

An Exploratory Electromyography-Based Coactivation Index for the Cervical Spine

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Objective: Develop a coactivation index for the neck and test its effectiveness with complex dynamic head motions.

Background: Studies describing coactivation for the cervical spine are sparse in the literature. Of those in existence, they were either limited to a priori definitions of agonist/antagonist activity that limited the testing to sagittal and lateral planes or consisted of isometric exertions. Multiplanar movements would allow for a more realistic understanding of naturalistic movements in the cervical spine and propensity for neck pain. However, a gap in the literature exists in which a method to describe coactivation during complex dynamic motions does not exist for the cervical spine.

Methods: An electromyography-based coactivation index was developed for the cervical spine based on previously tested methodology used on the lumbar spine without a high-end model and tested using a series of different postures and speeds.

Results: Complex motions involving twisting (i.e., flexion and twisting) and higher speed had higher magnitudes of coactivation than uniplanar motions in the sagittal or lateral plane, which was expected. The coupled motion of flexion and twisting showed four to five times higher coactivation than uniplanar (sagittal or lateral) movements.

Conclusion: The coactivation index developed accommodates multiplanar, naturalistic movements. Testing of the index showed that motions requiring higher degrees of head control had higher effort due to coactivation, which was expected.

Application: Overall, this coactivation index may be utilized to understand the neuromuscular effort of various tasks in the cervical spine.

Keywords: co-contraction, neuromuscular, neck muscles, coactivation

INTRODUCTION

Musculoskeletal disorders (MSDs) of the neck-shoulder region are one of the most frequently reported problems for the working population (Larsson, Sjøgaard, & Rosendal, 2007; Yang et al., 2015) and present an economic burden to society, with medical costs estimated at US\$86 billion a year (Martin et al., 2008). To mitigate the burden, it is imperative to understand the etiology of neck pain to enhance work (re)design and rehabilitation. One of the underlying mechanisms for neck pain involves the alterations in neuromuscular control for head stabilization and during pain (Falla & Farina, 2008). This mechanism may be described by coactivation, or the synchronous activation of agonist and antagonist musculature for postural stabilization (Lavender, Tsuang, Hafezi, et al., 1992). The coordination between agonist and antagonist activity results in a level of neuromuscular effort to accomplish a task. All tasks require some level of coactivation. However, it is the level beyond what is necessary to accomplish the task that increases the neuromuscular load. For example, patients have higher muscular activations across a multiple muscle system (i.e., low back) when compared to asymptomatic individuals (Marras, Ferguson, Burr, Davis, & Gupta, 2004). To describe the overall activity of the system of muscles, a coactivation index is needed. Understanding coactivation from a systems perspective may provide insight on the neuromuscular effort needed for the adaptation to different tasks.

Given the complexity of the cervical spine, methods to describe coactivation in the neck as a system are sparse in the literature (Le, Best, Khan, Mendel, & Marras, 2017). Of the studies in existence to describe coactivation as an index, they were commonly limited in their utility due to a priori defined muscular contribution (agonist/antagonist) (Cheng et al., 2014; Cheng, Lin,

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& Wang, 2008; Choi, 2003). Based on the dependence of coactivation patterns to stabilize posture and external loads, changes in the location of the load may require shifts in agonist/antagonist activity to adjust posture relative to the load (Lavender, Tsuang, Andersson, Hafezi, & Shin, 1992). Therefore, predefining muscle activity as agonist or antagonist limits the tests to isometric testing or uniplanar dynamic movements (sagittal or frontal planes). When testing under the isometric approach, activities of daily living as well as naturalistic movements (axial twisting and other complex postures) may not be captured because dynamic muscular activity differs from static. Higher neuromuscular effort may be required for postural control in asymmetric postures. Currently, an index to quantify asymmetric multiplanar motions for the cervical spine does not exist.

In a previous manuscript, a method to describe coactivation for a multi-muscle system was defined for the lumbar spine (Le, Aurand, et al., 2017). This involved the calculation of the moments based on the active forces defined from the musculature and allowed for the assessment of coactivation for multiplanar dynamic tasks. Since this approach required the use of a biologically assisted model, another approach was made in case a model was not accessible (Le et al., in press). This method was dependent on torso kinematics and normalized electromyography (EMG) modulated by the cross-sectional area to represent a “simulated” force. Although the comparability of the EMG-based method was lower, it provided a similar measure of coactivation relative to the moment-based method. In general, the EMG-based method can detect higher coactivation during tasks where it was expected. These tasks involved higher degrees of postural control or overall muscle activity to generate higher external forces (i.e., precision placement and movement of a cart) throughout the series of complex dynamic tasks. Since the EMG-based method for the lumbar spine had a high fidelity when compared to the model-dependent, moment-based method, it was postulated that this methodology could be applied to describe coactivation in the cervical spine without a model.

