

# Deep and superficial cervical muscles respond differently to unstable motor skill tasks

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## ARTICLE INFO

### Keywords:

Electromyography  
Motor task  
Neck muscles  
Postural control  
Unstable system

## ABSTRACT

Biomechanical modelling and physiological studies suggest that various spinal muscle layers differ in their contribution to spine movement and stiffness. This study aimed to investigate the activation of deep and superficial muscles in stable and unstable task conditions. Nine healthy participants performed a task of controlling a metal ball on a plate fixed to the head in seated position. In unstable tasks, visual feedback was provided by mirrors to move the ball to the centre of the plate by small head movements and maintain the position for 3 s. Task difficulty was adjusted in a stepwise progression of difficulty using five surfaces with materials of decreasing resistance. In the stable condition, the ball was fixed to the plate's centre. EMG was recorded with surface (sternocleidomastoid, anterior scalenes, upper trapezius) and fine-wire electrodes (rectus capitis posterior major, obliquus inferior, multifidus, semispinalis cervicis, splenius capitis). The outcome variable was root mean square (RMS) EMG during the part of the task when the ball was maintained in the centre position. Results revealed greater cervical muscle activity in the unstable than stable conditions ( $p < 0.001$ ,  $\eta_p^2 = 0.746$ ). Control of deep and superficial cervical muscles differed ( $p = 0.003$ ,  $\eta_p^2 = 0.354$ ). Deep cervical muscle activity was greater with unstable tasks, but did not differ with task difficulty. In contrast, superficial cervical muscle activity increased in a stepwise manner with increasing challenge. These results support the notion that the central nervous system uses different strategies for control of deep versus superficial muscle layers of the cervical spine in association with instability.

## 1. Introduction

It has been argued that various layers of spinal muscles have some specificity in their biomechanical functions (Bergmark, 1989). The deep muscles of the cervical spine have the anatomical location and morphological characteristics to stabilize at a segmental level (Boyd Clark, Briggs, & Galea, 2002; Boyd-Clark, Briggs, & Galea, 2001), while the larger superficial muscles have the ability to control the cervical spine en bloc, control larger loads and perturbations and perform head movement (Bergmark, 1989; Cheng, Chien, Hsu, Chen, & Cheng, 2016; Vasavada, Li, & Delp, 1998). This specificity between muscle layers has been confirmed under static conditions. In the cervical muscles, higher stiffness was evident in the deeper muscles multifidus and semispinalis cervicis than the more superficial muscles semispinalis capitis, splenius capitis and upper trapezius both at rest and during isometric loading in prone (Dieterich

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et al., 2017). Cheng et al. (2016) used a surface EMG-assisted optimization model to examine cervical muscle behavior at various loads and head positions. Their analysis implied that the deep muscles maintain stable head postures whereas the superficial muscles were the force generators and augment cervical spine stiffness when co-contracted with antagonist muscles.

Functionally, the muscle system is also subjected to dynamic challenge. Motor tasks involving dynamic unstable systems introduce specific challenges to the sensorimotor control systems (Franklin & Wolpert, 2011). Due to the unpredictable nature of unstable tasks, the central nervous system cannot rely only on feedforward control, and the feedback loops may be too slow to adequately stabilize the body (Burdet, Osu, Franklin, Milner, & Kawato, 2001). Consequently, a common finding in unstable tasks is increased co-activation of antagonist muscles to increase impedance or resistance to motion (Burdet et al., 2001; Franklin, Osu, Burdet, Kawato, & Milner, 2003). In some contexts, the magnitude of co-activation is related to the level of dynamic challenge (Franklin, So, Kawato, & Milner, 2004; Selen, Franklin, & Wolpert, 2009). This has been verified in several studies which have reported increased muscle activity during unstable tasks with differing stability demands (Anderson & Behm, 2005; Anderson, Gaetz, Holzm  nn, & Twist, 2013; Cimadoro, Paizis, Alberti, & Babault, 2013; Franklin et al., 2004; Vera-Garcia, Grenier, & McGill, 2000). These findings are in line with a goal to increase impedance in the presence of unpredictability (Franklin & Wolpert, 2011).

In relation to the behavior of spinal muscle layers, differences have been found in activity of the deep and superficial muscles of the trunk during tasks on stable and unstable surfaces, and with different stability demands. Weber et al. (2017) recorded more tonic activation in transversus abdominis when using an unstable treading device compared to walking and the activity of this muscle did not change with the level of stability demands. In contrast, activity in the superficial trunk muscles was less on the unstable treading device than treadmill walking but their activity was more responsive to the level of challenge. Neck muscle exercises using unstable tasks have been used in previous studies (Muceli, Farina, Kirkesola, Katch, & Falla, 2011; R  jjezon, Bj  rklund, Bergenheim, & Djupsj  backa, 2008; Rudolfsson, Djupsj  backa, H  ger, & Bj  rklund, 2014). However, the specific effects of dynamic challenges on activation of deep and superficial cervical muscles during graduated unstable motor tasks have not been investigated. Increased knowledge about these mechanisms is important for basic understanding about the neuromuscular control of the cervical spine, and for further development of assessment and interventions for neck pain conditions.

