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# The effect of cervical spine subtypes on center of pressure parameters in a large asymptomatic young adult population

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A R T I C L E I N F O

*Keywords:*
Asymptomatic
Postural control parameters
Radiographic classification
Cervical lordosis
Cervical kyphosis

A B S T R A C T

*Background:* Recent research highlighted that non-lordotic subtypes are common within an asymptomatic population of young adults. The potential mechanisms responsible for the decreased postural control witnessed in healthy participants exhibiting non-lordotic cervical alignment are unclear.

*Research question:* Therefore, the aim of this study is to compare and contrast asymptomatic radiographically derived sagittal cervical alignment subtypes with Center of Pressure (CoP) parameters.

*Methods:* In this cross-sectional study strict asymptomatic inclusion criteria were met by 150 of the original 182 volunteers. All radiographs were assessed using a multi-method subtype system with participants classified into lordotic and non-lordotic groups. Participants performed 90s narrow stance trials with their eyes closed whilst standing on both a firm surface (FS) and compliant surface (CS) (3 trials per surface). CoP parameters were recorded from a force platform sampling at 100 Hz. Nonparametric statistical tests were conducted to assess differences between groups for each surface type and to determine differences in CoP parameters between FS and CS types.

*Results:* Significant differences were found between groups on both surfaces for the anterior to posterior range (FS: $p = 0.013$; CS: $p = 0.023$), total excursion (FS: $p = 0.029$; CS: $p = 0.005$) and mean velocity of total excursion (FS: $p = 0.032$; CS: $p = 0.004$).

*Significance:* Our data suggest that sagittal plane cervical alignment is a measure capable of distinguishing between the postural control of asymptomatic lordotic and non-lordotic young adult participants on both surfaces types. Furthermore, decreased postural control is present in asymptomatic participants across all non-lordotic subtypes and is not isolated exclusively to those with forward head posture. Consequently, future research endeavours should investigate the clinical significance of these non-lordotic findings in relation to both the potential for early cervical osseous degeneration and the transitional stages of non-specific pain sufferers from previously asymptomatic young adults.

## 1. Introduction

Functional postural control is required to maintain and regulate a state of balanced equilibrium. Numerous complex coordinated neurological integrations are necessary to preserve the body's center of mass over either a static or dynamic base of support [1–3]. The excursion of the body's center of mass relative to the base of support is the measurable criteria referred to as postural sway, representing the body's small adjustments responsible for maintaining upright equilibrium. Force platform generated Center of Pressure (CoP) parameters are the gold standard when assessing postural control, with minimal excursion between the center of mass and the base of support indicating greater postural control and superior neurological coordination [1,4]. Reviews within this domain indicate CoP parameters are used in approximately 60% of the published literature that has assessed postural control [1,4]. These reviews highlight that researchers in this domain typically use CoP parameters to differentiate asymptomatic control groups from pathological groups and substantiate the clinical findings of applied postural control interventions.

Two landmark systematic reviews have independently concluded that statistically significant differences exist between the CoP parameters of asymptomatic (control), non-specific neck pain (NSNP) and whiplash associated disorder (WAD) participants [5,6]. These two reviews indicate asymptomatic participants have been shown to exhibit greater postural control when compared to both NSNP and WAD participants, while WAD participants have significantly less postural

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control than the other two cohorts. Even in asymptomatic populations researchers have linked forward head posture (FHP), a common postural condition, to decreases in postural control [7,8]. Radiographic evaluation has indicated a potential association between a loss or reduction in the cervical lordosis and the presence of neck pain [9,10]. Furthermore, other studies have identified an association between erect FHP assessed using photogrammetric techniques and the presence of neck pain [11,12]. Clearly, within an asymptomatic population there is the potential for individuals to exhibit FHP or a reduction in the cervical lordosis [13,14] and hence present with decreased postural control.

While the studies by Kang, Park [7] and Lee [8] are an important first step, a limitation of their methodology was the determination of FHP through only external photographic measures (EPM), an approach that may not provide critical information on the true nature of the underlying cervical vertebral alignment [15]. Additionally, gross measures of cervical posture such as those assessed using EPM fail to account for the numerous alternative cervical non-lordotic conditions that can only be classifiable radiologically [13,16–18]. Importantly, the correct identification of non-lordotic subtypes is vital, as recent evidence indicates that these alignment patterns promote the pathogenesis and rate of progression associated with a multitude of cervical osseous and myelopathic degenerative conditions [18–20].

