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Original article

Does posture of the cervical spine influence dorsal neck muscle activity when lifting?

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A B S T R A C T

Previous studies have shown that postural orientations of the neck, such as flexed or forward head postures, are associated with heightened activity of the dorsal neck muscles. While these studies describe the impact of variations in neck posture alone, there is scant literature regarding the effect of neck posture on muscle activity when combined with upper limb activities such as lifting. The purpose of this study was to evaluate the effect of three different neck postures on the activity of the different layers of the dorsal neck muscles during a lifting task. Ultrasound measurements of dorsal neck muscle deformation were compared over two time points (rest, during lift) during a lifting task performed in three different neck postural conditions (neutral, flexed and forward head posture) in 21 healthy subjects. Data were analysed by post-process speckle tracking analysis. Results demonstrated significantly greater muscle deformation induced by flexed and forward head postures, compared to the neutral posture, for all dorsal neck muscles at rest ($p < 0.05$). Significant condition by time interactions associated with the lift was observed for four out of the five dorsal muscles ($p < 0.02$). These findings demonstrate that posture of the cervical spine influenced the level of muscle deformation not only at rest, but also when lifting. The findings of the study suggest that neck posture should be considered during the evaluation or design of lifting activities as it may contribute to excessive demands on dorsal neck muscles with potential detrimental consequences.

1. Introduction

Neck pain is often associated with occupations that involve lifting (Ariens et al., 2000). This is possible by virtue of the shared muscle attachments between the scapula and axial skeleton, such as upper trapezius and levator scapulae which attach to the head and cervical spine respectively (Moore et al., 2009). Subsequently, loads imposed on the scapula during lifting are transferred to the head and neck. If these loads are excessive or poorly attenuated, they may have the potential to initiate injury or strain pain-sensitive cervical structures (Behrsin and Maguire, 1986). This may be a risk if lifting tasks are performed in the presence of impaired neuromuscular function of the cervical spine or shoulder girdle (Falla et al., 2004, O'Leary et al., 2007; Wegner et al., 2010; Zakharova-Luneva et al., 2012). This proposed mechanism of lifting-induced neck pain is credible considering the reliance of the cervical vertebral column on cervical muscles for physical support (Panjabi et al., 1998).

Another factor often associated with occupational neck pain is cervical posture (Eltayeb et al., 2009). Studies have shown that some postural orientations of the cervical spine, such as forward head posture (FHP), result in heightened gravitational load to some cervical motion segments (Harms-Ringdahl et al., 1986), as well as increased extensor muscle activity (Edmondston et al., 2011). Although these studies suggest a potential association between cervical posture and detrimental strain on the neck, a direct cause–effect relationship between these factors has not been established (Szeto et al., 2002). Additionally, while these studies describe the impact of variations in neck posture alone (Harms-Ringdahl et al., 1986), there is scant literature regarding the effect of neck

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posture on muscle activity when combined with upper limb activities such as lifting (Nimbarte et al., 2010).

The purpose of this study was to evaluate the effect of three different neck postures on the activity of the different layers of the dorsal neck muscles during a lifting task. Specifically, we utilised an ultrasound measurement application called speckle tracking analysis (Peolsson et al., 2012) to quantify the deformation (changes of longitudinal length of the muscle indicative of muscle activity) of multiple dorsal neck muscle layers during a lifting task in different neck postures. We hypothesised that neck posture will significantly alter the dorsal neck muscle activity during lifting. It is anticipated that the findings of this study will have relevance to understanding the potential for postural-based neck injury in occupational settings.

2. Methods

2.1. Participants

Twenty-one healthy subjects from a university population volunteered to participate in the study (male $n = 7$, female $n = 14$, mean age 26 years (SD 6.5)). Participants were all right hand dominant with no recent or previous history of a neck disorder requiring medical intervention, and absent signs of physical dysfunction in a clinical examination of the neck. Participants were excluded from the study if they reported any current shoulder disorders.

This study received approval from the Institutional Medical Research Ethics Committee and was conducted in accordance with the declaration of Helsinki. All participants received verbal and written information about the study and signed a consent form.