This study aimed to assess the effect of task instability on the activity of the deep and superficial cervical muscles, and whether this differed between muscle layers. We hypothesized that; neck muscle activity would increase with increased dynamic challenge of the task, and response to task instability would be greater for superficial than deep neck muscles.

## 2. Method

### 2.1. Participants

A convenience sample of nine healthy recreationally active participants (six men and three women; mean  $\pm$  SD age  $35 \pm 10$  years, height  $175 \pm 9$  cm and weight  $70 \pm 23$  kg) participated in the study. Recreationally active is here categorized as physically active people, as compared to people living a sedentary lifestyle, but not at an elite competing level, as compared to athletes. Participants were considered if aged between 20 and 60 years (i.e., within working age) with no history of neck pain for which they had sought treatment. Exclusion criteria included any history of major neurological or rheumatic disease, spinal scoliosis or any other known condition that could adversely affect cervical neuromuscular function. Participants were screened for these criteria by questions before entering the study. Ethical approval for the study was received from the Institutional Medical Ethics Committee (2002000741) and all participants provided written informed consent. All procedures were conducted according to the Declaration of Helsinki.

### 2.2. Electromyography

Electromyography (EMG) recordings were collected using a Power 1401 data acquisition system and Spike 2 software (Cambridge Electronic Design, UK). The skin areas for EMG measurements were shaved, abraded, and cleaned with alcohol. A combination of surface (10-mm-diam Ag/AgCl disks, inter-electrode distance of 20 mm, Noraxon dual electrodes (Noraxon, USA) and fine-wire electrodes was used. The fine wire electrodes were fabricated from two strands of 75  $\mu$ m diameter Teflon coated stainless steel wire (A-M systems, USA) inserted in pairs into a hypodermic  $0.6 \times 32$  mm needle (Terumo, Japan). Teflon insulation was removed from the wire tips (1 mm), which were bent back 2 and 3 mm to form hooks. Fine-wire electrodes were inserted with guidance of ultrasound imaging into the rectus capitis posterior major (RCPM), obliquus inferior (OI), multifidus (MF), semispinalis cervicis (SMC), and splenius capitis (SPC) as described previously (Bexander, Mellor, & Hodges, 2005). Then surface electrodes were placed on the sternocleidomastoid (SCM), anterior scalenes (AS) and upper trapezius (UT) in accordance with Falla, Dall'Alba, Rainoldi, Merletti, and Jull (2002). Based on the muscle's anatomy and location and for analysis, four muscles were categorized as deep cervical muscles (short muscle anatomy that cross few cervical segments and in close proximity to the centre of rotation of cervical segments): RCPM, OI, MF and SMC, and four as superficial muscles (long muscle anatomy that cross multiple segments and distant from centre of rotation): SPC, SCM, AS and UT. A ground electrode was placed over one of the spinous process between C7 to T4. EMG data were amplified  $5000\times$ , bandpass filtered between 20 Hz and 1000 kHz and sampled at 2000 Hz. EMG recordings were made on the cervical muscles on the right side.

### 2.3. Unstable neck motor skill task

A device was custom-made for the unstable neck motor skill task (R  jjezon et al., 2008). The device consisted of a plate, with a

Plexiglas surface, and a rim which was fixed on the head. A spirit level was used to assure the horizontal level of the plate with the neck and head in neutral position. A metal ball (220 g) was placed on the surface and could be viewed using two mirrors. One mirror was positioned in front and the other mirror above the participant, tilted in a way that the participant could see the complete plate with the ball (Fig. 1). The mirror system provided participants with visual feedback to control the movement of the ball on the plate by movement of the head. Separate removable surfaces were attached to the Plexiglas plate to vary the resistance to roll of the ball and thus the dynamic challenge of the task. Five surfaces were used in the study, from highest to lowest rolling resistance: fleece fabric (Malden Mills Polartec® Classic 100) (Fleece), cotton fabric (Cotton), paper on polypropylene board (Pope), copy paper (80 g/m<sup>2</sup>) (Paper), and an uncovered Plexiglas board (Plexi). The mass of the device was the same for all conditions.