The objectives of this study were twofold: (a) Develop a coactivation index for the cervical spine

using the approach from Le and colleagues (in press) and (b) test the index on a series of multiplanar, complex, dynamic head-neck motions. It was hypothesized that this methodology would be able to differentiate between uniplanar motions and complex multiplanar motions.

COACTIVATION INDEX STRUCTURE

The underlying logic of the EMG-based coactivation index was based on the determination of simulated force components previously described by Le and colleagues (in press). Twelve muscles were included in the index based on EMG from three bilateral regions of the neck: cervical extensors, sternocleidomastoid, and levator scapulae. The cervical extensors included: semispinalis capitis, semispinalis cervicis, splenius capitis/cervicis (grouped together), and the cervical trapezius. EMG collected from the extensors were applied to the simulated force equation for each of the cervical extensor muscles described. A cube exponential of the normalized cross-sectional area was utilized to modulate the normalized EMG to scale the effect of the “simulated” force (F'_i) (Equation 2). This method provided a similar trend as maximal force relative to cross-sectional area of muscles (CSA) (Le et al., in press). CSA data were extracted from Kamibayashi and Richmond (1998) with the exception of semispinalis cervicis, which was retrieved from Deng and Goldsmith (1987) (Table 1). For this pilot study, CSA data were fixed across all subjects. Force vectors (\vec{F}'_i) were defined as the product of the simulated force and the unit vectors relative to muscle lines of action (Table 2) and driven by the kinematics of the head using a quaternion rotation matrix (q_{Head}) (Equations 1, 2). These lines of action were operationally defined based on general anatomical data. The rotation/translation of the insertion points (Equation 1) was relative to the location of C7/T1. Simulated muscle moments (\vec{m}'_i) were the cross-product of the moment arm (\vec{r}'_i) and the associated force vector (\vec{F}'_i) relative to C7/T1 (Equation 3). The summation of the simulated muscle moments (\vec{m}'_i) resulted in the total simulated moment (\vec{M}'_i) (Equation 4). The dot product of the individual muscle moments (\vec{m}'_i) relative to the total moment (\vec{M}'_i) normalized by the magnitude of

TABLE 1: Muscle Cross-Sectional Area Data Used in Cervical Coactivation Index

	CSA (mm ²)	nCSA
Sternocleidomastoid	3.72	0.69
Levator scapula	2.18	0.40
Trapezius	1.96	0.36
Splenius capitis/cervicis	4.26	0.78
Semispinalis capitis	5.40	1.00
Semispinalis cervicis	0.72	0.13

Note. Cross-sectional area (CSA) was normalized (nCSA) relative to largest CSA in the system.

the total moment (\vec{M}_i) resulted in a scalar projection ($Proj_i$) defining an individual muscle's contribution as either an agonist (positive) or antagonist (negative) (Equations 5–7). Coactivation (CI) was then defined as the product between the balance of the antagonist/agonist systems and the normalized magnitude of the contribution (Equation 8). The normalization was operationally defined by the maximum activation of the data set (0.68). Further details of the logic behind the equation can be found in Le, Aurand, et al. (2017).

$$\vec{V}_i(t) = q_{Head}(t)^{-1} * V_i(t) \quad (1)$$

$$\vec{F}_i(t) = \left(\frac{\vec{V}_i(t)}{\|\vec{V}_i(t)\|} \right) * \frac{EMG_i(t)}{\max(EMG_i)}(t) * \left(\frac{CSA_i}{\max(CSA_{i=1:12})} \right)^3 \quad (2)$$

$$\vec{m}_i = \vec{r}_i \times \vec{F}_i \quad (3)$$

$$\vec{M}_i(t) = \sum_{i=1}^t \vec{m}_i \quad (4)$$

$$Proj_i = \frac{\vec{m}_i \cdot \vec{M}_i}{\|\vec{M}_i\|} \quad (5)$$

$$antagonist_i = \begin{cases} 0, Proj_i > 0 \\ |Proj_i|, Proj_i \leq 0 \end{cases} \quad (6)$$

$$agonist_i = \begin{cases} Proj_i, Proj_i > 0 \\ 0, Proj_i \leq 0 \end{cases} \quad (7)$$

$$CI(t) = \left(\frac{\sum_{i=1}^{12} antagonist_i(t)}{\sum_{i=1}^{12} agonist_i(t)} \right) * \quad (8)$$

$$\left(\frac{\sum_{i=1}^{12} antagonist_i(t) + \sum_{i=1}^{12} agonist_i(t)}{0.68} \right)$$