2.2. Measurements

2.2.1. Ultrasound recordings and speckle tracking analysis

Ultrasound measurements of the dorsal cervical muscles were recorded with a 12.0 MHz linear transducer (38 mm footprint) and an Ultrasound Vividi Dimension (GE Healthcare, Horten, Norway) unit utilising a high frame rate (50 frames/s) operated in B-mode and a 2D ultrasound imaging system. Using this method, ultrasound images of muscle contractions were recorded before (at rest) and during the lifting tasks and later analysed as image sequences ("videos") by post-process speckle tracking analysis.

Recordings were made of the dorsal neck muscles, including the Upper Trapezius, Splenius, Semispinalis Capitis and Semispinalis Cervicis, and cervical Multifidus muscles (Fig. 1). All recordings were made at the C4 vertebral level, identified by palpation of the C4 spinous process. The transducer was first positioned in a transverse orientation at the marked C4 level on the right side, so that the underlying muscle layers and bony landmarks were identified. The transducer was then rotated 90°, and orientated longitudinally to the dorsal muscles. This provided the optimal image plane required for the post-process speckle tracking analysis, based on the stable Farneback mathematical model (Peolsson et al., 2012).

2.2.2. Measurement of muscle deformation

Speckle tracking analysis was performed post process using the ultrasound movie sequence of images (AVI format). Ultrasound of muscle results in an interference pattern of acoustic markers referred to as a speckle pattern. In speckle tracking analysis the first frame of the video sequence is viewed and a region of interest frame (ROI; 10 × 2 mm) is positioned over a standardised location within the speckle pattern of each muscle. The ROI tracks its contained unique speckle pattern frame by frame through the movie

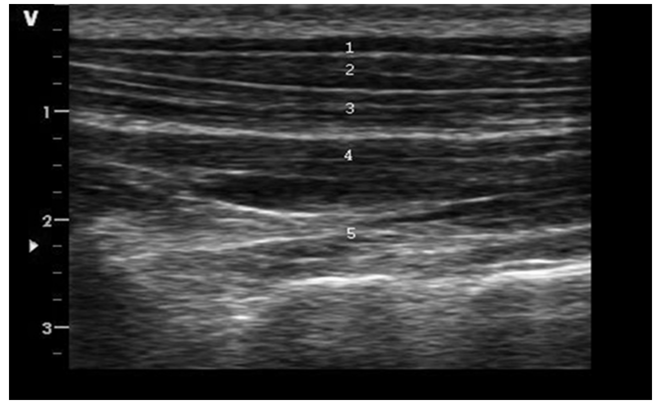

Fig. 1. Ultrasound image, dorsal view superficial and deep cervical muscles. 1 = Trapezius, 2 = Splenius, 3 = Semispinalis Capitis, 4 = Semispinalis Cervicis, 5 = Multifidus. Vertical axis in the figure shows the depth of the imaging into the tissues.

sequence. Consequently, as the contained speckle pattern changes length with muscle activity so does the length of the ROI. The change in the ROI length is measured as muscle deformation. The *Muscle Deformation* measure is calculated as the percentage change in the longitudinal median length variation of the ROI compared to that at rest (expressed as % strain). The rate of change in length of the ROI is measured as *Muscle Deformation Rate* which is deformation per time unit (expressed as % strain 1/s).

Tracking of the ROI in the movie sequence is done using a speckle tracking algorithm based on a stable mathematical model (Farneback). This research software tracks the unique speckle pattern contained within each ROI, dependent on at least 80% agreement of the speckle pattern between frames as sufficient for the software to accept that the identical muscle region is being accurately tracked (Peolsson et al., 2010). The calculating algorithm measures deformation of each ROI in each frame sequentially comparing it to its length in the initial resting movie frame.

It was ensured that the ROI representing each muscle was located in a standardised position between participants (midpoint of the muscle belly and orientated longitudinal to the muscle fibres). For each video sequence the optimal position of the ROI was checked by observing the video sequence in slow motion with the ROI's in situ to ensure that they were recognised by the measurement software and that the ROI representing other muscle layers did not cross each other. Once the investigator was satisfied with the location of each ROI the analysis was performed using the software.

