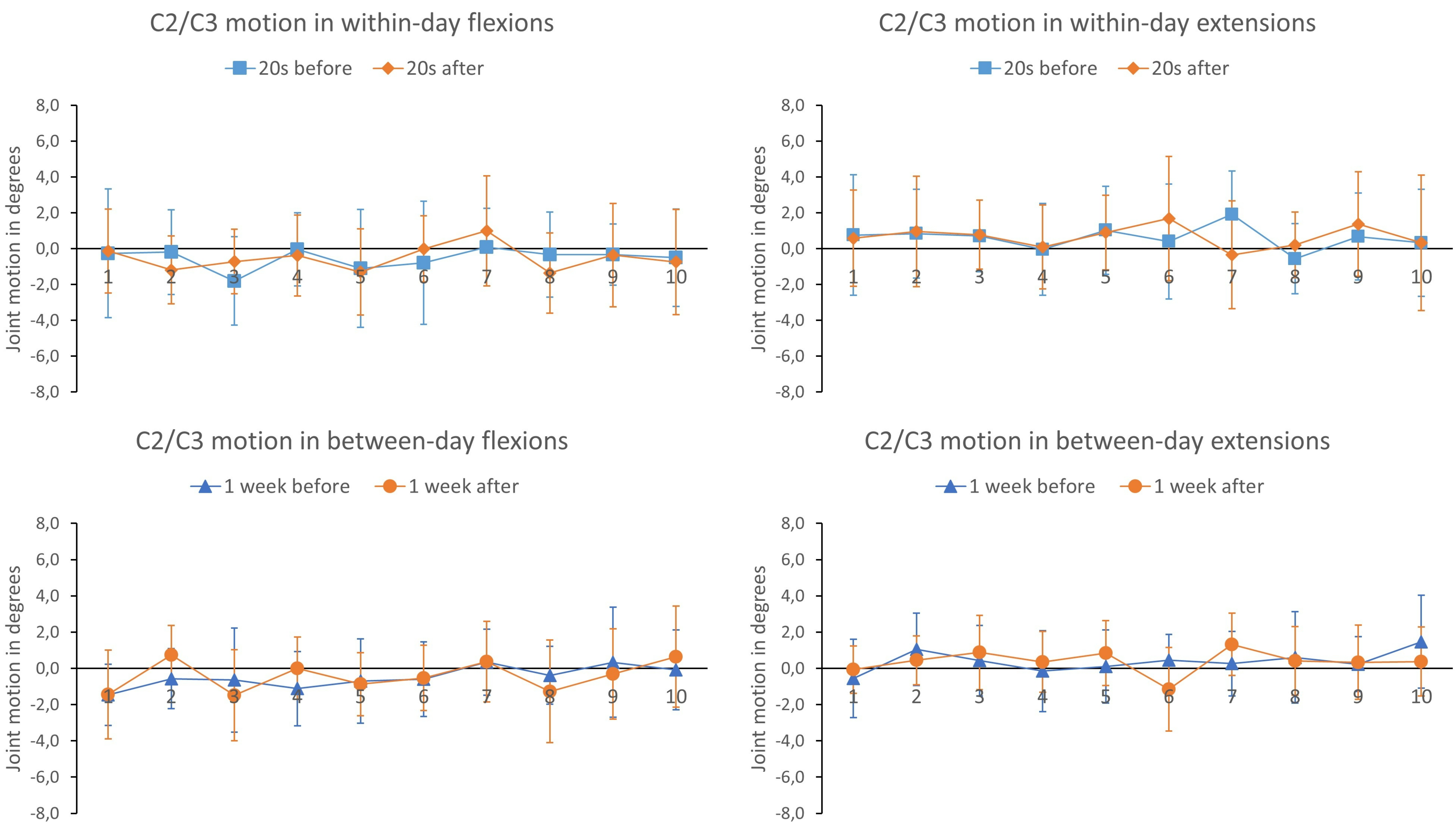


Cervical joint motion during extension
C0/C1
C1/C2
C2/C3
C3/C4
C4/C5
C5/C6
C6/C7
Joint motion in degrees
0
5
10
15
20
25
30
35
40
Start position
1
2
3
4
5
6
7
8
9
10
Epoch of each 10% C0/C7 range of motion

