On the relationship between pain intensity and postural sway in patients with non-specific neck pain

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Abstract.

INTRODUCTION: Increased center of pressure excursions are well documented in patients with non-specific neck pain. While a linear relationship between pain intensity and postural sway has been described in low back pain patients, no such investigation has been conducted in adults with non-specific neck pain.

METHODS: Seventy patients with non-specific neck pain and a matching number of healthy controls were enrolled. Center of pressure parameters were measured by three static bipedal standing tasks of 90 sec duration each with eyes closed on a force platform. The pain intensity was assessed by a numeric rating scale (NRS), an equal number of patients (\(n = 10\)) was enrolled per pain score.

RESULTS: The results confirmed an increased postural sway in pain sufferers compared to healthy controls. In addition, a significant and linear increase in postural sway was observed with higher pain ratings. Statistically significant changes in sway were reached with an incremental change in NRS scores of two to three points.

DISCUSSION AND CONCLUSIONS: Mean velocity and sway area are closely related to self-reported pain scores in neck pain patients. This relationship has implications for clinical applications such as an objective monitoring tool for patients under treatment or rehabilitation.

Keywords: Postural sway, center of pressure, force-plate, neck pain, pain intensity

1. Introduction

Increased postural sway is well documented in patients suffering from non-specific neck pain (NSNP) \[1\] and non-specific low back pain (NSLBP) \[2\]. One of the proposed underlying causes is that postural control mechanisms may be affected by damage to sensory tissues in the spine and trunk \[3\]. The resulting deterioration of proprioceptive information reduces the accuracy of sensory integration processes causing an imprecise estimation of the center of mass position \[4\], thereby inhibiting the required compensatory center of pressure (COP) shifts.

Another proposed mechanism is “pain interference” \[5\]. Here, discharge from high-threshold nociceptive afferents in the neck may interfere with spinal motor-pathways \[6\] and the motor cortex \[7\]. In addition, pain may cause an increased pre-synaptic inhibition of muscle afferents \[8\] and affect the central modulation of proprioceptive spindles of muscles \[9\], thereby causing prolonged latencies by a decrease in muscle spindle feedback.

Hodges advanced this concept to a new theory that proposes complementary, additive or competitive adaptations of the motor system during pain \[10\]. It has...
been shown that while the discharge rate of active motor units is reduced during experimental pain, the overall force output was maintained due to recruitment of additional, otherwise not active units [11]. These observations oppose the idea of a uniform “pain inhibition” of the motorneuron pool. However, it has to be kept in mind that for these experiments the motor recruitment pattern were investigated by electromyography (EMG) during voluntary, active movements. They do not necessarily reflect those employed involuntarily during static task conditions. Secondly, the nature of selective muscle actions observed on EMG (e.g. transversus abdominis [12]) may not necessarily correlate with COP excursions under static task conditions.

As outlined in a recent systematic literature review [2], several factors such as age [13–15], weight [16], and height [17] have shown to significantly affect postural sway. This study aims to investigate whether COP excursions of NSNP patients are also influenced by pain severity and pain duration. If present, this relationship is worthy of investigation as it may imply clinical significance for the application of COP measures.

Previous research has already demonstrated a linear relationship between the magnitude of COP excursions and the perceived pain intensity in patients suffering from NSLBP [18]. However, it is not known whether this relationship is also observed in patients with NSNP. So, in order to compare postural sway between different painful areas, it was decided to apply the same ‘best-practice’ experimental setup on a group of NSNP sufferers.

Therefore, the aim was to investigate whether postural sway is affected by perceived neck pain level and whether factors such as age [13–15], weight [16], height [17] or previous pain duration exhibit a significant effect on this postural sway.

2. Materials and methods

2.1. Participants

We aimed at enrolling a minimum of 70 participants in both the symptomatic and the control group. Previous sample size calculations using an Altman Nomogram [19] for a group of controls and symptomatic patients with an NRS-11 score of 4.8 ± 2.4 suggested recruitment of around 50 symptomatic and healthy participants each.