The speckle tracking analysis method of measurement has been shown to have excellent test–retest reliability for the measurement of deformation in the cervical muscles (ICC 0.71–0.99) (Peolsson, A., unpublished data). There is also evidence of a positive relationship between the magnitude of muscle deformation (recorded with speckle tracking analysis) and the magnitude of muscle activity using other measurements (force, progressive electrical stimulation) providing justification for the use of the measurements performed in this study (Lopata et al., 2010).

2.3. Lifting task

Subjects sat without back support, with their feet flat on the floor, and their spine positioned in a clinically evaluated neutral position. An inclinometer was attached to their head, and was centred over the tragus of the left ear. Participants held a hand weight (2.5 kg for male participants and 1.5 kg for females) with the shoulder in 70° flexion, the elbow extended, and the forearm in

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neutral pronation/supination (Fig. 2). This weight was placed on a trigger switch connected to the ultrasound, so that the moment of lift could be recorded within the video sequence for each repetition. Participants performed the upper limb task by swiftly flexing the shoulder approximately 10°, so that the hand weight just cleared the trigger switch. This elevated position was maintained for a period of 2 s before the weight was swiftly lowered back onto the trigger. In this manner, the period between when the hand weight was lifted and returned to the supporting surface was recorded within the ultrasound video sequence for later analysis.

2.4. Experimental neck postures

The lifting task was performed in three different cervical spine postures: Neutral, flexed neck posture (Flexed), and forward head posture (FHP) (Fig. 2). In the Neutral posture, the participants were guided to a clinically determined neutral orientation of the cervical spine and head, able to be sustained by the participant with minimal apparent effort. This was to account for individual differences in spinal flexibility and structure. In this neutral position, the dial of the inclinometer was set at 0° so that Flexed and FHP could be standardised from this neutral position. For Flexed, the subject was guided into 30° of lower cervical flexion as determined by the inclinometer. For the FHP, the participant was first facilitated into a position of 30° of lower cervical flexion, followed by extension of the upper cervical spine so that the subject's line of sight was straight ahead. The maintenance of these postures was continually monitored by an investigator sitting on the subject's left side. Measurements were repeated if the participant's neck posture deviated from the test position at any stage during the lift.

2.5. Procedure

Following screening and familiarisation processes, participants were given detailed instructions of the testing procedure and carried out a practice lift with their left arm. The C4 spinous process was then identified and marked to guide appropriate positioning of the ultrasound transducer for recording of the dorsal neck muscles. The order of the experimental neck postures (Neutral, Flexed, FHP) was randomised for each participant to minimise order effects. The lifting task was then performed and recorded for each of the postural conditions. Calculation of the deformation measure required a reference deformation value at rest (first 50 frames (1 s) of the video sequence) and thus video recordings for all experimental neck postures commenced with the head in a neutral posture. Participants were then facilitated to the experimental neck posture (remain in Neutral, or positioned in the Flexed or FHP), with this position being sustained for 2 s while recordings continued. The subject was then instructed by the investigator to perform the lifting task. For each experimental condition, the time point in the ultrasound video that corresponded to the participant adopting an experimental neck posture was registered into the ultrasound machine with a trigger switch. The raising and lowering of the weight on and off the trigger switch signified the commencement and completion of the lifting task. In this manner, post processing of the muscle deformation measure could be calculated at the correct time points (1. experimental neck posture, 2. during lifting task) relative to the starting rest position.

2.6. Data management and statistical analysis

For all three conditions (Neutral, Flexed, FHP), the deformation data of the dorsal neck muscles for the two time periods (experimental neck posture (0.4 s epoch (duration of analysed data), during lifting task (5 s epoch))) were expressed as the root mean square (RMS). This was based on the curve of the changes in deformation over the two epochs of interests during the ultrasound sequence.