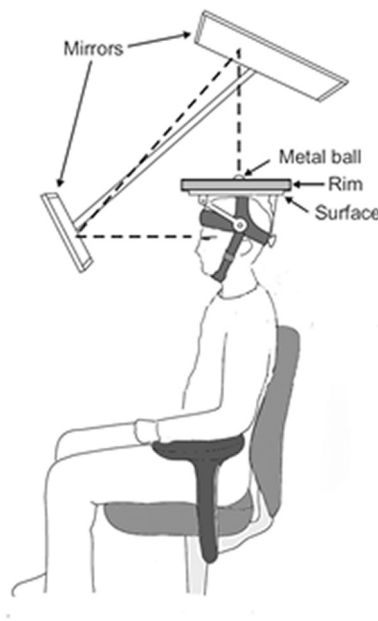
The neck motor skill task was performed with the participant in an upright supported sitting position with the hips and knees in ~90° flexion and the head balanced, in-line with the trunk. The task involved movement of the metal ball from one of four starting positions (front, right, back or left side of the plate) to a target positioned at the centre of the plate. The participant was instructed to move the ball with small head movements to the target and then maintain that position of the ball for 3 s. Surfaces from highest to lowest rolling resistance provided increasing challenge to the neck muscles, demanding a more precise position of the plate in the horizontal to hold the ball steady in the target position. After successful completion of the task, or after attempting the task unsuccessfully for 45 s, the participant was instructed to move the ball to another starting position and recommence the task. The trial time of 45 s was chosen to reduce the risk of fatigue and had been used in a previous pilot study (Røijezon et al., 2008). Six successive trials, without rest, were performed on each surface.

The starting positions and the target position were monitored by LED-photocell detectors, which provided signals for timekeeping, automation of the task and visual feedback from light emitting diodes on the plate. The light emitting diodes indicated the starting position and when the ball was at the centre of the plate. The signal was also used to mark the time periods for extraction of EMG-data, i.e., the time periods that the ball was maintained in a steady manner at the target position. These time periods (ball steady at the centre of the plate) were chosen to compare the task as this was instance when all factors except rolling resistance were as identical as possible across the trials.

#### 2.4. Procedure

Participants attended a familiarization session at least one day before the experimental trials. They practiced six trials on each of the five surfaces. Training difficulty was progressed by starting with the least dynamically challenging surface (Fleece) and finishing with the most challenging (Plexi).

For the experimental trials, after attachment of the electrodes and visually inspecting the signals for noise, each participant performed two practice rounds with six trials each on the slowest surface (Fleece) as a warm up prior to the experimental trials. As for the training session the motor skill tasks were performed in the same sequence for each participant, starting with the surface with the greatest rolling resistance and finishing with the least resistance, thereby progressing the challenge of the motor task from easy to difficult. The surface order was: Fleece (condition 2), Cotton (condition 3), Pope (condition 4), Paper (condition 5) and Plexi (condition



**Fig. 1.** Unstable neck motor skill task. Modified from Røijezon, U., Björklund, M., Bergenheim, M., & Djupsjöbacka, M. (2008). A novel method for neck coordination exercise—a pilot study on persons with chronic non-specific neck pain. *Journal of Neuroengineering and Rehabilitation*, 5(1), 36.

6). After the tasks were completed, a “stable” condition was recorded where the ball was fixed at the centre of the plate by placing it in a tape spool for ~35 s (condition 1). There was a 2 min pause between each progressive task to change the surface and allow for a short rest to reduce risk of fatigue.

## 2.5. Data analysis

All EMG signals were band-pass filtered using second-order Butterworth filters: Surface EMG signals were filtered at 20–500 Hz, whereas intramuscular EMG signals were filtered at 40–900 Hz. ECG de-contamination was performed using a combination of the Modified Turning Point algorithm and a non-negative matrix factorisation in the wavelet domain (Aminian, Ruffieux, & Robert, 1988; Niegowski & Zivanovic, 2016). For conditions where the ball was moving, i.e., unstable tasks (condition 2–6), the root mean square (RMS) amplitude of each EMG signal was calculated for the middle 2 s of the period when the ball was stable at the centre of the plate. In case the trial was unsuccessful (i.e., all periods with the ball in the centre <3 s), stable periods of at least 2 s were detected, and the RMS EMG was calculated over the central 2 s of the largest stable period. If all stable periods were smaller than 2 s, the trial was ignored. For the conditions when the ball was stable/fixed (condition 1), signals were cut into 6 equal segments (~6 s), and the RMS EMG was calculated over the last 2 s of each segment. This procedure ensured consistency of EMG measurements across all participants and estimates of RMS EMG for each condition.