A naturally lordotic alignment in the cervical spine is considered optimal for functionality and health-related quality of life factors [18,19]. Alarmingly, recent research highlighted that non-lordotic subtypes are common within an asymptomatic population of young adults [13,14]. Therefore it is tempting to suggest that many of the asymptomatic individuals that have been used as controls in previous studies are likely to also display cervical non-lordotic subtypes. This may explain the subtle differences in CoP parameters that exist within samples of asymptomatic individuals [7,8]. The question remains as to potential mechanisms responsible for decreased postural control witnessed in healthy participants exhibiting non-lordotic cervical alignment (FHP). Accordingly, the purpose of this research is to compare and contrast asymptomatic CoP parameters within radiologically determined cervical lordotic and non-lordotic groups.

## 2. Methods

### 2.1. Study design

This cross-sectional study required participants to attend a radiographic assessment and laboratory postural assessment sessions. Approval was obtained from the institutional Research Ethics Committee (S/14/607), with written informed consent obtained from all eligible volunteers in accordance with the institutional human research ethics requirements.

### 2.2. Participants

Participants were recruited from a university student population and their friends and families, with 182 individuals volunteering to participate. To assess a volunteer's eligibility to participate (i.e. to be asymptomatic) they underwent a comprehensive series of clinical and physical assessments including a project specific self-reporting questionnaire (See Supplementary material), 36-item short-form health survey, neck disability index and a physical examination as described by Daffin, Stuelcken [13]. If a volunteer failed any element of this screening process they were excluded from further participation. As a result, the questionnaires excluded 18 participants including all chronic musculoskeletal conditions regardless of the region either axial or appendicular. A key aspect of this research was the addition of a physical examination involving standardised orthopaedic and neurological testing procedures in conjunction with a comprehensive active, passive and resisted musculoskeletal evaluation of the cervical spine (See Supplementary material). The physical examination excluded a further 14 participants from the research project. Accordingly, 150 asymptomatic participants aged between 18 and 30 years met all the inclusion criteria consisting of: 61 males (age - 22.7 ± 3.6; height - 177.5 cm ± 7.1; mass - 79.1 kg ± 14.0) and 89 females (age - 22.5 ± 3.6; height - 166.1 cm ± 6.4; mass - 63.9 kg ± 11.1) (Table 1).

**Table 1**
Demographic and spinal health questionnaire results for the two groups used throughout the study. Data are presented as means (standard deviation).

| Research Participants | Age (years) | Height (cm) | Mass (kg) | NDI (100) |
|---|---|---|---|---|
| Lordotic Group 1 | 22.9 (3.9) | 173.5 (8.6) | 73.4 (13.0) | 3.6 (3.4) |
| Male ($n$ = 29, 56.9%) | 22.6 (3.7) | 178.3 (6.5) | 79.9 (11.0) | 2.9 (2.9) |
| Female ($n$ = 22, 43.1%) | 23.3 (4.2) | 166.5 (6.1) | 64.2 (9.6) | 4.6 (3.9) |
| Non-lordotic Group 2 | 22.4 (3.4) | 169.3 (8.5) | 68.3 (14.9) | 4.1 (3.7) |
| Male ($n$ = 32, 32.3%) | 22.7 (3.5) | 176.7 (7.6) | 78.4 (16.5) | 3.1 (3.4) |
| Female ($n$ = 67, 67.7%) | 22.2 (3.4) | 166.0 (6.6) | 63.8 (11.6) | 4.6 (3.8) |

### 2.3. Radiographic procedures, instruments and classification

A single lateral cervical radiograph was taken by the same radiographer and digital capturing unit using established radiological procedures [13,16]. The tube-to-wall mounted Bucky distance was 1.5 m with the central ray aligned at the level of C4. Each participant was positioned with their right shoulder touching the Bucky and instructed to adopt a relaxed neutral erect stance position with their head looking toward the horizon. The participant's shoulder girdles and arms hung relaxed by their sides, while their body weight was distributed evenly over both feet. The assumed position was not guided by the radiographer, and post positioning movements were kept to a minimum.

The principal researcher classified all cervical sagittal curves using a multi-method subtype system [13] (Fig. 1), representing an amalgamation of key reliable and valid classification methodologies [16,17]. Intra-rater testing on 30 randomly selected participants showed high levels of reliability for the classification of the various subtypes (Kappa = .836–.918). The association between non-lordotic subtypes and the biological mechanisms responsible for cervical degeneration [18–20] meant that we clustered subtypes into two groups: (1) lordotic, and (2) non-lordotic (i.e. straight, global kyphotic, sigmoidal, and reverse sigmoidal subtypes [Fig. 1]). The classification by Group was exceptionally reliable (Kappa = 1.0). There was a significant difference between lordotic and non-lordotic groups for both height ($p = 0.006$) and mass ($p = 0.041$) but not for age ($p > 0.05$). Further investigation indicated that within each group (lordotic and non-lordotic), the variance in the height, mass, or age did not explain more than 10% of the variance in any of the postural sway variables.