All new patients entering a private chiropractic clinic in Wolfsburg (Germany) were asked on the phone whether they would participate in this study. The healthy controls were friends and partners of already enrolled participants and were initially approached by them regarding the possibility of participation. If interest was displayed they were asked to contact the clinic for further details. After verbal and written information were given, all participants consented to participate in this study, which was approved by the Murdoch University Human Research Ethics Committee (Approval 2010/173).

The cut-off age for both controls and symptomatic individuals was 50 years, as after that age related impairments to postural stability could not be excluded [13–15].

Inclusion criteria for the symptomatic participants were NSNP of any duration and the presence of pain ≥ 2 on the NRS-11 scale at the time of the postural sway recordings. The NRS-11 pain scale ranges from 0 (no pain) to 10 (worst possible pain). It is easy to score and has good evidence for construct validity and reliability [20,21]. Participants were excluded if pain radiated further than the shoulder; there were positive nerve root findings, serious spinal deformities, any condition that might affect balance (e.g. whiplash associated disorder or vestibular pathologies) or previous significant injuries such as traumatic damage to the spine or spinal surgery. No pain medication was allowed within 24 hours prior to the recordings. Participants were also excluded if they were unable to perform the postural sway recording either due to any reason. We aimed at enrolling around 10 patients for the 9 pain intensity groups (NRS 2–10).

For the purpose of this study, healthy was defined as the absence of any self-reported neurological or musculoskeletal impairments, pain or disability for a minimum of 6 months prior to the time of evaluation. Individuals with a history of balance problems or the usage of medication associated with pain suppression or altered sensory perception were excluded. The physical examination of the control group must also have ruled out any neck, back or extremity complaints or significant biomechanical impairments that might influence the measurements.

2.2. Procedures

The experimental setup was based on an earlier literature review where a best practice setup with regards
to the reliability of COP data was published [22]. Accordingly, trials were conducted with eyes closed as the data obtained shows higher reliability than with eyes open.

The system used for this study was a Metitur GB300\textsuperscript{CE} forceplate (Metitur Oy, Finland). Signals were sampled at 100 Hz, amplified and converted from analogue to digital. High frequency noise was reduced by a low-pass filter with a cut-off frequency of 10 Hz.

Of the COP parameters calculated the software package of the forceplate (Good Balance, Version 3.20), mean sway velocity (mVel) in medio-lateral (ML) and antero-posterior (AP) direction was chosen as the main parameters as they have shown to be both reliable [22] and discriminative for NSLBP [2]. In addition, 90\% circle diameter, the diameter of a circle containing 90\% of the total sway path, was included as a descriptor of the sway area.

The participants were asked to remove their shoes and stand upright on the forceplate with their eyes closed, the head erect and their arms hanging loosely by their sides. The foot position was narrow stance with toes and heels touching. Three successive trials of 90 seconds duration each were conducted with a preceding 5 sec adaption period that was not recorded. The forceplate was calibrated prior to the recordings and further underwent an automatic calibration check before each trial.

3. Data analysis

3.1. Reliability

To test the reliability of the COP measures, a two-way mixed-effect intra-class correlation coefficient (ICC\textsubscript{2,k}) as described by Shrout et al. [23] was computed using absolute agreement. In addition, the standard error of measurement (SEM) and 95\% confidence intervals (CI) were calculated. The following results criteria were used: 0.0–0.39 poor, 0.40–0.59 fair, 0.60–0.74 good and 0.75–1.00 excellent [24].

3.2. Pain intensity

Stepwise univariate regression analysis was conducted to assess for the possible effect of the following variables: age, gender, weight, height, pain intensity and previous pain duration on COP mVel AP/ML and 90\% circle diameter. Those showing significance were included in the multivariate regression analysis.

To investigate the appropriate form of regression analysis, the SPSS Curve Estimation function was applied to a scatter plot for pain intensity (independent variable) and the COP parameters (dependent variables).

We used a Levene statistic to test for homogeneity of variance. A Shapiro-Wilk test was conducted to test for normality for all independent variables and the dependent variables separately per pain group. The COP data were further analyzed using the Games-Howell test to compare results between pain scores. Means, SDs and 95\% CIs were calculated for all dependent variables. In addition, collinearity diagnostics were applied. The level of statistical significance was set at \( p \leq 0.05 \).

All data were exported to PASW\textsuperscript{\textcopyright} Statistics 18 (SPSS Inc, 2009) for statistical analysis.