The average RMS EMG of each muscle was calculated over the six trials for each condition and each participant. The mean values for each muscle were normalized to the highest RMS EMG amplitude for that specific muscle in any of the conditions, i.e., RMS EMG values could range from 0 to 100% (Besomi et al., 2019). A value near 100% would be expected only if one of the conditions consistently had the highest, or close to highest, RMS EMG for all participants. This normalisation enables comparison of the activity within each muscle between tasks, and the relative normalized amplitude between muscles during the tasks. Time for task completion was calculated for conditions 2–6 as the time in seconds from start to successful completion of the trial (i.e. the end of the stable period used to calculate the RMS EMG). This data was used to assess the predicted progression in task difficulty, i.e., a more difficult task would take longer time to complete. Processed data were analyzed visually and trials containing large movement artefacts were identified and excluded.

## 2.6. Statistical analysis

All analyses were performed with SPSS statistics software version 26 (IBM, Armonk, New York). Shapiro-Wilks and visual inspection of histograms were used to assess for normal distribution. A repeated measures ANOVA was used to compare the *time to task completion* between conditions in which the ball moved freely (i.e., conditions 2–6). This was used as an index of the progression of difficulty of the task.

EMG data were analysed in 2 ways. First, muscle activation was compared between deep (RMS EMG averaged across RCPM, OI, MF and SMC) and superficial (RMS EMG averaged across SPC, SCM, AS and UT) cervical muscle groups and between conditions (6 conditions; Stable/fixed ball, Fleece, Cotton, Pope, Paper and Plexi) with a repeated measures MANOVA to investigate if there was any differences in behavior of the muscle groups with increased task instability. Second, two repeated measures MANOVAs were performed to compare the activation of individual muscle activation within the (i) deep and (ii) superficial muscle groups between the six

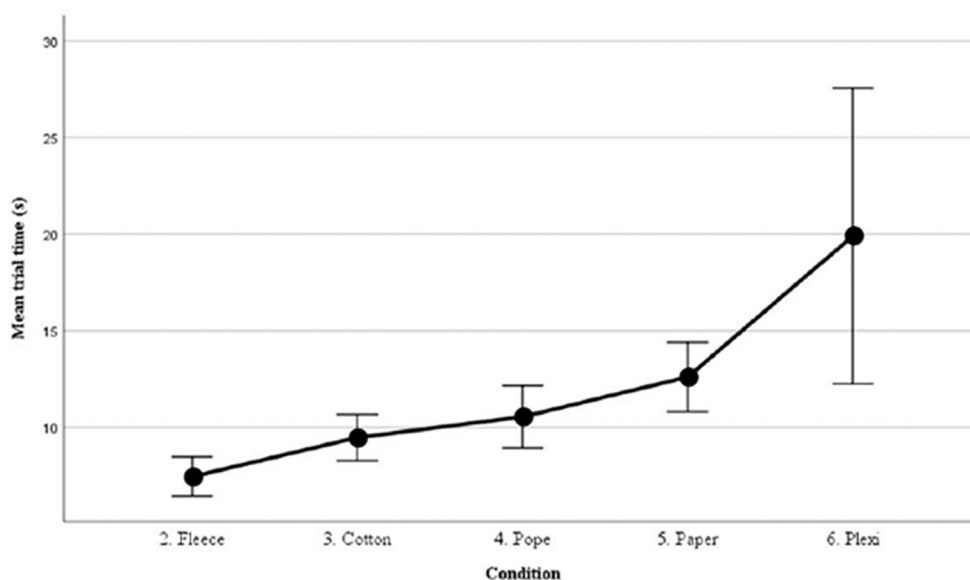


Fig. 2. Time to task completion (in seconds, represented as mean and 95% CI) for each of the 6 conditions in which the ball was able to move freely.

conditions to determine whether muscles within each group acted similarly over the 6 conditions.

Repeated measures MANOVA was used as the statistical model for assessment of within subject effects. In cases where Mauchly's test of sphericity was significant, the Greenhouse-Geisser correction was used. Post hoc analyses with Fisher's least significant difference (LSD) were used to compare the muscle activity between the conditions when the within subject effects were significant for the separate MANOVAs of the deep and superficial muscles, respectively. A  $p$ -value  $< 0.05$  was considered significant for all analyses.

