**Association of electromyographic activation patterns with pain and functional disability
in people with chronic neck pain**

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Abstract

Purpose This study examined the activation patterns of the cervical and thoracic muscles in people with and without chronic neck pain during functional activities and their associations with pain intensity and functional disability.

Methods Thirty-four adults with chronic neck pain and 34 asymptomatic adults were recruited. They were requested to perform active cervical movements and an upper limb lifting task. Electromyographic activation patterns (EMG) of bilateral upper trapezius (UTr), cervical erector spinae (CES), sternocleidomastoid (SCM), and thoracic erector spinae (TES) were recorded during these tasks. Correlation and multiple regression analysis were used to examine the associations between EMG variables and severity of pain and functional disability.

Results When performing the cervical movements, the neck pain group displayed lower EMG activity levels, especially in the cervical and thoracic extensors. In addition, significantly prolonged activation was observed in seven of the ten muscles during the upper limb lifting task. The changes in EMG amplitude and activation duration were found to be significantly correlated with severity of pain ($R^2 = 0.716$) and functional disability ($R^2 = 0.623$).

Conclusions Significant differences in the activation patterns of multiple cervical and thoracic muscles were found in individuals with neck pain compared with those without neck pain. These were significantly associated with their degree of pain and functional limitation. The findings of this study highlight the importance of assessing and optimising the neuromuscular activation of these muscles in the rehabilitation of those suffering from chronic neck pain.

Word count = 240

Keywords: Chronic neck pain, muscle activation, pain intensity, functional disability, cervical movements, upper limb lifting task

1 **Abbreviations:**

2	AS	Asymptomatic
3	CES	Cervical Erector Spinae
4	CMD	Coefficient of Multiple Determination
5	Cx	Cervical spine
6	EMG	Electromyography
7	ICC	Intraclass Correlation Coefficient
8	MCS	Mental Component Score
9	MIVC	Maximal Isometric Voluntary Contraction
10	NDI	Neck Disability Index
11	NP	Neck Pain
12	NPQ	Northwick Park Disability Questionnaire
13	NPRS	Numeric Pain Rating Scale
14	PCS	Physical Component Score
15	SCM	Sternocleidomastoid
16	SENIAM	Surface Electromyography for the Non-Invasive Assessment of Muscles
17	SF-12	Short Form 12 Health Survey
18	SMIVC	Sub-Maximal Isometric Voluntary Contraction
19	TES4	Thoracic Erector Spinae at 4 th thoracic spine level
20	TES9	Thoracic Erector Spinae at 9 th thoracic spine level
21	Tx	Thoracic spine
22	UTr	Upper Trapezius
23		

1 **Introduction**

2 Chronic neck pain is a highly prevalent global health problem that often leads to physical
3 impairments and functional disabilities (Côté et al. 2008; Vos et al. 2012). Approximately one
4 third of chronic neck pain sufferers are reported to have difficulties in performing various
5 activities in their daily lives (Picavet and Schouten 2003). Numerous physical and/or
6 biomechanical factors have been proposed to be associated with the functional limitations in
7 people with chronic neck pain (Côté et al. 2008). For instance, the extent of increased forward
8 head posture was moderately correlated with the degree of functional disability (Yip et al.
9 2008), whilst suboptimal motor control of the axio-scapular muscles has been considered as
10 one of the major contributing factors to functional disability in individuals with neck pain
11 (Christensen et al. 2017).

12
13 A recent study has revealed that a significantly higher degree of co-activation of the
14 sternocleidomastoid and splenius capitis was displayed in individuals with neck pain compared
15 to healthy controls when performing maximal isometric contractions of the cervical muscles in
16 different directions (Lindstrøm et al. 2011). Both the sternocleidomastoid and splenius capitis
17 remained highly active irrespective of the direction of contraction. The impaired directional
18 specificity and synergistic contribution of the cervical muscles displayed in individuals with
19 chronic neck pain were associated with underlying neuromuscular dysfunctions (Lindstrøm et
20 al. 2011; Falla et al. 2010; Falla et al. 2004b). Impairments such as augmented co-activation
21 and altered synergistic contribution of the cervical muscle system can either be mal-adaptive
22 or compensatory strategies in response to neck pain. If such impairments persist over time, they
23 may potentially contribute to a vicious cycle of undesirable changes in muscle properties,
24 motor control dysfunction, and perpetuation of neck symptoms (Falla and Farina 2007).
25 However, it remains unknown if this explicit muscle activation pattern is consistently elicited

1 in the neck pain group and across various functional tasks because only the isometric muscle
2 contractions have been investigated.

