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Original article

Higher variability in cervical force perception in people with neck pain

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ABSTRACT

Background: A reduced capacity to generate and sustain cervical muscle force over a range of contraction intensities is a feature of some participants with neck pain. To date there have been no studies comparing the accuracy of force perception in participants with and without neck pain.
Design: Cross-sectional observational study.
Methods: Participants with (n = 25) and without (n = 25) neck pain performed isometric muscle contractions at three progressive self-perceived (no feedback provided) intensities (10, 25, 50) % of their maximal voluntary contraction (MVC) in cervical: flexion, extension, right and left lateral flexion. Absolute error (AE), constant error (CE), and variable error (VE) between actual and targeted force values were calculated.
Results: The neck pain group had: (1) AE-combined direction -significantly higher at 10% and lower at 50% ($p < 0.05$); (2) significantly lower CE in most measures ($p < 0.05$); (3) higher mean VE in all measures, with 10, 25, and 50% combined direction and overall combined % extension significantly higher ($p < 0.05$).
Conclusions: Findings indicate higher variability in force generation perception across all directions and intensities in participants with neck pain compared to healthy controls. Potentially this greater variability might suggest impaired force sense, a construct of proprioception in participants with neck pain. Reduced force sense may have implications for participants with neck pain during functional activities requiring precision and may need to be trained. Further research is required.

1. Introduction

Neck pain is a common musculoskeletal disorder in the general population with a 12-month prevalence of 30–50% (Hogg-Johnson et al., 2008) and is one of the leading conditions in terms of overall years lived with disability (Murray et al., 2015). A known feature of neck pain disorders is impaired cervical motor function. One aspect of this is a reduced capacity to generate and sustain cervical muscle force over a range of contraction intensities (Ylinen et al., 2003, Cagnie et al., 2007, O'Leary et al., 2007a, b) which may share a similar mechanism to the observed deficits in proprioception reported in neck pain disorders (Treleaven, 2008; Roijezon et al., 2015; Treleaven et al., 2018; Werner et al., 2018).

Several studies have reported conscious proprioceptive deficits (eg. altered joint position and movement sense) in idiopathic and traumatic neck pain disorders (Woodhouse et al., 2010; de Vries et al., 2015; Stanton et al., 2016) (Treleaven, 2017) but few have investigated the impact of the presence of neck pain on the accuracy of force perception which is another construct of conscious proprioception (Roijezon et al., 2015). It is possible that the reduced capacity to accurately sustain a designated intensity of cervical muscle force despite the provision of real-time feedback in mechanical neck pain (O'Leary et al., 2007a) and tension type headache (Madsen et al., 2018). may not only reflect poorer muscle endurance but may reflect altered force perception or force sense.

One method by which force sense can be evaluated is by determining the accuracy of self-perceived force generation (ie. without feedback) over a range of exercise loads. In a recent study it was demonstrated that self-perceived sub-maximal cervical force generation (relative to an individuals recorded maximal force generation) could be inaccurate over a range of contraction intensities (25%–75% maximal) but particularly at the higher levels of force efforts (50%, and 75% of maximal force) (O'Leary et al., 2018) Furthermore this study also showed that for most tests, sub-maximal test accuracy was only marginally improved following the experience of performing a maximal contraction (O'Leary et al., 2018). This study however, was performed in predominantly healthy individuals with negligible, if any, presence of neck pain. To date, force sense, in terms of the accuracy of self-

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perceived force generation, has not been compared in those with and without neck pain. Potentially a reduced capacity to generate force at an accurate level may affect tasks that require high level of skill, and may serve as a useful clinical indicator in the investigation of neck pain conditions.

The purpose of this study was to compare sub-maximal cervical force generation perception in participants with and without mechanical neck pain over three force intensities (10, 25, and 50% of MVC) and in four force directions (cervical; flexion, extension, lateral flexion). This was evaluated without the participants having prior experience of a maximum force effort to eliminate the potential for aggravation of neck pain following maximal contractions, confounding subsequent force sense performance measures. It was hypothesised that greater force generation perception errors would be evident in participants with neck pain compared to the participants in the control group.

2. Methods

2.1. Design overview

Cross-sectional observational study.

2.2. Setting and participants

Twenty-five participants with neck pain between 18 and 65 years of age and 25 healthy asymptomatic controls were recruited. Participants were recruited via advertising within the Institute's campus between April and September 2017. Inclusion criteria for neck pain participants were: neck pain for at least three months and a Neck Disability Index (NDI) score greater than 10%. Exclusion criteria for both groups included: existing vestibular pathology; current or recent cervical fracture/dislocation; existing systemic diseases; existing neurological/cardiovascular/respiratory disorders affecting physical performance; history of traumatic head injury; inability to provide informed consent; or pregnancy. This study was approved by the Institutes Medical Research Ethics Committee.