Analysis was performed using a statistical package (SPSS version 20: IBM). For all three conditions, descriptive statistics (mean and SD) were calculated for the deformation RMS measurements at the two time points. Baseline characteristics of the three different postures (deformation values at rest) were compared with a paired *t*-test. A repeated measures general linear model was used to evaluate main effects for condition (Neutral, Flexed, FHP), time (experimental neck posture, during lift), and condition by time interactions. A Bonferroni correction was used for multiple comparisons of the deformation measurement. Tests for simple effects were performed post hoc when indicated. Statistical significance was accepted at the 0.05 alpha level. Effect size was calculated according to Armijo-Olivo et al. (2011) as the mean value number one minus mean value number two, divided with the pooled standard deviation of the two groups. Effect size ≥0.40 was set as clinical significance (Armijo-Olivo et al. 2011).

3. Results

The RMS data for all muscles for all conditions at both time points are shown in Table 1. Significant main effects for condition were found for all dorsal neck muscles ($p < 0.01$). Significant main effects for time were found for the Upper Trapezius, Splenius, Semispinalis Capitis, and Semispinalis Cervicis muscles ($p < 0.05$)

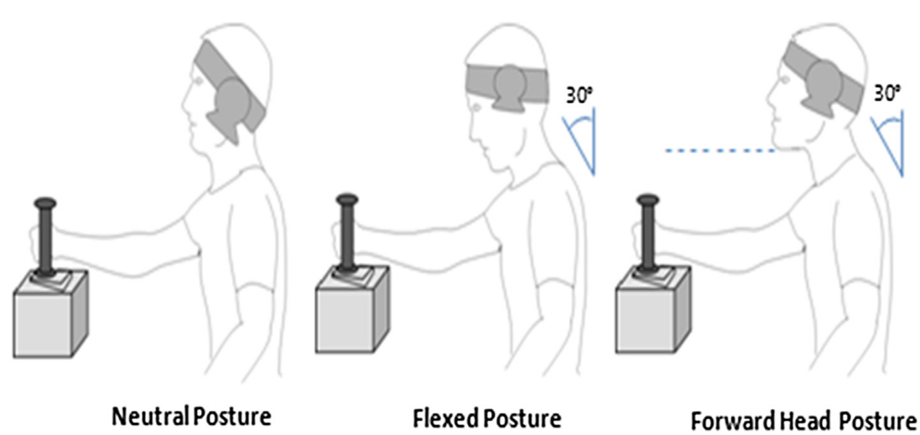

Fig. 2. The three different cervical postures in which dorsal cervical muscle activity was assessed.

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Table 1
Depicts time effects relative to rest in each of the three postures. Muscle deformation is expressed as percentage deformation compared to that at rest (strain %).

Muscle	Neutral		Flexed		Forward Head	
	Rest	Lift	Rest	Lift	Rest	Lift
Upper Trapezius	0.61 ± 0.47	2.75 ± 2.13*	5.78 ± 3.66	5.77 ± 4.01	3.14 ± 2.25	3.76 ± 2.13
Splenius	1.13 ± 0.91	3.1 ± 2.37*	11.07 ± 8.64	12.07 ± 10.4	7.82 ± 6.39	8.23 ± 4.91
Semispinalis Capitis	1.14 ± 0.89	3.77 ± 2.87*	10.3 ± 7.75	10.2 ± 7.66	8.63 ± 8.67	8.97 ± 8.22
Semispinalis Cervicis	1.9 ± 1.55	5.5 ± 3.13*	9.6 ± 7.49	9.27 ± 7.56	10.23 ± 6.87	11.07 ± 6.89
Multifidus	2.06 ± 2.63	5.63 ± 4.42*	15.9 ± 15.75	14.7 ± 13.02	11.37 ± 8.21	11.31 ± 7.32

* Significant differences ($p < 0.05$) between rest and lift.

(Table 1), but not the cervical Multifidus muscle ($p > 0.07$). Significant condition by time interactions was observed for the Upper Trapezius, Semispinalis Capitis, Semispinalis Cervicis, and cervical Multifidus muscles ($p < 0.02$), but not for the Splenius muscle ($p = 0.36$) (Fig. 3).