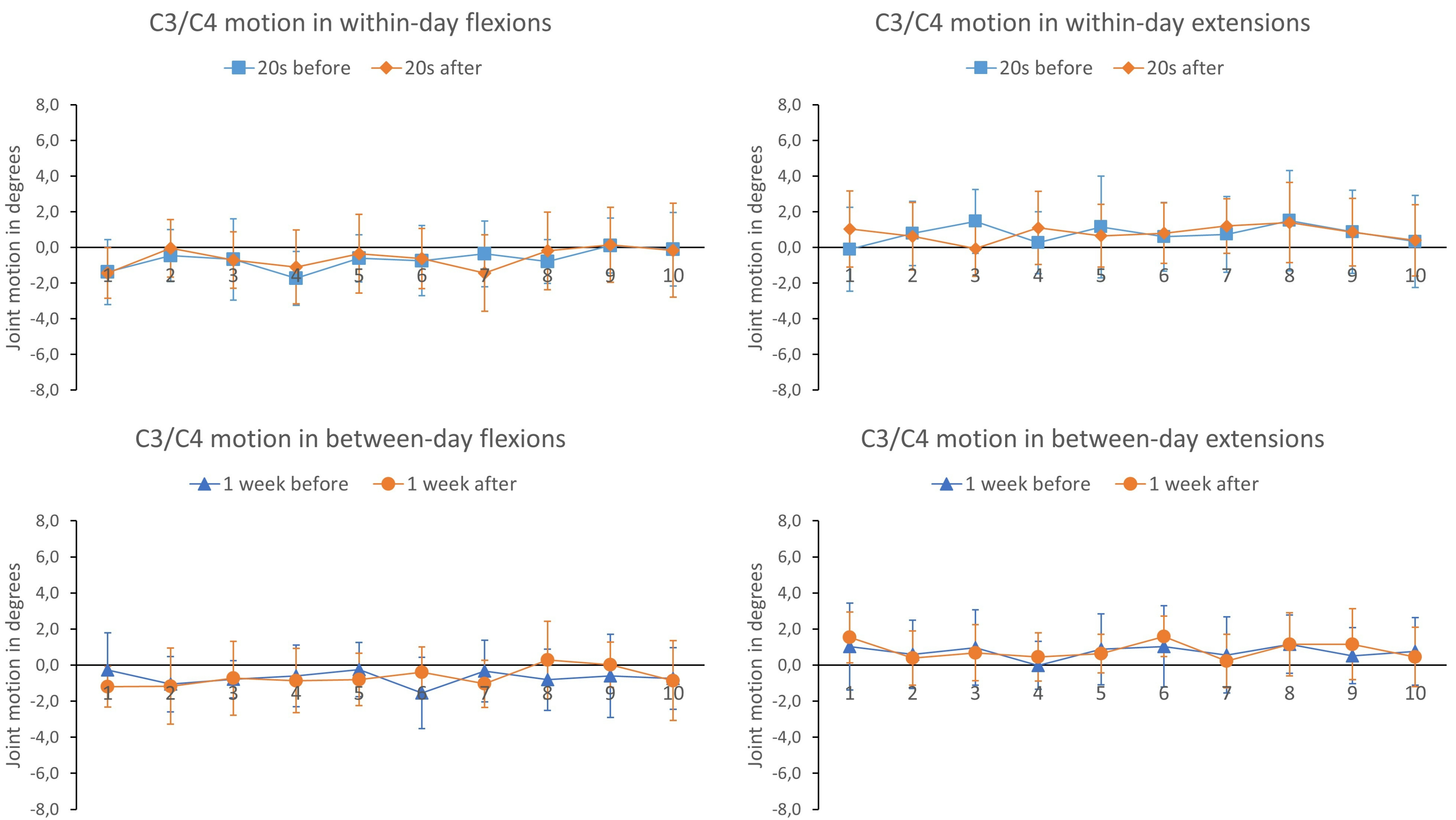

C0/C1 motion in within-day flexions
20s before
20s after
C0/C1 motion in within-day extensions
20s before
20s after
C0/C1 motion in between-day flexions
1 week before
1 week after
C0/C1 motion in between-day extensions
1 week before
1 week after
Joint motion in degrees
8,0
6,0
4,0
2,0
0,0
-2,0
-4,0
-6,0
-8,0
1
2
3
4
5
6
7
8
9
10


C6/C7 motion in within-day flexions
20s before
20s after
Joint motion in degrees
8,0
6,0
4,0
2,0
0,0
-2,0
-4,0
-6,0
-8,0
1
2
3
4
5
6
7
8
9
10
C6/C7 motion in within-day extensions
20s before
20s after
Joint motion in degrees
C6/C7 motion in between-day flexions
1 week before
1 week after
Joint motion in degrees
C6/C7 motion in between-day extensions
1 week before
1 week after
Joint motion in degrees