4. Results

4.1. Participants

We were unable to recruit the required number of 10 patients for NRS scores 9 (\( n = 3 \)) and 10 (\( n = 0 \)) and therefore limited this study to NRS scores 2–8. Seventy-five individuals suffering from NSNP initially volunteered to participate in this study. Five symptomatic participants were excluded as severe pain affected their ability to maintain quiet stance (\( n = 2 \)), exhibiting an antalgic posture when standing (\( n = 1 \)), being unable to complete the trial due to general loss of balance (\( n = 1 \)) or boredom (\( n = 1 \)). This left a total of 70 NSNP sufferers to which we matched an equal number of healthy controls with regards to their physical characteristics. The characteristics of the participants with non-specific neck pain are shown in Table 1.

4.2. Reliability

The COP measurements for the neck pain sufferers were assessed for their reliability. With three record-
ings being averaged, excellent reliability (ICC\(_{2,k} \geq 0.75\)) with narrow CIs was reached such that the data for mVel ML and mVel AP showed an ICC\(_{2,k}\) of 0.85 (95% CI 0.79–0.90, SEM 1.70) and 0.90 (95% CI 0.86–0.94, SEM 1.36) respectively. The parameter 90% circle diameter reached an ICC\(_{2,k}\) of 0.84 (95% CI 0.77–0.89, SEM 1.24).

4.3. Relationship between pain intensity and postural sway

Patients suffering from NSNP exhibited a greater postural instability than healthy controls signified by an increased mean sway velocity and sway area. A linear increase was observed in sway velocity (mVel) in antero-posterior (AP) and medio-lateral (ML) direction, as well as for the 90% circle diameter.

Compared to healthy controls, a highly significant difference (\(p \leq 0.001\)) in mVel was present in pain sufferers beginning at an NRS score of 5 in ML direction. Statistical significance (\(p \leq 0.05\)) was reached in AP direction at pain intensity of 3 with an increase to high significance from 5 to 8 (\(p \leq 0.001\)). Generally, there is a trend towards a larger 95% CI and SD with higher pain scores, particularly in the AP direction (Fig. 1).

Compared to healthy controls, a significantly larger difference in 90% circle diameter was seen in NSNP patients except for pain intensity 2 where they showed a decreased sway area compared to the controls (Fig. 2). The postural sway results associated with this NRS score are surprisingly lower compared to healthy individuals (\(p \leq 0.05\)). Beginning at NRS level 3 a steady increase in 95% circle diameter can be observed. The difference compared to asymptomatic controls reached high statistical significance at NRS scores of 6, 7 and 8 (\(p \leq 0.001\)).

With regards to mVel differences between the individual pain scores, significance was reached more readily in ML compared to AP direction. At higher pain intensities (NRS 7–8), no significant differences in postural sway could be observed (Table 2).

Table 3 shows the differences in postural sway between the various pain scores for the COP parameter 90% circle diameter indicating no significant differences between pain intensities above NRS score 5.

4.4. Regression analysis

Linear regression was used for further analyses of the data as the SPSS Curve Estimation function
Table 2
Sway differences between the individual NRS-11 scores for mean sway velocity AP and ML.

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AP: antero-posterior; ML: medio-lateral; NRS: numeric rating scale; n.s.: not significant ($p > 0.05$); -: not possible; Levels of significance: * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

Table 3
Sway differences between the individual NRS-11 scores for 90% circle diameter.

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NRS: numeric rating scale; n.s.: not significant ($p > 0.05$); -: not possible; Levels of significance: * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

extra pain level in AP direction ($\beta = 0.50$, $T = 8.4$).

90% circle diameter: The regression equation for pain intensity was a poor fit, describing 39.7% of the variance in velocity moment ($R^2_{adj} = 38.0\%$). The overall relationship, however, was highly significant ($F = 117.7$, $p < 0.001$). The 90% circle diameter of the COP excursion increased by 0.93 mm for every extra pain level ($\beta = 0.57$, $T = 10.0$).

5. Discussion

The reason that we were unable to enroll the required number of patients experiencing the highest pain intensities (NRS 9–10) was probably that such individuals are more likely to seek medical care instead of attending a chiropractic practice.