TABLE 2: Operationally Defined Anatomical Geometry of Muscle Lines of Action in Neutral Posture Relative to C7/T1 (mm)

	X _O	Y _O	Z _O	X _I	Y _I	Z _I
R sternocleidomastoid	-43.15	-30.91	55.76	-64.29	130.83	-6.65
L sternocleidomastoid	43.22	-30.91	55.74	62.02	130.79	-6.66
R levator scapula	-72.01	-32.01	-53.71	-37.77	101.86	-9.90
L levator scapula	72.05	-32.01	-53.71	37.81	101.86	-9.90
R semispinalis capitis	-22.20	11.64	-20.24	-28.90	124.11	-51.16
L semispinalis capitis	21.32	12.19	-20.51	27.82	124.09	-50.46
R semispinalis cervicis	-35.84	6.14	-18.45	-0.89	72.09	-41.15
L semispinalis cervicis	35.01	5.87	-18.02	-0.89	72.09	-41.15
R splenius	-4.98	6.42	-44.37	-39.66	140.56	-59.43
L splenius	4.82	6.42	-44.37	38.32	140.59	-59.43
R trapezius	-118.52	-12.04	-10.45	-16.18	146.21	-79.31
L trapezius	118.52	-12.01	-10.46	16.22	146.21	-79.31

Note. O = origin; I = insertion; X = left/right; Y = superior/inferior; Z = anterior/posterior.

TABLE 3: Description of the Different Postures and Speeds Endured

Posture	Speed
Neutral to flexion (3×)	Slow
Neutral to extension (3×)	Preferred
Flexion and extension (3×)	
R to L lateral bend (3×)	
Axial twist (3×)	
Flexion, hold then 3× twist while in flexion	
Extension, hold then 3× twist while in extension	

Note. R = right; L = left.

METHODS

Experimental Approach

A study was conducted to test the cervical spine EMG-based coactivation index through a series of complex dynamic head motions.

Subjects

Twelve subjects (5 males and 7 females) were recruited for this study (mean age = 27.8 years, $SD = 6.8$; mean mass = 69.6 kg, $SD = 15.1$; mean height = 170.9 cm, $SD = 9.7$). All subjects reported no medical visits for neck pain or surgery. This research complied with the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board at The Ohio State University. Informed consent was obtained from each subject prior to participation.

Experimental Design

Several combinations of head posture and speed of movement were used to assess the effectiveness of the cervical spine coactivation index.

Independent and dependent measures. The independent measures included seven different postures with two different speeds and were collected (7×2) and repeated twice for a total of 28 dynamic trials (Table 3). Each posture and speed combination entailed three repeated movements within the same trial while standing upright. Speed of movement was subjectively defined as slow ($\sim 15^\circ/s$) and normal/preferred ($\sim 50^\circ/s$). The

dependent measures collected were the peak coactivation index and peak head kinematics (range of motion and velocity).

Apparatus

EMG data were collected with a 16-channel MA400-28 EMG system (Motion Lab Systems, Inc., Baton Rouge, LA, USA) and sampled at a rate of 1000 Hz. Signals were high-pass filtered at 30 Hz, low-pass filtered at 450 Hz, and notch filtered at 60 Hz as well as its aliases. Signals were rectified and smoothed using a zero-phase moving average filter. Kinematic data were collected using the 36 infrared camera OptiTrack Flex 41 motion capture system (NaturalPoint, Corvallis, OR, USA).

Procedure

The subject was informed about the details of the experiment, and after providing consent, anthropometry was collected. Surface EMG electrodes were placed bilaterally on the cervical extensors, levator scapulae, and sternocleidomastoids (Sommerich, Joines, Hermans, & Moon, 2000). EMG on the cervical extensors represented the following muscles in the index: semispinalis capitis and cervicis, splenius capitis/cervicis, and cervical trapezius. Reflective markers were placed on 41 landmarks for whole-body optical motion capture. Although only the head/neck data were extracted, the 41-landmark setup was necessary to define the different segments of the body. The subjects were then asked to complete a series of maximum voluntary exertions (MVEs) while standing, which involved resistance during abduction of the arms in the scapular plane and then head flexion, extension, and lateral bends (Schuldt, 1988). Each exertion was collected twice. After MVEs were collected, the subject was instructed on the different motions involved and allowed ample time to practice before the study commenced. Each movement was repeated three times within a single trial (i.e., lateral bend involved three sets of right to left motions).