3
4 Myriad muscle impairments, including changes in physical structure, behaviour, and function
5 of muscles, have been found to be connected to the development and persistence of neck pain
6 (O'Leary et al. 2009). However, manifestations of altered motor control revealed by amplitude
7 of electromyographic (EMG) activity of the cervical muscles in people with neck pain were
8 found to vary between studies (Castelein et al. 2015). The diversity of amplitude presentations
9 across studies could partly be explained by differences in muscle activation in response to
10 nociceptive stimuli; some people were found to be inhibited in this regard (Lund et al. 1991),
11 whilst others had augmented muscle activation (Johansson and Sojka 1991). Furthermore,
12 individual differences in the synergistic contributions within the complex cervical muscle
13 system could also contribute to the reported variations in EMG amplitude (Gizzi et al. 2015;
14 Rana et al. 2015). In addition to studying EMG amplitude, the detection of onset and cessation
15 of EMG activity during task cycles using the threshold algorithm can help evaluate the timing
16 and duration of muscle activation (Hodges and Bui 1996; Bonato et al. 2002; Benedetti et al.
17 1999). Delayed onset of the deep cervical flexors activity during the rapid shoulder flexion task
18 was found to be significantly correlated with increase in pain intensity in individuals with
19 persistent neck pain (Falla et al. 2011). Meanwhile, over-activity of the superficial cervical
20 muscles was shown to be one of the classic manifestations signalling a compensatory strategy
21 for the underlying deficiency of the deep cervical muscles in symptomatic individuals (Jull
22 2000; Jull and Falla 2016). Consequently, assessment of both EMG amplitude and activation
23 duration of the superficial cervical muscles would be particularly useful for revealing the
24 heterogeneous manifestations of muscle activation patterns underlying motor control
25 dysfunction related to neck conditions. In addition, our previous studies have demonstrated that

people with chronic neck pain displayed an impaired movement coordination between the cervical and thoracic spine (Tsang et al. 2014, 2013). Investigating the interactive recruitment of the key spinal muscles between these two spinal regions would therefore be important for assessing the role of the recruitment pattern in the maintenance of neck pain and the associated limitations in performing daily activities.

The first purpose of this study was to examine the activation patterns of the key cervical and thoracic spinal muscles expressed in the amplitude of the EMG activity and the percentage of activation duration of the task cycle. Second, it also aimed to investigate the associations between activation patterns, quantified by spatial and temporal features of EMG activity of spinal muscles, severity of neck pain, and degree of functional disability in chronic neck pain sufferers when performing active cervical movements and an upper limb lifting task.

Methods

Subjects

Thirty-four adults with chronic neck pain (25 females and 9 males) who fulfilled the inclusion and exclusion criteria (NP group) and thirty-four age- and gender-matched asymptomatic subjects (AS group) recruited from the local community participated in this study on a voluntary basis. Subjects recruited in the NP group were adults who were experiencing neck pain that had lasted longer than three months continuously or had presented itself mostly over the previous twelve months with non-traumatic history on onset; the severity of the neck condition had required medical care. All subjects in the AS group had been symptom free in all their spinal regions during the previous 12 months. Individuals who had any known neurological or orthopaedic disorders, previous surgery or trauma to the brain or spine, sensory or vestibular conditions, bony abnormalities, deformities of the trunk, or rheumatic disease

were excluded. Ethical approvals for this study were obtained from The Hong Kong Polytechnic University and the procedures were conducted in accordance to the Declarations of Helsinki. All subjects were informed about the experimental procedures and any potential risks prior to the attainment of written consent. All subjects completed the Short Form 12 Health Survey (SF-12) while those recruited to the NP group also rated the intensity of their neck pain on the Numeric Pain Rating Scale (NPRS 0-10) (Cleland et al. 2008) and the degree of their functional limitation on the Northwick Park neck pain questionnaire (NPQ) (Leak et al. 1994).