We were able to demonstrate a linear relationship between pain intensity and postural sway. In practical terms, NSNP patients exhibited an increase of about 15% in sway velocity and of 8% in circle diameter per NRS score when taking data from healthy controls as a reference. This study is in agreement with altered postural sway characteristics previously reported in a systematic review of studies about NSNP sufferers [1].

![Fig. 2. Relationship between pain intensity and 90% circle diameter. NRS: numeric rating scale](image)
In the AP direction, a significant increase in sway velocity compared to healthy controls started at lower pain intensities (NRS 3 compared NRS 5 in ML direction), while the ML sway velocity increased at a faster rate. With regards to 90% circle diameter, a larger and significantly different sway area started at an NRS score of 5. Unfortunately, a comparison of this parameter to other studies is not possible as it is exclusively used with the GB300 forceplate. Furthermore, as no other studies have looked into the relationship between a broader range of pain intensities and COP measures it is not possible to compare our results.

Our study data does allow a better insight into the interpretation of studies that curiously reported no significant differences in postural sway between symptomatic individuals and healthy controls [25]. In those instances, the observations may be attributable to low perceived pain intensities of the patients enrolled. Depending on the research purpose, the inclusion criteria for any future studies should focus on those with NRS-scores of 5 or higher as this will allow for easier and better comparison with controls.

While neck pain sufferers show higher variability in the results, the linear trend between pain intensity and COP excursions observed in this study is very similar to results obtained from non-specific low back pain patients with an identical experimental setup [18]. However, at similar COP mean values, both SDs and 95% CIs were larger for all NRS scores at similar COP mean values in NSNP patients. This was most obvious at higher pain intensities where the CIs were about twice as wide. When looking at the overall results, however, it appears that there are no significant differences in postural sway between patients with neck and low back pain across the pain scores.

To appreciate the results of this study and possible clinical implications, a closer look at what may be responsible for the altered postural sway is necessary. The increased COP excursions observed here may be explained by abundant cervical sensory receptors in joints and muscles [26,27] as well as their central and reflex connections to visual, vestibular and postural control systems [28]. The neck is particularly prone to effects of nociceptive stimuli and this may explain the increased instability compared to NSLBP patients.

However, considering the low sample size per NRS score (n = 10) the interpretation of any difference warrants caution. For example, inter-subject variability in pain perception may have affected the results. The significantly lower 90% circle diameter of NSNP patients at NRS-2 compared to the control group (n = 70) illustrates this (Fig. 2).

Furthermore, three important aspects seem to point towards “pain interference” rather than the damage or impairment of proprioceptive structures as the causative factor for the reported larger COP excursions.

Firstly, Vuillerme et al. demonstrated that inducing pain in healthy individuals instantly triggered altered sway pattern. At an average pain intensity of VAS 7.1 (SD 1.7), the postural sway velocity climbed from 11.3 mm/s to around 17.0 mm/s [29]. This result is very similar to our observations at a comparable pain severity level (Fig. 1).

Secondly, Treleaven et al. were unable to identify patients with chronic whiplash associated disorder (WAD) where damage to proprioceptive structures would be expected. They tested these patients by using COP total path length under various testing conditions. However, when they used wavelet analysis they were able to discriminate WAD cases from healthy controls [30]. In this type of analysis signal data is converted into coefficients that capture information about the signal at locations and for different frequencies [31]. Although a single recording of 30 seconds may have limited the reliability of the data [22], this nevertheless indicates that traditional parameters such as mVel or area may only be sensitive to larger sway alterations associated with certain degrees of pain perception. Unfortunately, Treleaven et al. did not report pain levels in this study. However, as the sway values were very similar to those reported in a study with an identical setup and pain at VAS 2.8–4.1 [32], the pain intensities are probably similar. These lower pain scores are only associated with early and minor sway alterations (Fig. 1), accordingly, difficulty in detecting changes in the COP excursions may be explained.

Furthermore, the increased postural instability observed in our study is unlikely to be associated with attentional effects such as distraction from the postural task or, in contrast, with demanding particular attention. It has been shown that performing cognitive tasks during COP recordings causes a decrease in postural sway [33,34], thereby showing the opposite effect to our pain related observations.