Statistical Analysis

General linear models (SAS 9.2, SAS Institute, Cary, NC, USA) were used to evaluate

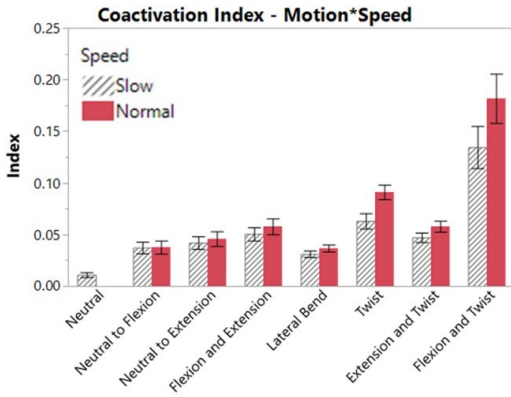


Figure 1. Coactivation index results for the interaction of motion and speed ($p = .0136$). Data are presented as mean and standard error. Note the higher levels of coactivity for more complex motions involving axial twisting/rotation.

peak coactivation index relative to the main effects and their interactions at $\alpha = .05$. Post hoc Tukey tests were performed to assess the differences between conditions.

RESULTS

The coactivation index developed for the cervical spine displayed statistically significant results ($\alpha = .05$) between the different motions ($p < .0001$), speeds ($p = .0065$), and interaction of motion and speed ($p = .0136$) (Figure 1). Uniplanar motions (flexion/extension and lateral bending) had higher levels of coactivity relative to the neutral posture. As the motion became more complex through twisting/rotation, coactivation became higher than the uniplanar motions, where the combination of flexion and twisting was the highest. The speed was also directly associated with the level of coactivation, especially during the axial rotation/twisting combinations. Normal/preferred speeds incurred higher coactivity than slow speeds during movements involving twisting. The covariate of gender showed that females exhibited higher coactivation (mean index = $.047$, $SD = .039$) than males (mean index = $.028$, $SD = .025$) across all motions ($p = .0002$). Most differences appeared during flexion and extension as well as flexion and twisting motions

(Figure 2a). Higher coactivity among females was likely due to the higher contribution found in the sternocleidomastoid (SCM) muscles ($p < .0001$) (Figure 2b).

Since kinematics are interrelated to the levels of coactivity for postural stabilization, it is also important to understand the ranges of motion experienced during each condition. As seen in Figure 3, the peak ranges of motion across the tasks show increases in lateral and axial motions with increasing complexity. During these motions, peak coactivity tended to occur at the end ranges of motion. To understand how the coactivation index was affected by the agonist/antagonist system classifications, two-dimensional visualizations (classified using 3-D data) of mean agonist (green) versus antagonist (red) data across all subjects can be seen for flexion/extension (Figure 4), lateral bending (Figure 5), and axial rotation (Figure 6). During sagittal or lateral movements, the classifications appear to be split perpendicular at C7/T1 relative to the direction of the movement. However, during axial twisting (Figure 6), the classification is more complex as lateral and axial motions both occur within this postural transition (Figure 3). As for the magnitude of individual muscular contributions relative to the classifications (represented by the size of the circles), higher muscular contributions typically occur with more complex postures. More specifically, the sternocleidomastoid appeared to be a strong contributor to the direction of coactivity, especially during lateral bending and twisting.

DISCUSSION

The purpose of this pilot study was to provide an approach to assess coactivation in the cervical spine for complex dynamic motions. This objective was achieved through the development of a method based on simulated moment contributions driven by muscle activity and kinematic data. The intent was to provide a systems-perspective description of the neuromuscular effort of coactivation for multiplanar motions. The main findings showed that: (1) complex, multiplanar motions required higher coactivation; (2) higher speed resulted in higher coactivation during axial rotation/twisting motions when compared to uniplanar motions (sagittal