2.3. Self-reported measures

All participants completed questionnaires listed below. Participants in the neck pain group also completed a proforma reflecting their neck condition (eg. area of pain, duration, cause of onset).

1. Neck Disability Index (NDI) (Vernon and Mior, 1991)- an assessment tool for disability due to neck pain, consisting of 10 items related to activities of daily living. Each item was rated 0–5, and the sum (0–100) was represented as a percentage.
2. Pain on Movement Questionnaire (POMQ) (Lauche et al., 2014)- a Visual Analogue Scale (VAS), where participants were requested to indicate on a 100 mm line the point that best represented their intensity of neck pain during neck movements in the order of flexion, extension, left rotation, right rotation, left lateral flexion, and right lateral flexion. 'No Pain' is indicated as 0 mm while 'Worst Pain Imaginable' is indicated as 100 mm. Summation of the distances represented an overall pain intensity out of 600 mm.
3. Numeric Pain Rating Scale (NPRS) (Jensen and McFarland, 1993) - an 11-point scale from 0 to 10, where 0 indicates 'No pain' and 10 indicates the 'Worst Pain Imaginable'.

2.4. MVC and SMVC recordings

All isometric MVC reference measurements and SMVC experimental trials in all directions (cervical flexion, extension, and lateral flexion) were recorded with a Mecmesin Basic Force Gauge BFG 1000N dynamometer (Mecmesin Limited, Newton House, West Sussex, UK) attached to a rigid frame that positioned the participant in sitting (Fig. 1).

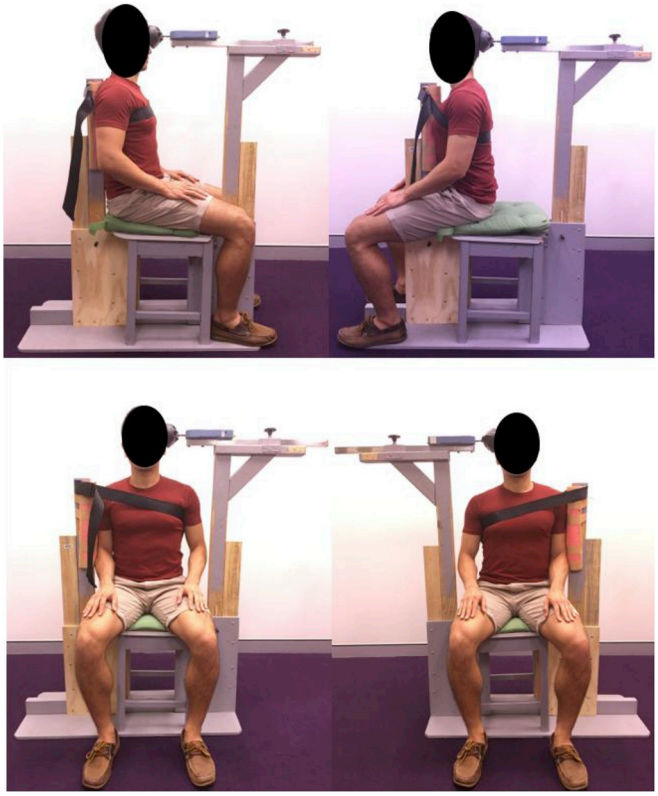


Fig. 1. Clockwise from top-left: Set up of participant for flexion, extension, right lateral flexion, and left lateral flexion isometric submaximal voluntary contraction and maximal voluntary isometric contraction testing. The order was randomized.

All recordings of MVC were in kilograms as this was the default setting of the force gauge during the study period. These recordings were not converted to Newtons (standard unit of force) as maintaining the recording in kilograms appropriately served the purposes of the study (ie proportional accuracy of submaximal contractions). During testing the participant was positioned such that their trunk on the opposite side to the resistance pad of the dynamometer was supported on a padded bar that for all tests was standardly set to a height level with the top of their sternum. A seat belt attached to the top of this padded bar was placed around their chest to ensure the trunk was securely supported to minimize trunk motion. An adjustable resistance pad attached to the dynamometer, was aligned to the glabella (above the apex of the ears), the level of the eye brows, and the level of the external occipital protuberance, during tests of cervical lateral flexion, cervical flexion, and cervical extension, respectively. During testing participants were asked to push their head against the application pad of the dynamometer in an arc toward the floor in front, behind, to the side, of them for tests of flexion, extension and lateral flexion, respectively.

2.5. Procedure

Following informed consent procedures participants completed the questionnaires. The POMQ was performed in sitting immediately prior to the SMVC and MVC trials under the supervision of the investigator to ensure correct performance of the intended movement direction. This also served as a standardized warm up for the testing procedures.