Experimental procedures

Subjects were asked to sit naturally on a wooden chair with the seat height adjusted to achieve 90° flexion at their hip and knee joints, their hands rested on their thighs, and their feet rested on the floor (foot position was standardised with the shoulder width) (Fig. 1). An inelastic strap was applied across the pelvis to minimise contribution of movements from the lumbo-sacral region. Subjects were then asked to perform the active physiological neck movements and an upper limb lifting task using their dominant hand. All subjects recruited in this study were right handed. Standardised instructions were used for all data collections for all subjects. During the physiological neck movement task, subjects were asked to perform the cervical movements to their full excursion in the three anatomical planes at their own, comfortable pace. The cervical movements included the flexion-extension, left and right rotation, and left and right side flexion; the order of the movement directions was randomised (Fig. 1 and 2a). Cervical movements in each of the three anatomical planes were repeated three times continuously. A 2-minute rest period was given to subjects between trials. For the upper limb lifting task, executed whilst sitting, subjects were asked to pick up a 2kg-weight from a desk using their right upper limb and transfer it to an overhead shelf located 70cm above the desk, releasing the weight

completely on the shelf, and then bringing it back down to the desk level (Fig. 1 and 2b). The lifting task was performed three times consecutively; two pressure sensors were placed, one on the desk and one on the overhead shelf, to define a complete cycle of the lifting task. No attempt was made to correct the movement pattern during both tasks as the purpose was to examine the natural movement patterns occurring at the cervical and thoracic spine during these two tasks. All subjects were allowed to familiarise themselves with the experimental tasks by practising the movements three to five times each before data collection.

[Insert Fig. 1, 2a and b here]

Measurements

Spinal kinematics

Kinematics of the cervical and thoracic spine were acquired with an electromagnetic tracking system (Fastrak, Polhemus Inc. Colchester, VT, USA) using customised software at a sampling frequency of 30Hz (Fig. 1). The system consists of a source that produces a low-frequency magnetic field that is detected by sensors. The source was placed at a standardised distance (0.25m) behind the subjects. Three sensors were placed, one over the external occipital protuberance of the skull, and one each over the spinous processes of T1 and T12, for measurement of the angular displacement of the cervical (Cx) and thoracic (Tx) regions. Sensors placed over the spinous processes were further secured with sports tape to minimise movement between the sensors and the underlying skin during task performance. All kinematic data was filtered with a 5th order low-pass filter with a cut-off of 3Hz using a customised MATLAB software programme (The MathWorksTM, Natick, MA, USA). The angular displacements of the cervical and thoracic spine during the two experimental tasks were computed based on the 3x3 direction cosine matrix described in previous studies (Grood and

Suntay 1983; Pearcy 1986; Pearcy and Hindle 1989). The task cycle of the cervical movement task was defined by the angular displacements of the cervical spine, whilst the data obtained from the pressure sensors described above was used to define the task cycle of the upper limb lifting task for analysis of the activation pattern of the spinal muscles described in the following sections.

Electromyography

Electromyographic (EMG) activity of five pairs of muscles, including the upper trapezius (UTr), cervical erector spinae (CES) at C4 level, sternocleidomastoid (SCM), thoracic erector spinae at T4 (TES 4) and T9 (TES 9) levels on both sides, was recorded at a sampling frequency of 1024Hz (Noraxon Telemetry Wire system 9000, USA Inc.). Disposable disc shaped bipolar Ag-AgCl surface EMG electrodes (10mm Ø) were used for all muscles, with an inter-electrode distance of 20mm. The placement of surface EMG electrodes for the five pairs of muscles were applied according to SENIAM recommendations (Hermens et al. 1999) and details of the electrode placements have been reported in Tsang et al. (2016). Standardised skin preparation (light abrasion by sand paper, cleansing by alcohol swab, and shaving, if indicated) was applied to the relevant skin area before the EMG electrode placements. The level of the electrical impedance of the skin was set at $\leq 5 \text{ k}\Omega$ in the present study.

The raw EMG data was band-pass filtered between 10 and 500Hz, full-wave rectified, and low-pass filtered with a cutoff frequency of 10Hz for smoothing with the length of the time window of 128 samples to produce a linear envelope for studying the muscle recruitment patterns during the execution of tasks. For analysis of spatial and temporal EMG variables, the EMG linear envelope collected in one task cycle defined according to task was standardised to 100 time points, enabling comparison between individuals and between groups.