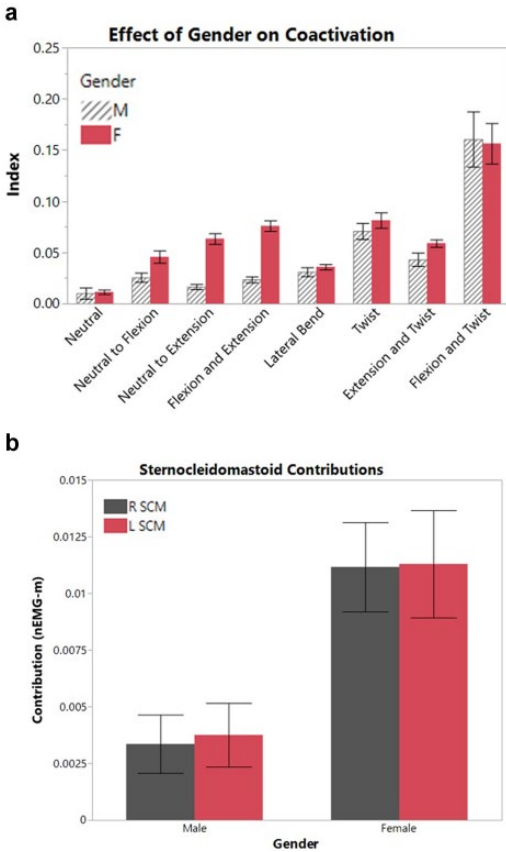


Figure 2. (a) Differences in coactivation between genders for the various motions endured ($p = 0.0002$). Females typically had higher coactivity across many of the motions. (b) This was likely due to the higher sternocleidomastoid (SCM) contribution among female subjects ($p < .0001$). Data are presented as mean and standard error.

or lateral); and (3) female subjects had higher magnitudes of coactivation relative to males. The results of the EMG-based, cervical coactivation index provided insight on normal neuromuscular control among asymptomatic subjects and may be used to explore other variations of complex tasks as well as patient populations to assess the effectiveness of rehabilitative efforts in comparison to asymptomatic populations.

The cervical coactivation index was developed based on the idea that the agonist/antagonist nature of a muscle may be determined by its active moment directionality relative to the total active moment (Le, Aurand, et al., 2017).

Although it is understood that passive components may also play a role in driving muscle forces, the coactivation method described is solely based on the active contributions of the system of muscles, thus limiting it to the contractile components of the musculature. Through this methodology, it was postulated that when the direction of the muscle moment vector was within 180° of the total active moment vector, the scalar projection would be positive, thereby deeming it an agonist (Andrews & Hay, 1983). On the other hand, if it is obtuse relative to the direction of the total active moment, the projection would be negative, thereby deeming the muscle antagonist. Through the assessment of contribution from the system of antagonist muscles relative to the agonist system and the total activation of the system, it can be inferred how much neuromuscular effort can be attributed to coactivation.

Currently, there is no gold standard to define dynamic forces and moments in the cervical spine as there is in the lumbar spine. Hence, a surrogate approach was sought to provide a measure of coactivity independent of a model. A coactivation index was first developed for the lumbar spine without high-end modeling efforts and then compared to an index dependent on a computational model to assess its external validity (Le et al., in press). The general approach entailed the examination of the different modulation factors that may be accessible without a model. Modulation factors were necessary to properly scale each muscle's contribution. These included CSA, lines of action, kinematics, and EMG. Overall, it was found that the normalized CSA cubed was a reasonable alternative to a model by weighting the level of coactivity in the lumbar spine (Equation 8). The fidelity was reasonable relative to the moment-based, model-dependent method ($r^2 = 0.78$) while differentiating between the tasks at similar index magnitudes.

Given the complexity in the lumbar spine as well as the cervical spine muscles due to the various muscle lines of action, it was postulated that if the methodology was applicable in the lumbar spine, it may also work for the cervical spine. Hence, the non-model based approach was applied to the cervical spine driven by