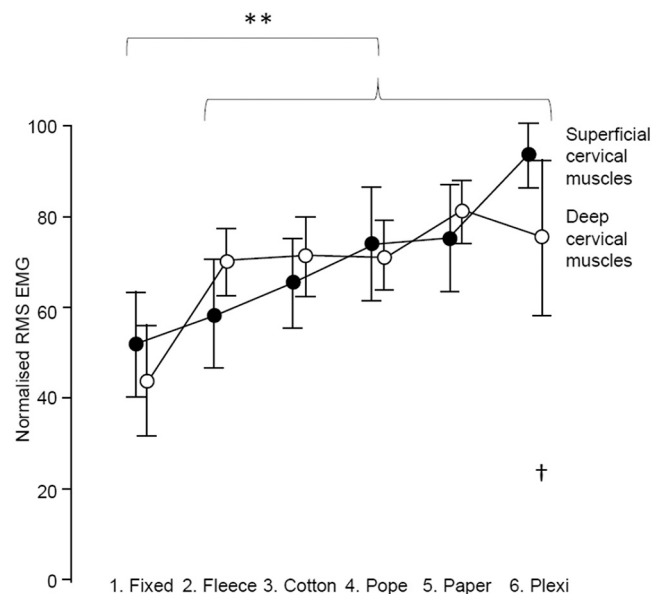
### 3. Results

All participants were able to complete all tasks, but not all were able to complete six successful trials in each condition. In total, 19 of 324 trials ( $< 6\%$ ) were unsuccessful and were excluded from the analyses, 18 of these occurred in the most challenging condition 6 (Plexi), and one in condition 4 (Pope). Visual inspection of the processed data revealed large artefacts in 41 out of 2440 EMG recordings ( $< 2\%$ ). Final analyses included 2399 EMG measures.

The mean time for trial completion between conditions increased progressively from condition 2 to 6 ( $F_{1,17} = 9.41, p = 0.011$ ). This is consistent with the expected progressive increase in difficulty across tasks (Fig. 2).

#### 3.1. Difference in behavior between the deep and superficial cervical muscle groups

The repeated measures MANOVA of the pooled data of the deep and superficial muscle groups revealed a significant interaction for muscle group  $\times$  condition ( $F_5 = 4.38, p = 0.003$ , with effect size  $\eta_p^2 = 0.354$  and observed power = 0.942) and a significant effect for condition ( $F_5 = 23.56, p < 0.001$ , with effect size  $\eta_p^2 = 0.746$  and observed power = 1.000), but not muscle group ( $F_1 = 0.046, p = 0.835$ , with effect size  $\eta_p^2 = 0.006$  and observed power = 0.054). Post hoc tests of muscle group  $\times$  condition showed that there was a significant difference between muscle groups at condition 6, with larger increase for superficial muscle group ( $p = 0.033$ ) (Fig. 3). Moreover, the post hoc test revealed that there was a significant difference between the first (Fixed) condition and all unstable conditions for both the deep cervical and the superficial cervical muscle group, respectively ( $p < 0.01$ ). Compared to condition 1 with the fixed ball, the normalized RMS EMG of the deep cervical muscles increased by 60% in condition 2, 62% in condition 3, 63% in condition 4, 85% in condition 5 and 72% in condition 6. In contrast, activation of the superficial muscles increased in more stepwise manner (Fig. 3). Compared to condition 1 with the fixed ball, the normalized RMS EMG of the superficial cervical muscles increased with 13% in condition 2, 26% in condition 3, 43% in condition 4, 45% in condition 5 and 80% in condition 6. A more in-depth analysis of the differences between the conditions for the four deep cervical muscles and the four superficial cervical muscles, respectively, are presented below.



**Fig. 3.** Normalized RMS EMG (mean and 95% CI) of the pooled data from deep (○) and superficial (●) cervical muscle groups in each condition. Deep cervical muscles include multifidus, obliquus inferior, rectus capitis posterior major and semispinalis cervicis. Superficial cervical muscles include splenius capitis, sternocleidomastoid, anterior scalene and upper trapezius. Note the different muscle activation levels between deep and superficial cervical muscles as rolling resistance decreased, with a more stepwise increase for superficial muscles. †  $P < 0.05$  indicates a significant difference between deep and superficial muscle activity for condition 6. \*\*  $P < 0.01$  indicates a significant increase in muscle activity for all unstable conditions compared to the first (Fixed) condition for both deep cervical and superficial cervical muscles, respectively.