Participants then performed the SMVC trials at a requested intensity of 10%, 25%, and 50% of their perceived maximal force with no feedback of force given. Three trials were recorded for each requested levels of force with a 30 s rest interval between trials. During each of the SMVC trials participants were instructed to gradually increase the force until they were satisfied the requested force level was reached, at which

point they gently released the force. This was done to limit overshoot and thus the maximal force achieved would be consistent with their self-perceived attempt at each of the submaximal load tasks. This was repeated over three trials which was followed by three MVC trials in the same direction with a one minute rest period between trials. During the MVC trials standardized verbal encouragement was provided to optimize a maximal effort. The order of test direction (cervical flexion, extension, and right and left lateral flexion) was randomized between participants. The order of trials (ie 10%, 25%, 50%, MVC) were not randomized to reduce the risk of aggravating symptoms in participants with neck pain that may have occurred if the stronger contractions were performed first.

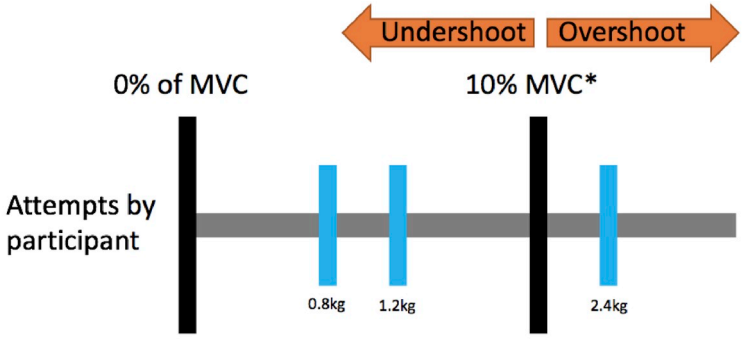
Previous studies have shown isometric cervical dynamometry measurements of MVC to be highly reliable (Van Wyk et al., 2010; O'Leary et al., 2017).

2.6. Data management and statistical analysis

For all SMVC trials the peak force recorded during each trial was used for analysis. For MVC trials the peak force recorded over the three trials was used as the reference MVC recording for the specific test direction. Each of the SMVC trials were then calculated as a percentage of the direction specific MVC reference measure. As depicted in Fig. 2 the difference between the targeted and the actual percentage of MVC for each of the SMVC trials was then calculated as a percentage of the targeted SMVC, to reflect the proportion of error and allow comparison between participant groups, SMVC force levels, and directions of testing. This error was expressed in terms of Absolute Error (AE), Constant Error (CE), and Variable Error (VE) calculated from formulas used in previous research evaluating cervical joint position sense (Hill et al., 2009; O'Leary et al., 2018) Fig. 2 provides a working example of the method by which these measures of error were derived over three trials of a 10% SMVC test in one test direction.

Statistical analyses were all undertaken using IBM SPSS Statistics for Windows, version 21 (IBM Corp., Armonk, N.Y., USA). Data were initially checked for normality. A generalized linear model with covariates of age and gender was used to determine between group differences where data were normalized and Mann Whitney U tests were used for non-normalized data. Fishers exact test was used to determine differences between categorical data.

Preliminary analysis on AE, CE, and VE was performed for each movement direction and SMVC condition and indicated that it was feasible to collapse the data as the agreement across the MVC percentages for all movement directions as to whether or not significant group differences were seen was 100% for CE, 50–100% for AE and 50–75% for VE. For the different movement directions across the 3 different MVC percentages there was 100% agreement, 60% for AE and 60–100% for VE. Thus to ease interpretation of the findings and decrease the number of statistical comparisons required, the AE, CE, and VE in two forms: (1) combined direction mean % errors of each isometric SMVC% for all directions combined (e.g. mean AE of attempts on 10% MVIC for flexion, extension, right lateral flexion, and left lateral flexion combined) coded as $SMVC_{10}$, $SMVC_{25}$, and $SMVC_{50}$ for 10%, 25% and 50% MVIC respectively, and (2) combined percentage mean errors of each direction for all isometric SMVCs attempted in that direction combined (e.g. mean AE of flexion for 10%, 25%, and 50% MVICs combined) coded as $SMVC_F$, $SMVC_E$, $SMVC_{RLF}$, $SMVC_{LLF}$ for flexion, extension, right lateral flexion, and left lateral flexion were conducted respectively.



*Taking MVC to be 20kg in this example, attempts at 10% MVC will be aiming to achieve a load of 2kg.