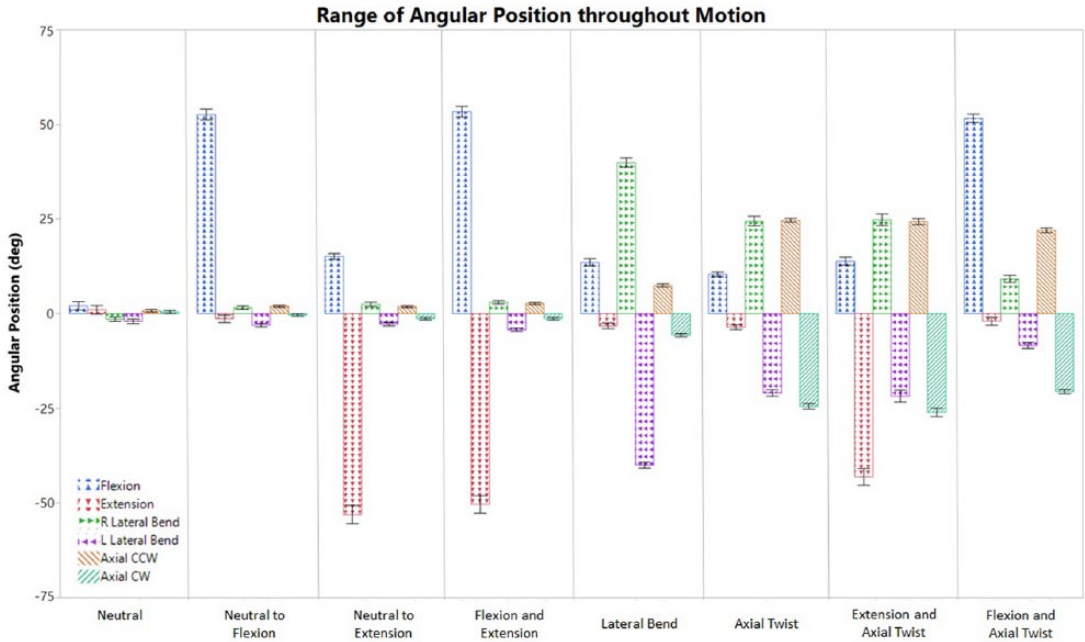


Figure 3. Peak range of motion data (across all subjects) for each motion condition in each of the three anatomical planes (sagittal flexion/extension, right/left lateral bending, and clockwise/counterclockwise axial twisting). Data are presented as mean and standard error.

normalized EMG from the cervical extensors, sternocleidomastoids, levator scapulae, anatomically defined lines of action relative to C7/T1, and head kinematics. A series of motions were tested to assess the effectiveness of the cervical coactivation index to differentiate between complex multiplanar motions. Many of the findings were anticipated in comparison to reports in the literature.

Coactivation is highly dependent on posture and speed and was highest at the end ranges of motion for each of the different motions. As the motion becomes more complex (multiplanar), a higher level of neuromuscular control is necessary to stabilize the head/neck. Therefore, agonist/antagonist classification is important to understand during these motions. As can generally be seen in Figure 6 as compared to Figures 4 and 5 (flexion/extension and lateral bending), axial rotation/twisting incites higher coactivity due to the multiplanar motion. Based on the assumption that the agonist is considered a primary mover dependent on moment contributions, which is also dependent on the level of

muscle activation (Vasavada, Li, & Delp, 1998), as expected, the cervical extensors were deemed agonist during peak coactivation during flexion and antagonist during extension (Figure 4). During lateral bending, antagonistic muscle contributions were typically contralateral to the motion endured (Figure 5) and agreed with the a priori classification from Cheng et al. (2008). However, the findings from our study of coactivity during lateral bending were lower than initially anticipated. Based on the level of activation from the agonist and antagonist musculature during lateral bending found in this study relative to the other motions, it was inferred that it may be possible that the lower activity may be attributed to lower range of motion and decreased contralateral moment-generating capacity (Vasavada et al., 1998), thereby rendering the effort due to coactivation to be lower. During axial rotation, mean scalar projection classifications (Figure 6) agreed with some of the agonist classifications from Vasavada et al. (1998) where the left splenius, right sternocleidomastoid, and ipsilateral cervical extensors acted as synergists

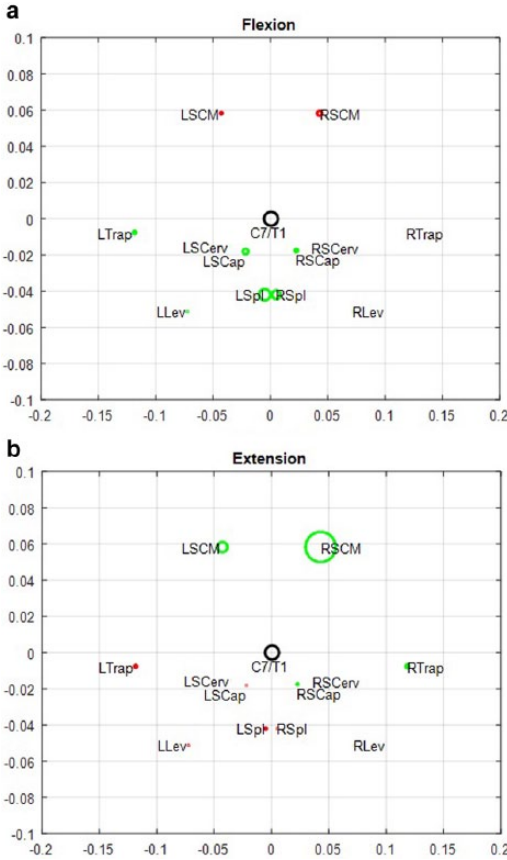


Figure 4. Two-dimensional visualization of antagonist (red) and agonist (green) activity for the mean of the peak coactivation (across all subjects) during (a) flexion and (b) extension. Size of the circle represents the mean contribution of the particular muscle across all subjects. The x- and y-axes represent the location of each muscle's origin relative to C7/T1 in meters from Table 2 as X₀ and Z₀, respectively. Although the visualization is in 2-D, classifications were still based on 3-D data. R/L = right/left; SCM = sternocleidomastoid; Trap = cervical trapezius; SCerv = semispinalis cervicis; SCap = seminspinalis capitis; Spl = splenius; Lev = levator scapulae.