Analysis of activation patterns of the cervical and thoracic muscles

Both EMG amplitude and percentage of activation duration recorded during the respective task cycles were analysed to evaluate the activation patterns of the ten key spinal muscles examined. The mean value of the root mean square (RMS) of the EMG amplitude linear envelope in each complete task cycle was calculated. The percentage of activation duration during the task cycle was calculated based on the length of the cycles of muscle activation versus inactivation, detected using the threshold algorithm method described in a previous work (Hodges and Bui 1996). The onset and cessation of EMG activity was defined with reference to the baseline EMG activity level of the corresponding muscles of each subject (an EMG amplitude window of 50ms prior to the commencement of the cervical movement was adopted as the baseline EMG activity level). The time point that indicated the onset of the activation for each muscles was then identified as when the EMG activity reached the level of three standard deviations (SD) $\geq$ the baseline level and lasted ≥ 25 ms (Hodges and Bui 1996). The percentage of activation duration was then calculated and expressed as the percentage of the task cycle with the activation of that muscle as denominator, with 100% activation duration indicating that the corresponding muscle was active throughout the whole task cycle. The same data analysis approach was applied for the EMG data recorded in both experimental tasks in this study.

Statistical analysis

The Coefficient of Multiple Determination (CMD), described by Kadaba et al. (1989), was used to examine the reliability of the trajectory of the kinematic and EMG data between the three cycles of movement in the same direction. In addition, Intraclass Correlation Coefficient ($ICC_{(3,1)}$) was used to examine the reliability of the mean values of the EMG amplitude linear envelope and the percentage of activation duration between trials of the same tasks. The values

of the EMG amplitude and the percentages of activation duration for the muscles during task performance were compared between the AS and the NP groups using the Independent T-test. Pearson's correlation analysis was used to assess the associations between NPRS, NPQ score, and EMG variables during active cervical movements and the upper limb lifting task. EMG variables which appeared to have significant correlations with NPRS and NPQ scores were then included for further examination using multiple regression analysis. SPSS Statistics 23.0 (IBM Corp., Armonk, NY) was used to analyse the data with a significance level of 0.05 set for all statistical tests.

Results

The mean (SD) value of the degree of neck pain and functional disability reported by the NP group was 3.9 (SD 1.6) on the NPRS 0-10 and 29.7% (11.9) on the Northwick Park Disability Questionnaire (NPQ). The values of the self-reported pain intensity and NPQ score suggested that subjects recruited in this study experienced a mild degree of neck pain and functional disability associated with their neck pain (Jensen et al. 2003; Leak et al. 1994). There were no significant differences in the demographics between the two groups except regarding the Physical Component Score (PCS) and Mental Component Score (MCS) of the SF-12 Health Survey (Table 1).

[Insert Table 1 here]

Reliability of the spinal kinematics and EMG data

The CMD values ranged between 0.771 and 0.814 for the kinematics, and between 0.752 and 0.821 for the EMG data (Tsang et al. 2014, 2013). The ICC values ranged between 0.987 and

0.996 for the EMG amplitude and between 0.827 and 0.960 for the percentage of activation duration between trials.

The mean (SD) values for the duration of the movements required to carry out the tasks at a comfortable pace for both groups are presented in Table 2. There are significant between-group differences in the time taken to perform the left-right rotation movement and the upper limb lifting task ($p < 0.05$).

[Insert Table 2 here]

Activation patterns when performing cervical movements

The traces of the group mean of the EMG amplitude linear envelope when subjects performed active cervical movements and the upper limb lifting task are presented in Fig. 3a-d. The scale of the EMG amplitude between two groups for the same task was standardised to allow comparison of the level of EMG activity of the ten muscles under investigation. In addition, the comparisons of the activation patterns of the muscles analysed using the mean RMS value and the percentage of activation durations of active physiological movements are shown in Figure 4 a and b respectively.

[Insert Fig. 3a and b here]

[Insert Fig. 4a and b here]

For all cervical movements except for rotation direction, the NP group generally showed a lower level of EMG activity in the majority of the muscle pairs compared to the AS group (Fig.

4a). Significant between-group differences were found on bilateral CES, TES4, and TES9 during flexion-extension; on left TES4 and bilateral TES9 during left-right rotation; and on left UTr and bilateral CES, TES4, and TES9 during left-right side flexion ($p < 0.05$).

Regarding comparisons of the percentage of activation duration of the spinal muscles, the NP group showed a similar pattern in terms of the length of activation when compared to the AS group, with the same activation duration in the same muscle pairs except for the UTr muscles (Fig. 4b). Significant between-group differences were found in the right UTr ($p < 0.05$), in which the NP group demonstrated significantly prolonged activation when executing the flexion-extension and left-right rotation movements (Fig. 4b).