Attempts at 10% of MVC	1	2	3
Data recorded	0.8kg (4% MVC)	1.2kg (6% MVC)	2.4kg (12% MVC)
Raw error	-6%	-4%	+2%
Error as a percentage of desired SMVC	-6% ÷ 10% x 100% = -60%	-4% ÷ 10% x 100% = -40%	2% ÷ 10% x 100% = 20%

Absolute Error (AE) - the mean of the error as a percentage of desired SMVC over the three attempts, ignoring positive (overshoot) and negative (undershoot) values, i.e.,

$$(60\% + 40\% + 20\%) \div 3 = 40\%$$

Constant Error (CE) - the mean of the error as a percentage of desired SMVC over the three attempts, incorporating the positive and negative values in each trial, i.e.,

$$((-60\%) + (-40\%) + 20\%) \div 3 = -26.7\%$$

Variable Error (VE) - the variability between the three attempts, i.e.,

$$\sqrt{((\text{raw error attempt } 1 - CE)^2 + (\text{raw error attempt } 2 - CE)^2 + (\text{raw error attempt } 3 - CE)^2) \div 3}$$

$$= \sqrt{((-60\% - (-26.7\%))^2 + (-40\% - (-26.7\%))^2 + (20\% - (-26.7\%))^2 \div 3)}$$

$$= 33.99\%$$

Fig. 2. Example of errors calculated as a percentage of the desired submaximal voluntary contraction (SMVC) at 10% of maximal voluntary isometric contraction (MVC) when performed over the three trials.

Table 1
Demographics of participants.

Variable	Control Group (n = 25)	Neck Pain Group (n = 25)
Gender: females, males	15 F, 10 M	20 F, 5 M
Age (years)	23.0 (3)	27.0 (16.0)
Duration of pain (months)	NA	18.0 (44.0)
NDI (%)	0.0 (0.0)	18.0 (11.3)
POMQ/600 mm	1.65 (0.3)	107.9 (102)
Pain Intensity/10	0.0	3.0 (2.0)

NDI = Neck Disability Index, POMQ = Pain on Movement Questionnaire, and NA = not applicable. Values are presented with median (± interquartile range) or numbers.

3. Results

Characteristic features for each group are depicted in Table 1.

To assist interpretation of the group data results from a control participant and a participant with neck pain performing three trials of each of the 3 targeted extension SMVCs (10, 25 and 50%) is demonstrated graphically in Fig. 3. The mean error was reported as the percentage error of the targeted SMVC performed by the participants. Whereby accurately achieving the targeted SMVC equated to 0% error. For example, see Fig. 3 where the control participant was on average performing contractions at 25.06% MVIC over the 3 attempts (green lines) when perceiving that they were performing at an intensity of 50% MVIC. This equates to an AE of 49.88% (circled in red on Fig. 3). The control participant also had more consistent attempts (less variable error) at each level of MVC when compared to the participant with neck pain.

The results for overall AE, CE, and VE of $SMVC_{10}$, $SMVC_{25}$, $SMVC_{50}$, $SMVC_F$, $SMVC_E$, $SMVC_{RLF}$, $SMVC_{LLF}$ are presented in Figs. 4–6 respectively.

The neck pain group had significantly larger AE in $SMVC_{10}$, but significantly smaller AE in $SMVC_{50}$. There were no other differences for AE seen between the groups (Fig. 4). Overall participants in both groups tended to have errors between 37 and 75%.