### 3.2. Deep cervical muscles

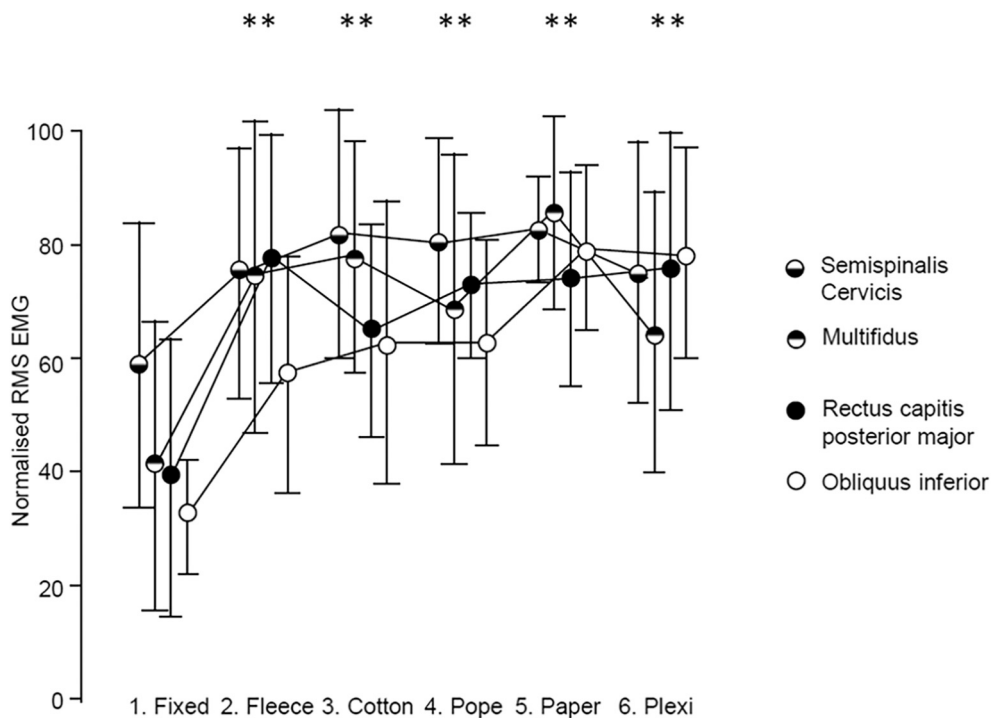
The repeated measures MANOVA for RCPM, OI, MF and SMC revealed a significant effect for condition ( $F_5 = 9.181$ ,  $p < 0.001$ , with effect size  $\eta_p^2 = 0.567$  and observed power = 1.000) but not for muscle ( $F_3 = 0.865$ ,  $p = 0.475$ , with effect size  $\eta_p^2 = 0.110$  and observed power = 0.206). The interaction between muscle and condition was not significant, which means all muscles responded in a similar manner to the increase in difficulty of the task ( $F_{15} = 1.095$ ,  $p = 0.370$ , with effect size  $\eta_p^2 = 0.135$  and observed power = 0.664). Post hoc analysis confirmed a significant increase in activity of the deep muscles between the stable (fixed ball) task and each of the conditions with the ball moving freely ( $p < 0.01$ ), but no further increase with increasing instability of the task from conditions 2 to 6 (post hoc all:  $p > 0.05$ ) (Fig. 4).

### 3.3. Superficial cervical muscles

The repeated measures MANOVA for SPC, SCM, AS and UT showed a significant effect for condition ( $F_5 = 19.017$ ,  $p < 0.001$ , with effect size  $\eta_p^2 = 0.704$  and observed power = 0.999) but not for muscle ( $F_{1.38} = 1.731$ ,  $p = 0.22$ , with effect size  $\eta_p^2 = 0.220$  and observed power = 0.251). Again, there were no interactions between muscle and condition, indicating that all muscles responded to increasing task instability in a similar manner ( $F_{4.09} = 1.686$ ,  $p = 0.18$ , with effect size  $\eta_p^2 = 0.174$  and observed power = 0.465). Post hoc analyses revealed significant differences ( $p < 0.05$ ) for the superficial muscles between all conditions, except between conditions 4 and 5 ( $p = 0.61$ ; Fig. 5).