Activation patterns when performing right upper limb lifting task

During the upper limb lifting task, comparable levels of EMG activity were found between the NP and AS groups in terms of the mean RMS values among the ten spinal muscles studied ($p > 0.05$) (Fig. 5a). The right UTr showed the highest activity level among all ten muscles since the lifting task was performed by the dominant right upper limb for all subjects. For comparisons of the percentage of activation duration within the task cycles, the values were generally greater in the NP group except for the right CES and bilateral TES9 muscles (Fig. 5b). Significant between-group differences were found for the bilateral SCM, UTr, TES4, and the left CES muscles ($p < 0.05$); the NP group had significantly prolonged activation in these muscles compared to the AS group.

[Insert Fig. 5a and b]

Associations between the EMG variables, pain intensity, and functional disability score

Results of the associations between the NPRS, NPQ score, and EMG variables during active cervical movements and the upper limb lifting task are presented in Table 3. A total of 11 EMG variables (5 on EMG amplitude and 6 on EMG activation duration) were found to have significant correlations with NPRS in the NP group with the correlation coefficient r ranging between -0.449 and 0.522 ($p < 0.05$). The 11 EMG variables included the mean RMS value of EMG activity of the bilateral CES during cervical side flexion and the upper limb lifting task, RMS value of left SCM during upper limb lifting task, EMG activation duration of bilateral TES9 during cervical flexion-extension, left TES9 during cervical side flexion, right UTr during cervical rotation, and bilateral CES during upper limb lifting task. A multiple regression analysis was run to predict the NPRS in the NP group with these 11 EMG variables that are significantly correlated with pain intensity. These EMG variables statistically significantly predicted the NPRS: $F(11, 22) = 5.032$, $p = 0.001$, $R^2 = 0.716$.

For analysis of the associations between the NPQ score and the listed EMG variables, a total of 12 EMG variables (2 EMG amplitude and 10 EMG activation duration variables) were found to have significant correlations with degree of functional disability reported in the NP group. The values of correlation coefficient r ranged between -0.337 and 0.569 ($p < 0.05$). The two EMG amplitude variables were the mean RMS values of EMG activity of left CES during cervical side flexion and right UTr during the upper limb lifting task. The remaining 10 variables included the EMG activation duration value on the bilateral TES4 and TES9 during flexion-extension and side flexion movements of the cervical spine, the right UTr during rotation, and the left CES during side flexion movements of the neck. A multiple regression analysis was run to predict NPQ score from the list of 12 EMG variables that were significantly

correlated with NPQ score. These EMG variables statistically significantly predicted the NPQ score: $F(12, 21) = 2.888$, $p = 0.016$, $R^2 = 0.623$.

[Insert Table 3]

Discussion

The present study revealed the distinct activation patterns of the major cervical and thoracic muscles in individuals with chronic neck pain compared to asymptomatic controls. The CMD and ICC values of the present study suggested good to excellent repeatability of the data between trials (Kadaba et al. 1989; Shrout and Fleiss 1979). Multiple EMG variables were found to be significantly correlated with the intensity of neck pain and degree of functional limitation reported by subjects in the symptomatic group.

Patterns of muscle activation and differences between groups

Since EMG amplitude was analysed without normalisation in this study, comparisons of EMG activity level were therefore focused on the overall activation patterns displayed in each group and between different tasks. The NP group generally showed a lower EMG activity level in cervical and thoracic extensors (CES and TES) and the major cervical flexor (SCM) in sagittal and coronal plane movements. Individuals with neck pain are commonly found to have impaired neural control of various cervical muscles (Falla and Farina 2007), leading to augmented level of activity in the SCM and anterior scalene muscles during low-load activities and upper limb movement tasks, as has been reported previously (Falla et al. 2004a; Falla et al. 2004b). Since the EMG amplitudes reported in these prior studies were either normalised to the maximal or submaximal isometric contraction of the respective muscles, it remains difficult to compare directly their findings with those obtained from the present study.