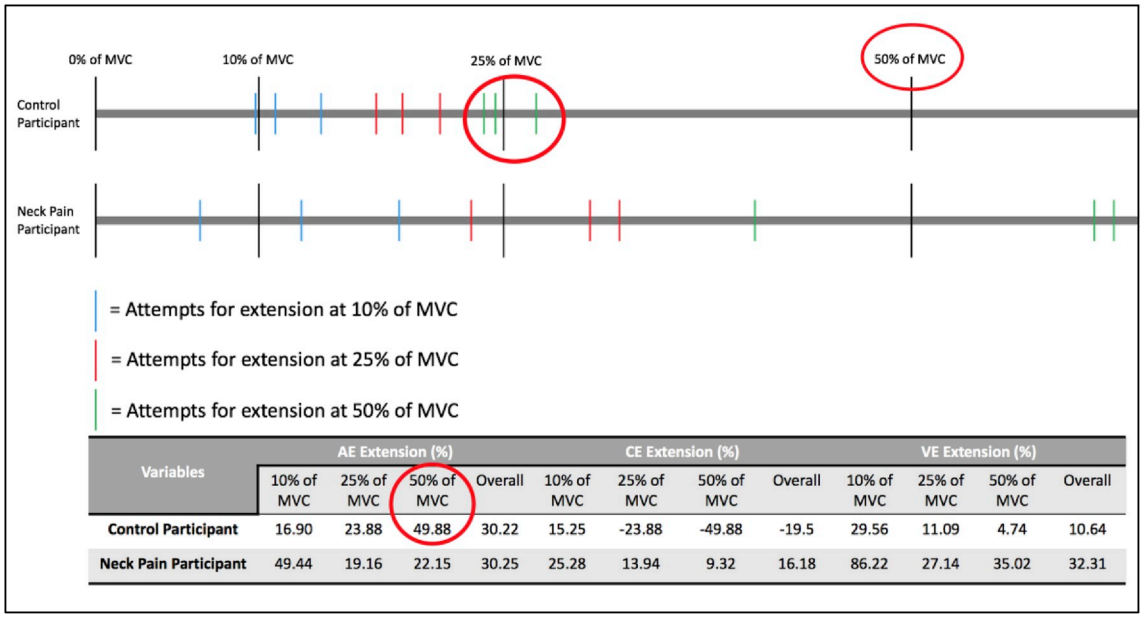
The neck pain group had significantly larger CE in $SMVC_{10}$, but significantly smaller CEs in $SMVC_{25}$, $SMVC_{50}$, $SMVC_F$, $SMVC_E$, and $SMVC_{LLF}$. No differences for CE in $SMVC_{RLF}$ was seen between the groups (Fig. 5). Overall there was a tendency for control participants to undershoot by more than 20% and neck pain participants to overshoot by less than 20%.

This difference in CE and similarities in AE can be explained by the trend for average VE to be greater for all measures in the neck pain group with significantly larger VEs in $SMVC_{10}$, $SMVC_{25}$, $SMVC_{50}$, and $SMVC_E$ (Fig. 6). This indicates that they were more inconsistent with their responses, sometimes overshooting and sometimes undershooting.

4. Discussion

The findings of the study do not fully support our hypothesis in that there was quite widespread inaccuracy in force generation perception regardless of group (neck pain or control). Force perception errors were evident in both groups regardless of the percentage MVC (10,25,50%) or direction of movement tested (flex, ext, lateral flexion), with mean AEs ranging from 37.74% to 74.54% of the targeted force level.

In partial support of our hypothesis some differences in the characteristics of force perception error were evident between groups. There were between group differences in AE for some of the conditions (Fig. 4). However, results suggest the AE calculation (absolute average error) may not be the most suitable outcome measure as it did not provide sufficient information regarding the consistency of test performance (ie. overshooting or undershooting) (Guth, 1990). This is particularly highlighted in that the neck pain group also often demonstrated lower CE and higher VE over the various force perception test conditions, suggesting less consistency compared to the control group. Thus care must be taken when interpreting the meaning of the generally higher mean CEs in the control group. The CE measures the amount of error with additional consideration of overshooting or undershooting. A generally higher VE in the neck pain group suggests this group was more inconsistent with respect to overshooting and undershooting, with possible effects of cancellation that resulted in lower CE values (Treleaven and Takasaki, 2015). This is in contrast to the healthy control group that consistently undershot their force by more than 20% of the targeted force regardless of test direction or targeted force level (Fig. 5). Undershooting was consistent with the findings of the previous study in healthy individuals(O'Leary et al., 2018). In contrast



Variables	AE Extension (%)				CE Extension (%)				VE Extension (%)			
	10% of MVC	25% of MVC	50% of MVC	Overall	10% of MVC	25% of MVC	50% of MVC	Overall	10% of MVC	25% of MVC	50% of MVC	Overall
Control Participant	16.90	23.88	49.88	30.22	15.25	-23.88	-49.88	-19.5	29.56	11.09	4.74	10.64
Neck Pain Participant	49.44	19.16	22.15	30.25	25.28	13.94	9.32	16.18	86.22	27.14	35.02	32.31

Fig. 3. An example of each of the three attempts at each submaximal voluntary contraction (SMVC) percentage (10%, 25%, 50%) of their maximal voluntary isometric contraction (MVC) for extension. As depicted, there is similar overall absolute error (AE) and constant error (CE), but higher variable error (VE) in the neck pain participant's attempts when compared to the control participant.