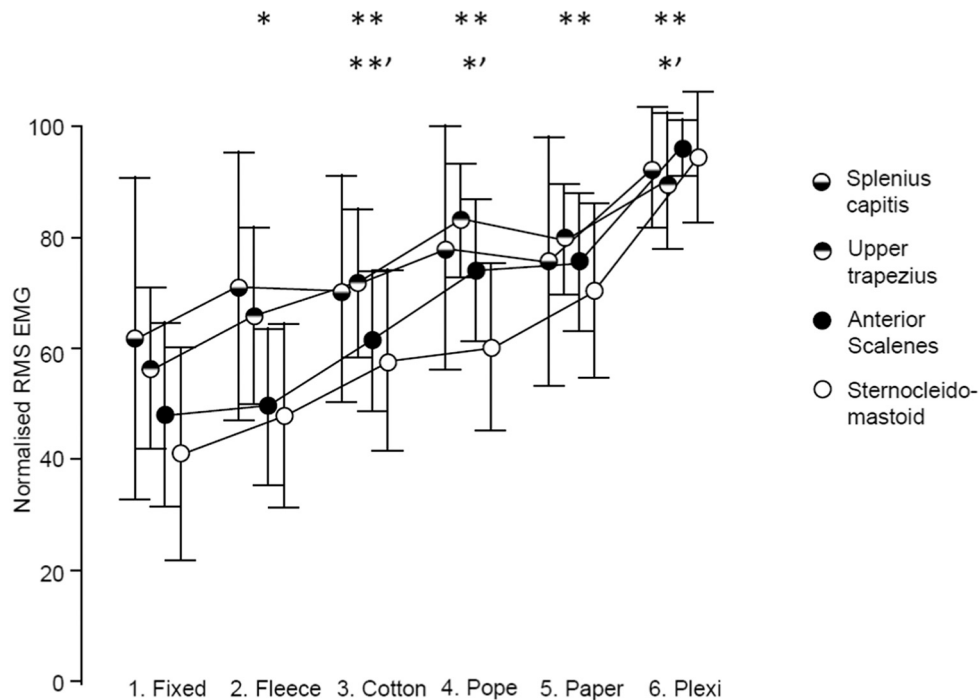
## 4. Discussion

This study used a dynamic motor task with a progressive increase in difficulty as a result of a stepwise decrease in rolling resistance. The longer time taken to complete the task from condition 2 to 6 affirmed the increase in difficulty in accordance with Røijezon et al. (2008). The results revealed increased cervical muscle activity during the unstable compared to the stable condition. Notably, different strategies were evident between deep and superficial cervical muscles as resistance to rolling of the ball decreased. Deep cervical muscle EMG amplitude increased when instability was introduced to the task (condition 2), but there was no further change in mean activation level to the increasing difficulty of the task. In contrast, the superficial cervical muscles increased their mean activity in stepwise manner with the increasing difficulty from conditions 2 to 6.



**Fig. 4.** Normalized RMS EMG (mean and 95% CI) from the deep cervical muscles rectus capitis posterior major (RCPM), obliquus inferior (OI), multifidus (MF) and semispinalis cervicis (SMC) in the separate conditions 1–6. Note the increased muscle activity between conditions 1 and 2, but no further increase in the more challenging conditions. Due to missing values,  $n = 8$  for RCPM during condition 1. Fixed. \*\*  $P < 0.01$  indicates a significant increase in muscle activity compared to the first (Fixed) condition. There was no significant difference between any of the unstable conditions.





**Fig. 5.** Normalized RMS EMG (mean and 95% CI) from the superficial cervical muscles splenius capitis (SPC), sternocleidomastoid (SCM), anterior scalene (AS) and upper trapezius (UT) for each task condition. Note the stepwise increase in muscle activity due to increased task challenge in condition 1 to 6, with the exception between 4 and 5. \*  $P < 0.05$  indicates a significant increase in muscle activity compared to the first (Fixed) condition. \*\*  $P < 0.01$  indicates a significant increase in muscle activity compared to the first (Fixed) condition. \*  $P < 0.05$  indicates a significant increase in muscle activity compared to the previous unstable condition. \*\*\*  $P < 0.01$  indicates a significant increase in muscle activity compared to the previous unstable condition.

These data support our first hypothesis that muscle activity would be greater in an unstable than a stable task. As our analysis was limited to the steady hold phase of the task (i.e. when the ball was maintained in the centre of the plate) the difference in activation between the fixed ball (stable) and moving ball (unstable) tasks is not explained by additional muscle activity required in the moving tasks to move the head to shift the moving ball to the centre of the plate. Thus, the difference in activity during the steady hold phase is likely to represent a neural adaptation to increase impedance control in unpredictable motor tasks (Franklin & Wolpert, 2011). This is supported by the similar increase in RMS EMG for the separate muscles among the superficial layers and deep layers, respectively, including the agonist-antagonist superficial flexor (sternocleidomastoid and anterior scalene) and extensor (splenius capitis) muscles, as presented in Fig. 5. Although there are no similar studies of cervical muscles, studies of lumbar muscle have similarly found increased activity of the trunk muscles during unstable tasks or tasks of increasing challenge (Anderson et al., 2013; Anderson & Behm, 2005; Imai et al., 2010; Vera-Garcia et al., 2000). Our second hypothesis that response to task instability would differ between the deep and the superficial neck muscles was also supported: Activity increased in the superficial muscles with each incremental task demand, but no further increase (above that in response to the least unstable task) was observed in the activity of the deep muscles. This finding concurs with the differential response reported by Weber et al. (2017) with respect to deep and superficial abdominal and back muscles in response to dynamic challenges.

The different strategies between the deep and superficial cervical muscles during progressively more challenging unstable tasks, supports the notion that the central nervous system uses a combination of different strategies to accomplish the task and maintain the upright position of the cervical spine and head during unstable, dynamic tasks. This is in accord with the biomechanical functions of the cervical muscles where the deep muscles have the anatomical location and morphological characteristics to increase spine stiffness at a segmental level (Boyd Clark et al., 2002; Boyd-Clark et al., 2001) but with relatively small forces insufficient to support head load or produce torque to move the neck. In contrast, the larger superficial muscles with larger moment arms have the capacity to control head load and the cervical spine en bloc to counteract external perturbations as well as perform head movement (Bergmark, 1989; Cheng et al., 2016; Vasavada et al., 1998). Similar arguments have been proposed to explain differential activation of lumbar muscles in dynamic tasks (Hodges & Richardson, 1997; Moseley, Hodges, & Gandevia, 2003).