This leaves conscious or unconscious pain avoidance strategies as a contributing factor for the increased COP excursions. First of all, pain perception exceeding the intensity identified in our studies to cause postural sway alterations are not associated per se with such an effect. A postural response occurs only if structures involved in maintaining posture (e.g. neck, low back or legs) are affected. Painful stimuli to the arms [35]
or hands [36], for example, does not increase postural instability, while pain in the feet does [36]. Generally, an effect of pain avoidance cannot be fully excluded. However, no trend of increasing sway with discomfort was observed across the three repetitions or reported by the patients. The differences between the recordings remained "not significant".

Our results also show that factors such as previous pain duration and short term learning or fatigue effects exhibit no effect on postural sway. Furthermore, and in contrast to other studies [14,16,37,38], we could not demonstrate any significant effect of age, height or weight on COP excursions. This may be attributed to the demographics and physical characteristics of our participants. Although a relationship between height and the magnitude of the COP excursions in participants between 150 cm and 190 cm was demonstrated [37], the fairly low variability in height found in our participants (177.0 ± 8.5 cm) may explain why no significant correlation could be identified. The same is true with regards to age related alterations as other relevant studies [14,38] employed elderly participants older than 60 yrs. Our study had a cut-off age of 50 yrs. Finally, when body weight was investigated as a predictor of postural stability [16], the close association identified was based on a very wide weight range from 59.2–209.5 kg while ours was quite narrow at 76.4 ± 11.0 kg.

5.1. Clinical considerations

The linear relationship between pain intensity and postural sway indicates that COP measurements may be suitable as a discreet objective outcome measure for clinical monitoring purposes. However, the results are unidirectional in that increasing pain was associated with increasing postural sway. We have not established that decreasing pain leads to a decreasing postural sway and future experiments may focus on this interesting aspect. If the linear trend observed in NSNP patients is maintained as pain scores decrease, this may allow an interesting insight into the objectiveness of pain scoring, despite any inter-subject variability in perception of nociceptive stimuli.

The excellent reliability of the data obtained from the enrolled patients and the fact that all participants completed the trials without reporting any difficulties underlines the suitability of the selected experimental setup for clinical research purposes. In addition, these results indicate that the COP data was not affected by fatigue or learning over the course of the three repetitions.

The results of this study indicate that there may be various clinical applications for COP measurements. This would require further studies looking at the psychometric properties of the measurements but there may be application in identifying malingers. Even if an individual is aware that pain is associated with greater COP excursions, imitating pain related sway pattern is difficult and the resulting COP excursions have been shown to exceed those expected from a real pain sufferer [39]. Secondly, as pain interference appears a likely underlying mechanism for the observed sway alterations, the focus of a rehabilitative approach in pain sufferers with increased COP excursions should be on pain reduction rather than proprioceptive training. This may also have potential benefits if analgesic treatments are used in the elderly with neck pain by lowering postural instability which is closely associated with falls in this population [40–42].

5.2. Strengths and limitations

A best practice experimental setup constitutes a major strength of this study, ensuring reliable data collection and showing no short-term effects of fatigue and learning effects. Our inclusion and exclusion criteria further prevented our overall results from being affected by demographic or anthropometric factors.

Because of the comparable small sample size per NRS group, our results are prone to be affected by extreme COP measures. As a consequence, other sample groups with identical NRS scores may therefore show varying results. However, the linear trend observed here is expected to be preserved. Similar studies with an identical experimental setup and larger sample sizes should be conducted to confirm our results.

The subjective nature of pain perception and rating is likely to have affected this cross-sectional study. In addition, pain perception between younger and older NSLBP participants varies [28]. Although this does not affect our sample groups with a cut-off age of 50 yrs, it nevertheless prevents our results to be generalized to elderly patients.

6. Conclusions

The results of this study show that irrespective of the subjective nature of pain perception and unclear causative factors, COP sway velocity and perceived pain intensity appear closely and positively related in adults between 18 and 50 years of age. This trend is
also apparent for sway area. Although routine COP measurements during the rehabilitation or treatment process may offer an objective insight into recovery progress of a NSNSP patient, more research into the clinimetrics of the use of COP measures needs to be undertaken.

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