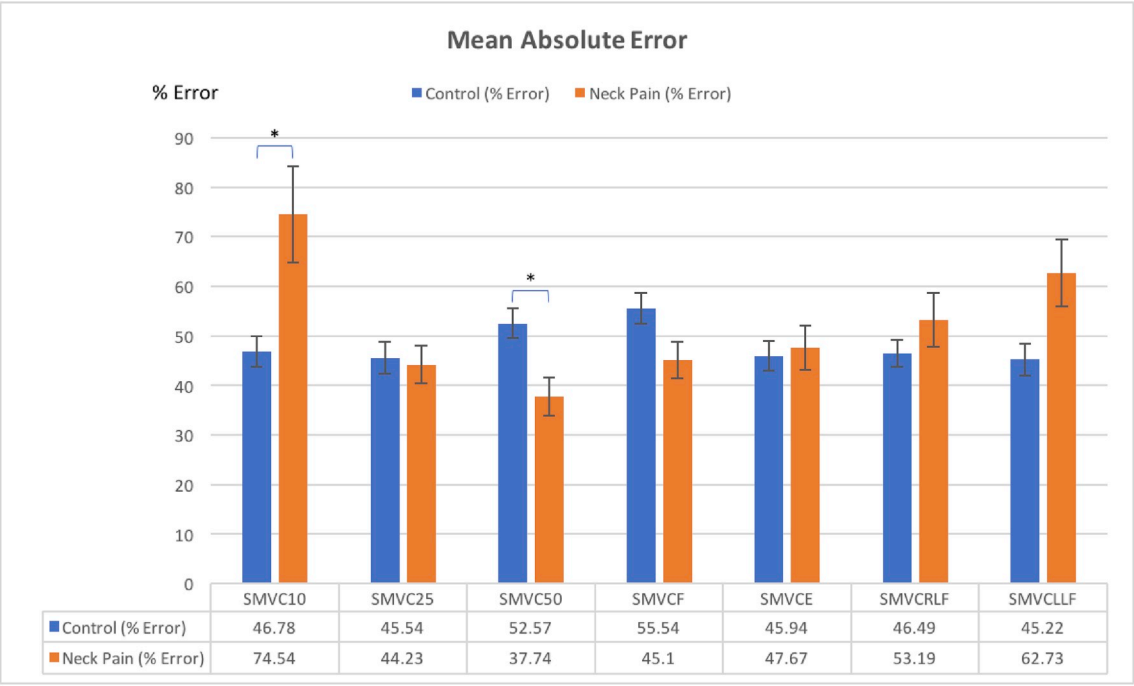


Fig. 4. Measure of overall absolute error (AE) (%) for the compiled submaximal voluntary contractions (SMVCs) from combined directions and the overall AE of each direction tested with percentages combined. (*p < 0.05). $SMVC_{10}$ = combined error of 10% maximal voluntary isometric contraction (MVIC) from all directions tested, $SMVC_{25}$ = combined error of 25% MVIC from all directions tested, $SMVC_{50}$ = combined error of 50% MVIC from all directions tested, $SMVC_F$ = combined error from all isometric SMVC tested in flexion, $SMVC_E$ = combined error from all isometric SMVC tested in extension, $SMVC_{RLF}$ = combined error from all isometric SMVC tested in right lateral flexion, $SMVC_{LLF}$ = combined error from all isometric SMVC tested in left lateral flexion. Errors are expressed as percentage of error from the desired SMVC.