This study included only healthy participants without a history of neck pain. Research is now needed in a clinical group to understand how the central nervous system's regulation of neck muscle function might be affected in pain and whether this protocol to test dynamic task performance and stability capacity can make further unique contributions to current knowledge (Elgueta-Cancino, Marinovic, Jull, & Hodges, 2019). It is reasonable to speculate that the muscle activity during this motor task might differ among individuals with neck pain. In the presence of neck pain, changes have already been shown in the behavior and interactions between

the deep and superficial neck muscles in eye-head co-ordination tasks (Bexander & Hodges, 2012; Bexander & Hodges, 2019), in response to external perturbations (Falla, Jull, & Hodges, 2004a) as well as in performance of the neck movement of craniocervical flexion (Falla, Jull, & Hodges, 2004b). It is possible that unstable tasks, as investigated in this current study, might also be beneficial to retrain deep and superficial cervical muscle function because our data show that even a small degree of challenge activates the deep muscles to a similar degree as a more challenging task. This protocol for challenging the dynamic stability capacity of the neck muscle might provide an early rehabilitation strategy in cases where pain is severe and loading tolerance reduced. It may also be useful to train fine-tuned superficial muscle activation in relation to the level of challenge. Rehabilitation applications need to be investigated in future studies.

A limitation of the study was that in our test protocol we used a stepwise increase in task challenges, rather than randomization of the order of test conditions. This may have led to skill acquisition during the test procedure and may have influenced the change in muscle activation over the task conditions. It could also have contributed to muscle fatigue leading to a stepwise increase in RMS EMG over the conditions. However, a 2 min pause was introduced between each condition to avoid fatigue and the control condition, which showed the lowest muscle activity for all muscles, was performed after the unstable conditions indicating that muscle activity amplitude was related to the task rather than fatigue. Although we considered randomization, due to high risk of task failure in the more challenging conditions, we chose the stepwise progression to minimize loss of data. Another potential limitation was that we did not fix the trunk during the tasks. However, posture was visually inspected, and if needed corrected, before each condition to assure neutral position and avoid change in geometrical configuration of the head and trunk across conditions. Other limitations include a small sample ( $n = 9$ ), more males than females (6/3) and with a wide age spread (20–60 years of age). Future studies should consider larger and more homogenic groups of participants. Also, it would be relevant to compare women and men since previous studies have reported sex differences in cervical spine morphology and neuromuscular control as plausible causes of the higher risk for neck and head injuries among women (Alsalaheen et al., 2019; Stemper & Corner, 2016). We elected to measure muscle activity unilaterally given the rather large number of muscle groups (4 deep and 4 superficial muscles) studied. Fine wire electrodes were inserted into five muscles. This is an invasive method that could be unpleasant. Performing measures bilaterally could increase risk for discomfort. The unilateral setup makes it, however, impossible to investigate any asymmetries between left and right muscle groups during the tasks. Since our results indicate different behavior between muscle groups, but similar behavior between muscles within each muscle group, future studies could consider bilateral measurement using fewer muscles. Regarding the statistical analyses, there is always a risk for either type 1 or type 2 error due to data and choice of statistical models. In this study we chose the Fischer's LSD for post hoc tests. A more conservative approach would be to use, e.g., Bonferroni compensation, which may however increase the risk for type 2 error. In our study we used post hoc test only after the within subject effects were significant between conditions in the MANOVAs, which has been argued to be an effective test for detecting true differences in means (Montgomery, 2005). Finally, this study did not include kinematic data. To track movement while trying to stabilize the ball would be an interesting future study.

## 5. Conclusion

The central nervous system uses strategies of activation that are different between the deep and superficial cervical muscle layers in association with graded instability and levels of task difficulty. The deep cervical muscle activation increased with subtle instability of the task, but there was no or small difference in activity between the progressive conditions with decreasing rolling resistance. The superficial muscles demonstrated contrasting control with a more stepwise increase in activation, in conjunction with decreases in rolling resistance. Studies of persons with neck pain are needed to explore the neuromuscular mechanism in spine stability control in pain conditions.

## Source of funding

This project was supported by the Swedish Insurance Society - Land och Sjöfonden, Sweden and the National Health and Medical Research Council (NHMRC) of Australia (Program Grant: APP1091302). PH was supported by a Senior Principal Research Fellowship from the NHMRC (APP1102905). The funding sources had no involvement in any part of the research.

## Acknowledgement

None.

## Declaration of Competing Interest

None.

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