Tests of simple effects revealed muscle deformation values for the Flexed and FHP conditions were significantly greater at rest (in the postural position prior to the lift) compared to the Neutral condition for all muscles ($p < 0.01$). Deformation at rest was significantly different between the Flexed and FHP conditions ($p < 0.01$) for the Upper Trapezius muscle (higher in the Flexed posture) only. Significant increases ($p < 0.05$) in dorsal neck muscle deformation in response to the lift only occurred during lifting when in the Neutral posture (Effect sizes in Neutral condition 0.48–1.44 and in Flexed and FHP 0.003–0.28) (Table 1).

4. Discussion

This study investigated the effect of different neck postures on dorsal neck muscle activity during a lifting task. The significant condition by time interactions for four out of the five dorsal neck muscles observed in this study suggest that neck posture has a significant influence on the pattern of dorsal neck muscle activity when lifting (Fig. 3), thus supporting our hypothesis. We also showed that muscle deformation at rest, before the arm lift was performed, was heightened in the Flexed and FHP position compared to Neutral, indicating that neck posture alone will significantly alter dorsal muscle activity.

Tests of simple effects revealed that significant changes in muscle deformation between the rest and lifting time points for each condition were only evident when lifting was performed in the Neutral posture (Table 1). The findings were supported by the effect size calculations to be of clinical significance only in the Neutral condition. This may partly be explained by the differences in muscle deformation observed at rest between these different

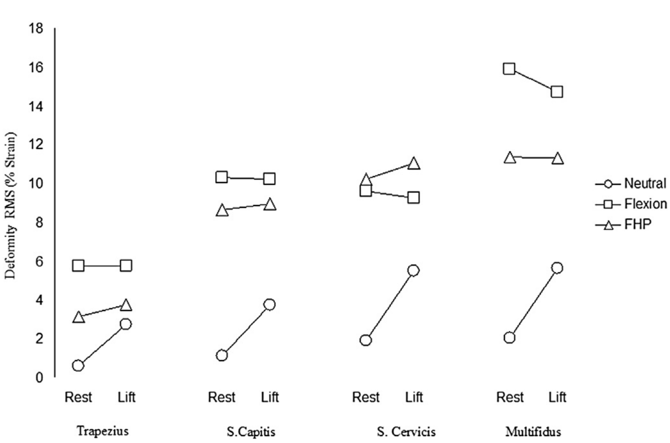

Fig. 3. Depicts deformity values for all muscles with a significant time × condition interaction. S. = Semispinalis.

postural conditions. Compared to the Neutral posture, dorsal muscle deformation in the Flexed and FHP conditions was already at a significantly elevated level even before lifting was commenced (Fig. 3, Table 1). This probably reflects the increased flexion moment arm of gravity brought about by displacement of the head anterior to the thorax in these postures. In this manner, the lack of significant changes in deformation during lifting in the Flexed and FHP conditions may reflect that the muscles were already in a state of contraction in their heightened antigravity role at rest. In contrast to Neutral, the dorsal neck muscles in Flexed and FHP may not have needed to increase their level of deformation to additionally counteract the forces imposed by the lift. While this is speculative, the significant increases in dorsal muscle deformation observed in response to the lift in the Neutral posture (Table 1), but not the Flexed or FHP conditions, may explain the significant condition by time interactions observed for most of the dorsal neck muscles. With the current state of evidence as to role of the multilayered dorsal muscles of the neck we cannot feasibly say why not all muscles (e.g. cervical multifidus) showed a significant main effect of time ($p = 0.07$) despite demonstrating a time by condition interaction.

The heightened activity of the extensor muscles in Flexed and FHP compared to the Neutral posture at rest (prior to the commencement of the lift) observed in this study is consistent with previous investigations using EMG (Caneiro et al., 2010; Edmondston et al., 2011). Nimbarte et al. (2010) measured Upper Trapezius activity with EMG and found increased muscle activity during lifting of low loads when performed in a maximally flexed neck posture compared to lifting in a neutral posture. Even though there are differences in methodology, the overall pattern of activity seen in Flexed and Neutral postures corresponds with our findings. These EMG studies were limited to the measurement of superficial dorsal muscles. The ultrasound measurement used in this study overcomes this limitation by providing a measure of activity of multiple dorsal muscle layers. Consideration of multiple muscles is necessary as functional Magnetic Resonance Imaging studies have indicated that craniocervical postural alterations can significantly influence recruitment patterns between different dorsal neck muscle layers (Elliott et al., 2010). Similarly, as evident in Fig. 3, this study demonstrates apparent changes in activity between the different muscle layers in response to postural orientations of the neck.