during left axial rotation. These classifications can be affected during rotation because axial rotation is typically accompanied by lateral bending (Figure 3) (Iai et al., 1993; Mimura et al., 1989; Panjabi, Oda, Crisco, Dvorak, & Grob, 1993). As previously seen in the lumbar spine, asymmetric postures have been known to incite higher levels of coactivity (Marras &

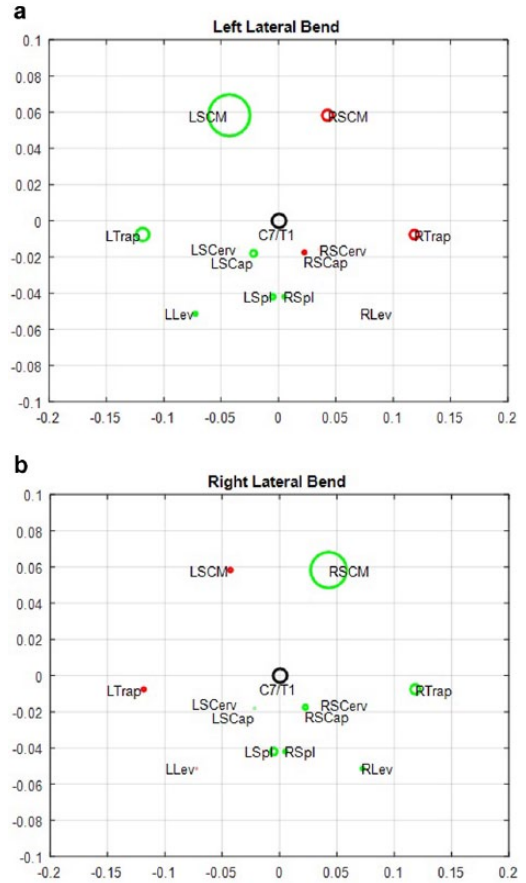


Figure 5. Two-dimensional visualization of antagonist (red) and agonist (green) activity for the mean of the peak coactivation (across all subjects) during (a) left lateral bend and (b) right lateral bend. Size of the circle represents the mean contribution of the particular muscle across all subjects. The x- and y-axes represent the location of each muscle's origin relative to C7/T1 in meters from Table 2 as X₀ and Z₀, respectively. Although the visualization is in 2-D, classifications were still based on 3-D data. R/L = right/left; SCM = sternocleidomastoid; Trap = cervical trapezius; SCerv = semispinalis cervicis; SCap = seminspinalis capitis; Spl = splenius; Lev = levator scapulae.

Granata, 1995). Hence, it may be inferred that the head postures requiring axial rotation as well as rotation coupled with flexion would also have higher levels of coactivity relative to flexion/extension and lateral bending (Figure 1). Interestingly, the coupled movement of extension and rotation appeared to have lower coactivity

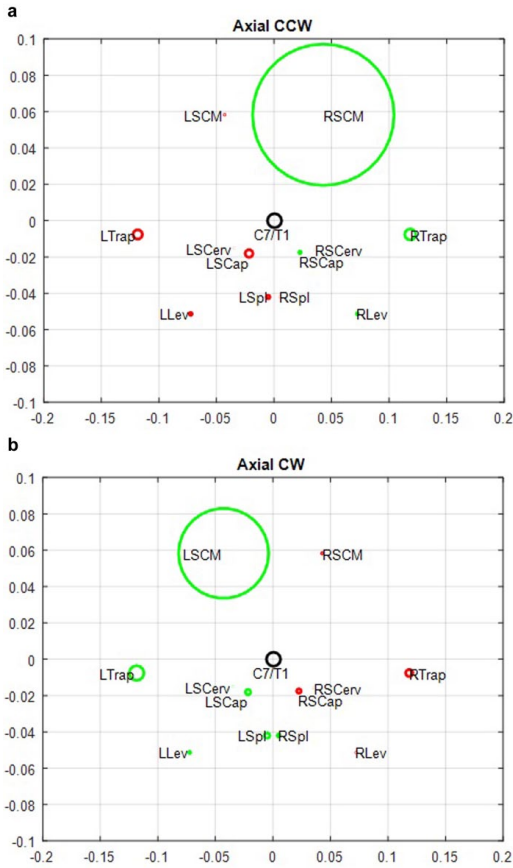


Figure 6. Two-dimensional visualization of antagonist (red) and agonist (green) activity for the mean of the peak coactivation (across all subjects) during (a) counterclockwise (CCW) axial rotation and (b) clockwise (CW) axial rotation. Size of the circle represents the mean contribution of the particular muscle across all subjects. The x- and y-axes represent the location of each muscle's origin relative to C7/T1 in meters from Table 2 as X_0 and Z_0 , respectively. Although the visualization is in 2-D, classifications were still based on 3-D data. R/L = right/left; SCM = sternocleidomastoid; Trap = cervical trapezius; SCerv = semispinalis cervicis; SCap = semispinalis capitis; Spl = splenius; Lev = levator scapulae.