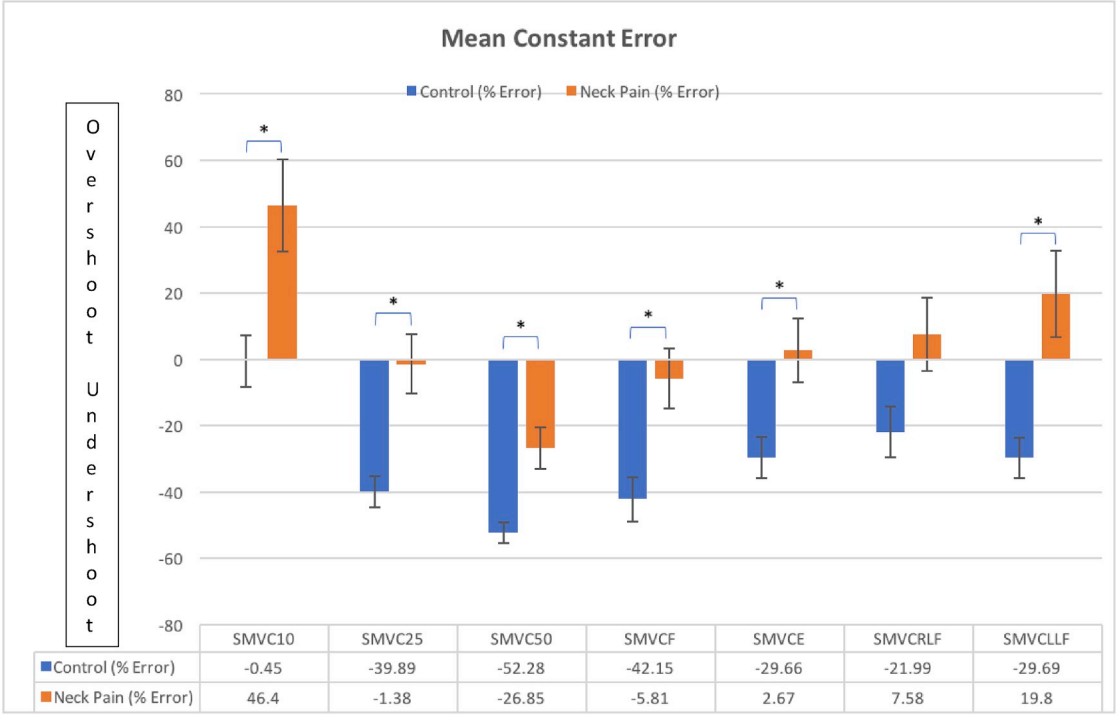
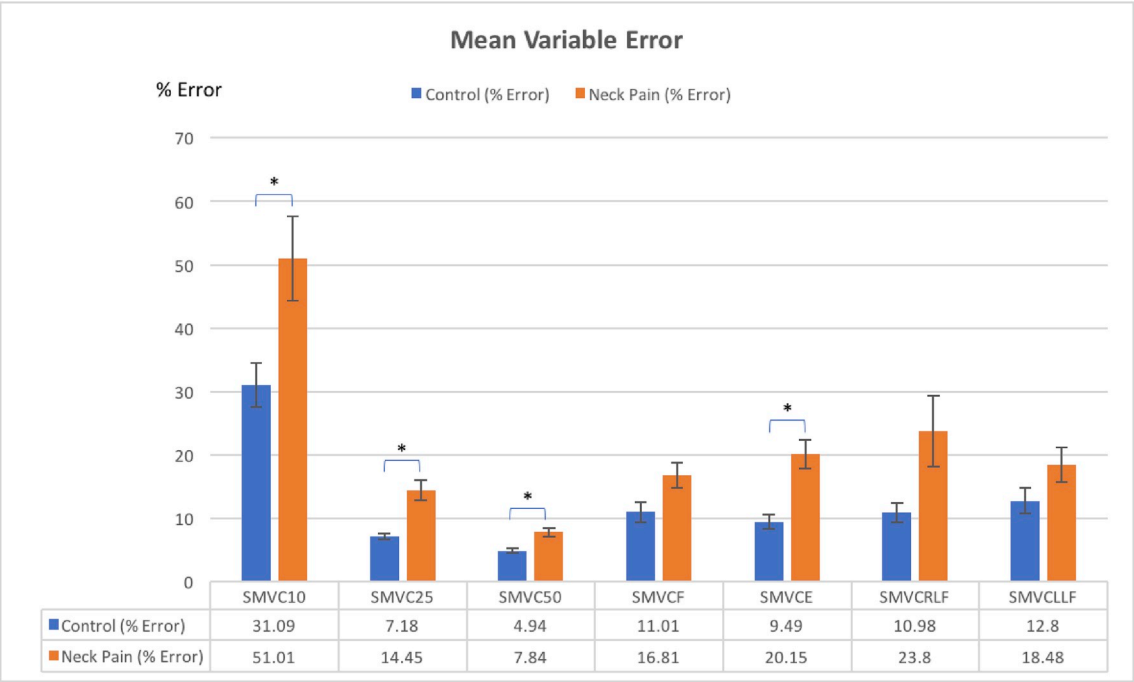


Fig. 5. Measure of overall constant error (CE) (%) for the compiled submaximal voluntary contractions (SMVCs) from combined directions and the overall CE of each direction tested with percentages combined. (*p < 0.05). $SMVC_{10}$ = combined error of 10% maximal voluntary isometric contraction (MVIC) from all directions tested, $SMVC_{25}$ = combined error of 25% MVIC from all directions tested, $SMVC_{50}$ = combined error of 50% MVIC from all directions tested, $SMVC_F$ = combined error from all isometric SMVC tested in flexion, $SMVC_E$ = combined error from all isometric SMVC tested in extension, $SMVC_{RLF}$ = combined error from all isometric SMVC tested in right lateral flexion, $SMVC_{LLF}$ = combined error from all isometric SMVC tested in left lateral flexion. Errors are expressed as percentage of error from the desired SMVC.