1
2 From the analysis of the percentage of activation duration, a similar pattern was shown between
3 the two groups except regarding the right UTr, which remained active with significantly longer
4 duration in the NP group when performing cervical flexion-extension and rotations movements.
5 This specific finding concurs with previous reports of the reduced ability to relax the UTr in
6 people with neck pain following activation (Falla et al. 2004a; Barton and Hayes 1996;
7 Johnston et al. 2008; Szeto et al. 2009). In addition, the UTr has also been shown to have
8 reduced rest periods in symptomatic individuals when performing repetitive tasks (Østensvik
9 et al. 2009). The relationship between the length of UTr activation and pain perceived in
10 symptomatic individuals was further supported by a recent study; Hanvold et al. (2013)
11 investigated if sustained activity of the UTr would predict the intensity of self-reported neck
12 and shoulder pain over a two-year period. Their results showed that individuals with a high
13 level of sustained UTr activity during work reported a rate of neck and shoulder pain three
14 times higher than those with a lower level of sustained activity.

15
16 In contrast to the findings regarding cervical movements, a comparable level of EMG activity
17 in all ten key cervical and thoracic muscles was found between the two groups when the right
18 upper limb lifting task was performed. More importantly, seven out of ten key muscles, all
19 except the right CES and bilateral TES9, were found to have been activated for significantly
20 longer durations within the task cycle in the NP group. The significantly prolonged activation
21 of muscles revealed in the NP group was not limited to the UTr and SCM on both sides, but to
22 the extensor muscle groups of the cervical and upper thoracic spine (the left CES and bilateral
23 TES4) when a light weight was lifted and transferred between altitudes. This is therefore the
24 first study to report the presence of the prolonged activation in the thoracic spinal muscles
25 beyond the major muscles located in the cervical region. The presence of co-contractions of

various muscles was supported by the values of the percentage of activation duration in the NP group (ranging from 63% to as high as 93% of the task cycle). With the muscle activity level equivalent between the two groups, but selective muscles remaining activated over much longer duty cycles in the symptomatic group, it seems that the health of the spinal column could be compromised by the compressive loading related to prolonged co-contractions of various superficial cervical musculatures (Cheng et al. 2014; Marras et al. 2006).

Associations between EMG variables, pain intensity, and functional disability score

EMG amplitude correlates

A strong and positive association has previously been found between UTr activity level and the degree of neck pain perceived in manual workers, but not in office workers (Vasseljen and Westgaard 1995). This is contrary to the findings of the present study; none of the EMG variables measured for the UTr in the present study was found to be significantly correlated with pain intensity in the NP group. Only the right UTr EMG amplitude showed a significant negative correlation with the degree of functional disability. Various causes, including differences in the subjects' factors, the experimental tasks, and the methods used to analyse the muscle activity, would have contributed to the variations found between studies. Therefore, the present findings would only be applicable to the subjects, experimental procedures, and method of analysis specified in this study.

EMG activation duration correlates

Substantially more EMG variables in the activation duration category than in amplitude category were found to have significant associations in predicting these two clinical outcomes (16 EMG activation duration variables versus 7 EMG amplitude variables), particularly regarding the analysis of the NPQ score. These findings suggest a stronger relationship between

the clinical outcomes and the duration of muscle activation than with the magnitude of the muscle activity. More importantly, our present findings revealed the combination of positive and negative correlations between EMG variables and clinical outcomes. These findings highlight the complexity and heterogeneity of the muscle recruitment pattern exhibited in individuals with neck pain. For instance, severity of pain was positively correlated to bilateral CES activity level and activation duration of the bilateral TES9 of selected cervical movement directions. However, pain intensity was negatively correlated with the activity level of bilateral CES and left SCM as well as the activation duration of the right UTr recorded during the upper limb lifting task. Meanwhile, the activation duration of bilateral TES4 and TES9 and left CES (primary extensors of the cervical and thoracic spine) and the muscle activity level of the left CES during cervical movements were positively correlated with the degree of functional disability.

Strength and limitations of the study

Different from previous studies, the present study extended the investigation of EMG activity to the TES in the thoracic region. The present study is the first to report the association found between the altered neuromuscular activity, in terms of both the magnitude and duration of activation, of multiple key muscles of the cervical and thoracic spine and the intensity of neck pain and degree of functional disability. It is important to specify that the present study only examined the associations between pain intensity, reported functional disability level, and spatial and temporal EMG variables. With the cross-sectional study design, it remains impossible to explain the cause and effect of this association. However, the findings of the associations using the multiple regression analysis have provided fundamental knowledge for prospective research further investigating the complex relationship between muscle activation patterns and clinical outcomes in chronic neck pain sufferers.