than twisting alone. Relative to the findings from Harms-Ringdahl, Ekholm, Schuldt, Nemeth, and Arborelius (1986), it was possible that extension required higher tension in the passive tissues. This in combination with increased load distribution to the vertebral structures due to the

center of mass of the head may have reduced the active contributions, thereby reducing the coactivation index. During flexion with axial rotation, extensor activity increased to support the forward head moment, and SCM activity increased for axial rotation. This synergistic combination increased both the ratio of antagonist to agonist as well as total system activation, thereby resulting in a high coactivity index. When accounting for speed, the level of coactivity increased for tasks requiring axial rotation/twisting, particularly during normal/preferred speed (Figure 1). It is important to note that the motions endured were continuously repeated three times within a trial at a very slow and controlled speed or comfortably at a normal speed. Fast motions were not tested to mitigate risk of motion sickness. This increase in coactivity typically occurred at the end ranges of motion, likely due to deceleration of the movement to switch direction. Gender differences were also seen between the tasks (Figure 2a). Females tended to have higher levels of coactivity across the different tasks, and it appeared to be associated with higher sternocleidomastoid activations (Figure 2b). This finding may be supported by a study by Nimbarte (2014), which also described the relative strength differences in sternocleidomastoid activation between males and females. Overall, the coactivation index developed for the cervical spine could distinguish different levels of coactivation relative to complexity in movement.

To place this study in perspective, a series of limitations must be noted. First, the same set of muscle lines of action and cross-sectional area data were used for all the subjects. A more personalized model would account for some of the variability found in the data. However, this information was not available for our subjects. In addition, other personalized factors such as anthropometric differences were not addressed in this study. These differences affect strength outputs and possibly levels of coactivity (Vasavada, Danaraj, & Siegmund, 2008). Second, maximum voluntary exertions were collected to normalize the EMG values. The problem with the head and neck region was that some subjects were more hesitant to fully exert their maximum efforts for fear of injury, hence a better series of

reference contractions may be needed to account for those issues, particularly for studying a patient population. A lower maximum effort may affect the index depending on the set of muscles in which the effort was lower. It was speculated that while affecting the normalization of the EMG, it would increase the magnitude of the index. Hence, a non-max routine may be warranted (Dufour, Marras, & Knapik, 2013). Third, only head motions were tested while standing. The addition of upper extremity or lumbar-related tasks in different postures and motions may affect the findings in the cervical spine, especially if forces are needed to execute the task (Nimbarte, 2014; Nimbarte, Aghazadeh, Ikuma, & Harvey, 2010). The study was only limited to the motion of the head to examine the effect of complex dynamic motions on coactivity. Previous studies have been limited to uniplanar motions (sagittal or lateral) or isometric exertions. Our study included multiplanar motions. Fourth, the system of neck muscles is highly complex. The use of surface EMG only allowed for the collection of superficial musculature, possibly missing some of the antagonist/agonist behavior of the deeper muscles. However, a study by Blouin, Siegmund, Carpenter, and Inglis (2007) showed that the neural control of agonists between superficial and deep musculature in the neck may share a common neural drive. Considering the limitations, the study still provides a novel approach to understanding coactivation in the cervical spine during complex dynamic tasks. Future studies would address more personalized approaches, better reference contractions, and a wider variety of tasks.

CONCLUSION

This study provided a description of a coactivation index intended to assess the neuromuscular effort required of the cervical spine from a variety of head motions. Through the use of EMG, kinematic data, muscular lines of action, and CSA data, we were able to apply an approach previously tested in the lumbar spine (Le et al., in press) to the cervical spine. Testing of the index showed that increased complexity in motion (particularly motions requiring twisting) tended to have higher coactivity due to the increased

need for postural control. Overall, this methodology may be applied to assess the neuromuscular efforts from complex dynamic head/neck motions for various tasks.

KEY POINTS

- The coactivation index developed for the cervical spine allows for the assessment of multiplanar, complex, dynamic head motions.
- Index was highest during conditions involving axial rotation.
- Index may be applied for task assessment comparisons involving the cervical spine (e.g., tasks requiring non-neutral head positions with and without loads on the head).

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