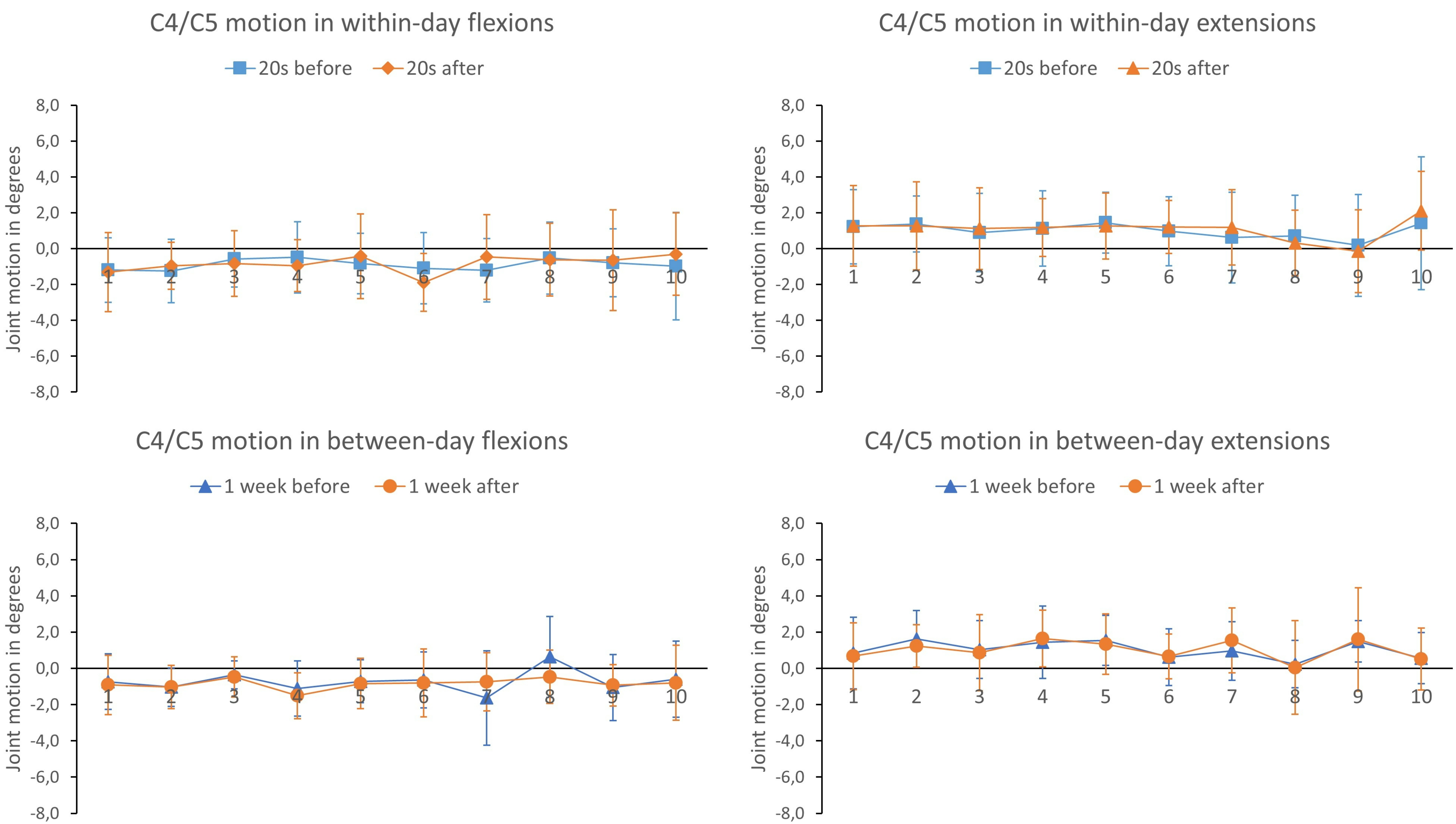

C1/C2 motion in within-day flexions
20s before
20s after
C1/C2 motion in within-day extensions
20s before
20s after
C1/C2 motion in between-day flexions
1 week before
1 week after
C1/C2 motion in between-day extensions
1 week before
1 week after
Joint motion in degrees
8,0
6,0
4,0
2,0
0,0
-2,0
-4,0
-6,0
-8,0
1
2
3
4
5
6
7
8
9
10