	SMVC10	SMVC25	SMVC50	SMVCF	SMVCE	SMVCRLF	SMVCLLF
Control (% Error)	31.09	7.18	4.94	11.01	9.49	10.98	12.8
Neck Pain (% Error)	51.01	14.45	7.84	16.81	20.15	23.8	18.48

Fig. 6. Measure of overall variable error (VE) (%) for the compiled submaximal voluntary contractions (SMVCs) from combined directions and the overall VE of each direction tested with percentages combined. (*p < 0.05). $SMVC_{10}$ = combined error of 10% maximal voluntary isometric contraction (MVIC) from all directions tested, $SMVC_{25}$ = combined error of 25% MVIC from all directions tested, $SMVC_{50}$ = combined error of 50% MVIC from all directions tested, $SMVC_F$ = combined error from all isometric SMVC tested in flexion, $SMVC_E$ = combined error from all isometric SMVC tested in extension, $SMVC_{RLF}$ = combined error from all isometric SMVC tested in right lateral flexion, $SMVC_{LLF}$ = combined error from all isometric SMVC tested in left lateral flexion. Errors are expressed as percentage of error from the desired SMVC.

participants with neck pain whilst inconsistent in their performance overall, overshot by small amounts ie < 20% for most measures (Fig. 5). Interestingly this finding of overshooting in the participants with neck pain (not the healthy controls) infers differences in force perception capacity rather than an inability to achieve the magnitude of force required.

Higher VE in cervical force sense in participants with neck pain is also consistent with studies investigating other common musculoskeletal conditions; ankle instability, and patello-femoral pain (Docherty et al., 2006; Docherty and Arnold, 2008). (Salahzadeh et al., 2013) Similarly in another test of proprioception in neck pain, higher VE rather than CE or AE was demonstrated in a vertical perception task in those with idiopathic neck pain (Treleaven and Takasaki, 2015) The findings in this current study, particularly during the $SMVC_{10}$ conditions, are also consistent with the observed poor contraction steadiness in participants with mechanical neck pain during sustained low load contractions (at 20% of MVC) (O'Leary et al., 2007a) Nevertheless direct comparison is difficult as tasks performed in the former study were during a sustained contraction and with visual feedback provided to the subjects.

4.1. Future directions and clinical implications

From a clinical perspective the observations of more variable force generation perception may have implications for skilled activities of daily living, particularly for tasks that require precision of head positioning. This is particularly relevant given the well documented sensorimotor role of the cervical spine and known impairments in other constructs of cervical propriocepetion ie movement and position sense associated with neck pain (Treleaven, 2008). (Woodhouse et al., 2010; de Vries et al., 2015; Stanton et al., 2016; Treleaven, 2017; Werner et al., 2018).

Consistent with our previous study (O'Leary et al., 2018), the error in perceived force generation observed in this study question the appropriateness of perceived force effort in regulating exercise load in the clinical management of neck pain. The use of resistance exercises (ie. strength and endurance) in the management of neck pain is recommended (Jull et al., 2018), but the findings of this current study and the previous study (O'Leary et al., 2018) suggests that where applicable it may be advisable to provide some form of quantitative load (eg. dynamometer, calibrated weights) to improve the accuracy of force produced during exercise.

4.2. Limitations

There are some strengths and limitations of this study. One limitation was that the device used to measure force could only capture the maximal reading for each attempt, and any correction for overshooting or variation during the attempt was not recorded. Nevertheless, the participants were instructed to gently ease into each of the contractions and stop when they felt they had reached the desired force. This should have eliminated unintentional overshoots. Interestingly overshooting was observed in the group with neck pain (not the healthy controls) suggesting this was more likely due to altered force perception rather than ability to generate the magnitude of force. However, it is possible that the force perception/sense errors reported could also be related to the participants inability to estimate their maximum effort without prior experience of a maximal trial. In this study, the accuracy of perceived force generation was not evaluated following the experience of the maximal force effort. While this was deliberately done to avoid the potentially confounding effects of aggravating neck pain on proprioception that may have occurred if MVC contractions were performed initially. It will be interesting to explore in a subsequent study if this improves force perception accuracy.

Finally, it should also be noted that neck pain participants in this study were of mild neck pain severity and mild neck disability with an average NDI score of 18% (Vernon and Mior, 1991). It could be reasoned that a larger error may be observed from neck pain participants

with higher levels of pain, disability and those with dizziness where higher levels of altered proprioception have generally been seen (Treleaven et al., 2003, 2011; Treleaven, 2017). The implications of these and psychosocial factors on the results could also be explored in future research.

5. Conclusion

This study has found higher variability in force perception across all force directions and intensities in participants with neck pain compared to healthy controls. In general people with neck pain tended to either undershoot or overshoot force targets while the healthy individuals tended to more consistently undershoot the targets.

Potentially this greater variability in force perception or sense in participants with neck pain may have implications for their function particularly during tasks that require precision and during tasks involving self perception of exercise load. Future research exploring other methods to measure force sense, such as when visual feedback is either provided or given immediately prior to force sense attempts, and the relationship between force sense and the symptoms associated with neck disorders is needed.

Conflicts of interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.msksp.2019.04.001.

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