4.1. Clinical implications

The primary purpose of this study was to evaluate the change in muscle deformation in varying neck postures in response to a lifting task. Interestingly, the largest difference between conditions was induced by the different neck postures before lifting commenced. Specifically, as evident in Fig. 3 and Table 1, maintaining either Flexed or FHP led to greater muscle deformation than that observed when maintaining the Neutral posture. Potentially sustaining Flexed or FHP for prolonged periods, even in the absence of additional lifting activities, may result in fatigue of these muscles which may contribute to the presentation of some neck pain

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disorders. These findings are also consistent with a previous study that has shown changes in deep cervical flexor muscle activity induced by subtle alterations in cervical posture (Falla et al., 2007). This previous study of Falla et al. (2007) showed a therapist-guided facilitation of a neutral cervical posture to increase activity of the deep cervical flexor muscles in comparison to an independent patient sitting posture correction. We are however unable to speculate regarding the interaction of the flexor and extensor muscles in these different postures based on the observations from this previous study and the current study, as not only did they use different measures of muscle activity (EMG and ultrasound), but also the study of Falla et al. (2007) did not specifically record flexor muscle activity in Flexed or FHP. However this is certainly an area for future research that would require both flexor and extensor muscle activity to be measured simultaneously during these different postural orientations. Notwithstanding, the findings of this current study as do those of Falla et al. (2007) lend support to clinical recommendations to consider postural habits in patients presenting with painful neck disorders (Jull, 2008).

The findings of heightened deformation in Flexed and FHP, together with the findings of altered patterns of activity during lifting (as evident by the significant condition by time interactions), has potential implications for increased loading of pain-sensitive cervical structures (Netto and Burnett, 2006; Zakharova-Luneva et al., 2012). Therefore, it may be beneficial to suggest that lifting tasks be performed with the neck in a neutral position.

4.2. Limitations and future recommendations

There are limitations to this study. One limitation is that subjects were not randomly selected, but were a sample of convenience. Furthermore, only asymptomatic subjects were included, and therefore the results cannot be directly extrapolated to a clinical population. However, obtaining data on muscle behaviour in the absence of pain provides a foundation for which studies investigating symptomatic participants can be compared. In relation to the lifting task, participants' levels of relative strength were not established. Consequently, the standard hand weights chosen may not have provided an equal challenge to the cervical muscles of all participants. Furthermore, it is quite possible that a heavier weight may have led to increased levels of deformation in the musculature (Nimbarte et al., 2010). However, the purpose of the study was to mimic loads more commonly encountered in everyday life. In a similar manner to limitations identified with the utilisation of EMG, measurements of muscle deformation over a specific ROI within the muscle using speckle tracking analysis may not provide an overall representation of activity levels in all regions of the muscle. Finally, although there is some correlation between levels of muscle deformation and EMG measurements (Lopata et al., 2010), more studies are required to validate this new method, particularly in regard to its relationship with muscle force.

Future trials are warranted investigating different populations (e.g. age, occupations, neck pain). Given the brief duration of the adapted posture prior to the upper limb task in this study, subsequent studies may consider incorporating prolonged postural loading conditions to more accurately mimic common demands of the workplace.

5. Conclusions

This study using ultrasound recording and speckle tracking analysis, demonstrated that posture of the cervical spine not only influenced the level of muscle deformation at rest, but also when lifting. The findings of the study suggest that neck posture should be considered during the evaluation or design of lifting activities as it may contribute to excessive demands on dorsal neck muscles with potential detrimental consequences.

Conflicts of Interests

The authors declare no conflicts of interests.

Acknowledgements

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