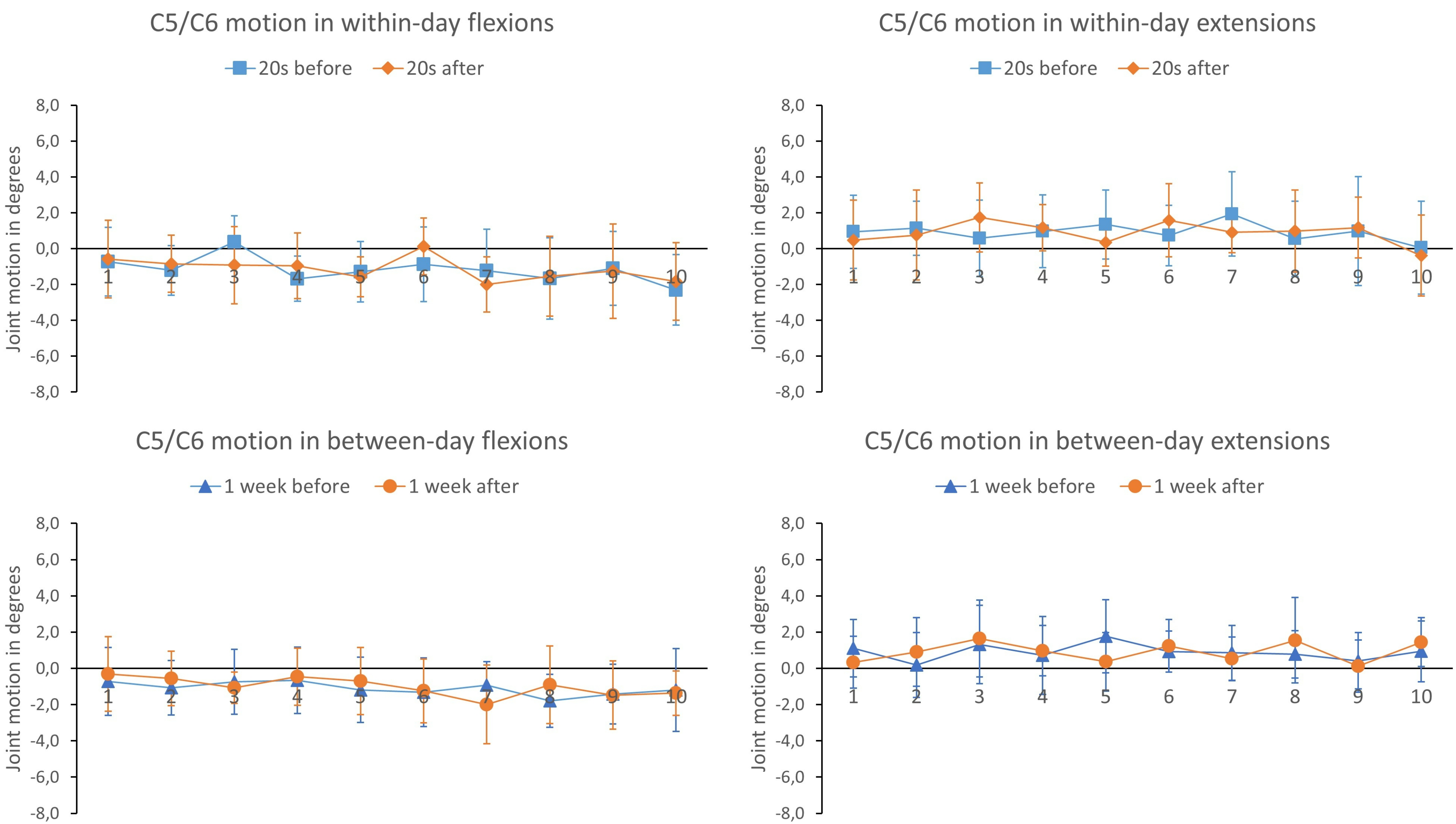


C2/C3 motion in within-day flexions
20s before
20s after
Joint motion in degrees
8,0
6,0
4,0
2,0
0,0
-2,0
-4,0
-6,0
-8,0
1
2
3
4
5
6
7
8
9
10
C2/C3 motion in within-day extensions
20s before
20s after
Joint motion in degrees
C2/C3 motion in between-day flexions
1 week before
1 week after
Joint motion in degrees
C2/C3 motion in between-day extensions
1 week before
1 week after
Joint motion in degrees



C3/C4 motion in within-day flexions
20s before
20s after
C3/C4 motion in within-day extensions
20s before
20s after
C3/C4 motion in between-day flexions
1 week before
1 week after
C3/C4 motion in between-day extensions
1 week before
1 week after
Joint motion in degrees
8,0
6,0
4,0
2,0
0,0
-2,0
-4,0
-6,0
-8,0
1
2
3
4
5
6
7
8
9
10


C4/C5 motion in within-day flexions
20s before
20s after
C4/C5 motion in within-day extensions
20s before
20s after
C4/C5 motion in between-day flexions
1 week before
1 week after
C4/C5 motion in between-day extensions
1 week before
1 week after
Joint motion in degrees
8,0
6,0
4,0
2,0
0,0
-2,0
-4,0
-6,0
-8,0
1
2
3
4
5
6
7
8
9
10


C5/C6 motion in within-day flexions
20s before
20s after
Joint motion in degrees
8,0
6,0
4,0
2,0
0,0
-2,0
-4,0
-6,0
-8,0
1
2
3
4
5
6
7
8
9
10
C5/C6 motion in within-day extensions
20s before
20s after
Joint motion in degrees
C5/C6 motion in between-day flexions
1 week before
1 week after
Joint motion in degrees
C5/C6 motion in between-day extensions
1 week before
1 week after
Joint motion in degrees