1 There were some limitations to this study. There were discrepancies in the time taken to
2 complete some of the experimental tasks between the two groups. Despite the small extent of
3 actual time differences, it remains impossible to entirely exclude their potentially confounding
4 effect on the muscle activity recorded. Also, although the authors acknowledged the
5 recommendation and usefulness of the normalisation method for EMG amplitude analysis, the
6 values of the EMG data normalised to their maximal voluntary isometric contraction (MVIC)
7 were found to have varied substantially between subjects in the NP group; multiple factors, for
8 example individuals' motivation, muscle fatigue, and synergistic contribution of the cervical
9 system, would have had a major effect on the reliability of the MVIC data recorded, particularly
10 for those who are symptomatic. Therefore, the non-normalised EMG amplitude, instead of the
11 normalised data, was presented in this study. Although this limits the direct comparison
12 between muscles and between subjects, the findings of the EMG amplitude analysis still
13 provide some evidence to reveal the heterogeneous muscle activity exhibited in NP individuals.

15 **Conclusion**

16 The present study investigated the activation patterns of ten key cervical and thoracic spinal
17 muscles when performing active cervical movements and an upper limb lifting task, using both
18 the EMG amplitude and the percentage of activation duration of the movement cycle. People
19 with chronic neck pain displayed a varied level of EMG magnitude between tasks but
20 consistently exhibited prolonged activation of the majority of the cervical and thoracic muscles
21 when performing the upper limb lifting task. Multiple EMG variables, which reflect this
22 specific activation pattern in individuals with neck pain, were found to be significantly
23 correlated with their pain intensity and degree of functional disability. The present findings
24 provide supporting evidence of the complexity of the muscle recruitment patterns underlying
25 neck dysfunction. The muscle activation patterns and their associations with the clinical

manifestations of pain and disability highlight the importance of assessing and optimising the neuromuscular activation of the cervical and thoracic spinal muscles in the rehabilitation of people with chronic neck pain.

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Captions of the figures

Fig. 1: The experimental set up of a) active physiological movements of the cervical spine and b) upper limb lifting task. S=the electromagnetic source of the 3D motion capturing system, O=occiput, T1=the first thoracic spine, T12=the twelfth thoracic spine, A and B=targeting positions and ①-③= steps of the upper limb lifting task.

Fig. 2: Illustration of a) a cycle of active physiological movements of the cervical spine and b) a cycle of upper limb lifting task. E=extension, F=flexion, L ROT= left rotation, L SF= left side flexion, R ROT= right rotation, R SF= right side flexion and ①-③= steps of the upper limb lifting task.

Fig. 3: Illustration of EMG amplitude linear envelope during a cycle of active physiological movements of the cervical spine in the three movement planes (a-c) and a cycle of upper limb lifting task (d). L UTr/R UTr= left/right upper trapezius, L CES/R CES= left/right cervical erector spinae, L SCM/R SCM= left/right sternocleidomastoid, L TES4/R TES4= left/right thoracic erector spinae at T4 level, L TES9/R TES9= left/right thoracic erector spinae at T9 level.

Fig. 4: Analysis of a) EMG amplitude (in root mean square) and b) activation pattern (in percentage of activation duration) of the cervical and thoracic muscles during active cervical movements. L UTr/R UTr= left/right upper trapezius, L CES/R CES= left/right cervical erector spinae, L SCM/R SCM= left/right sternocleidomastoid, L TES4/R TES4= left/right thoracic erector spinae at T4 level, L TES9/R TES9= left/right thoracic erector spinae at T9 level. *indicates significant differences $p<0.05$ and **indicates significant difference $p<0.01$ between groups.

1 **Fig. 5:** Analysis of a) EMG amplitude (in root mean square) and b) activation pattern (in
2 percentage of activation duration) of the cervical and thoracic muscles during upper limb lifting
3 task (performed by the right dominant arm). L UTr/R UTr= left/right upper trapezius, L CES/R
4 CES= left/right cervical erector spinae, L SCM/R SCM= left/right sternocleidomastoid, L
5 TES4/R TES4= left/right thoracic erector spinae at T4 level, L TES9/R TES9= left/right
6 thoracic erector spinae at T9 level. *indicates significant differences $p<0.05$ and **indicates
7 significant difference $p<0.01$ between groups.