## 3. Data collection

### 3.1. Center of pressure data acquisition and postural positioning protocols

A Qualisys motion capture system (Qualisys AB, Gothenburg, Sweden) was used to record ground reaction force data from a 400 x 600 mm force platform (Bertec Corporation, Columbus, USA), sampling at 100 Hz [21–23]. All six 'best practice' procedures for enhancing the reliability of CoP data were implemented [22]. Testing involved participants performing a series of 90 s trials on both a firm surface (FS) and compliant surface (CS), with the type of surface randomised between and within participants. Participants performed all 3 trials per surface with their eyes closed. The CS consisted of a 100 mm thick piece of high density foam [23,24]. Participants stood barefoot in a narrow stance position with their great toes and heels touching so their feet were parallel [21,24,25]. Once positioned all instructions

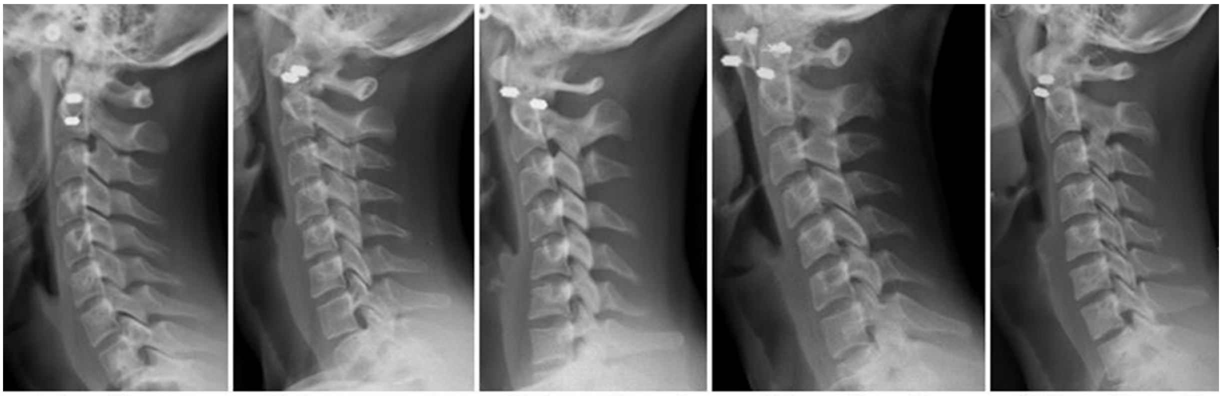


**Fig. 1.** Radiologically classified cervical subtype groupings by sex: A representation of the typical alignment patterns observed within each cervical subtype classification. Group 1 (n = 51, 34%): Lordotic (L-type, Male [M] n = 29, Female [F] n = 22). Group 2 Non-lordotic subtypes (n = 99, 66%): Straight (St-type, M: n = 14, F: n = 23), Global Kyphotic (GK-type, M: n = 2, F: n = 26), Sigmoidal (S-type, M: n = 4, F: n = 9), and Reverse Sigmoidal (RS-type, M: n = 12, F: n = 9).

were given on a television monitor positioned in front of the participants, with the final instruction being to "keep your gaze directed straight ahead, close your eyes now". A trial was terminated if any of the following balance errors were observed: (1) opening eyes during the trial, (2) lifting an arm or arms greater than 45° in any direction, (3) stepping off the platform, (4) stumbling or falling out of position, (5) lifting the forefoot or heel, and (6) failing to normalise the test position in 5 s [26]. No trials met these criteria. A 60 to 90 s rest period was provided between trials at the end of which participants returned to the force platform and readied themselves for the next trial [21,24,26].

### 3.2. Data processing

Data were exported and further processed using standard biomechanical analysis software (Visual3D, C-Motion, Inc. Maryland, USA). Data were filtered using a fourth order zero lag Butterworth filter with a cut off frequency of 10 Hz [22,25]. The eight standard CoP parameters that were computed for this study can be seen in Table 2 [4,27–29].

### 3.3. Statistical evaluation

Shapiro-Wilk tests for normality showed that none of the CoP parameters were normally distributed. Accordingly, nonparametric tests (Mann-Whitney U) were conducted to assess differences between groups for each surface type. The relative magnitude of the between group differences were quantified using r effect sizes ($Z/\sqrt{n}$), and assessed using the following scale: Trivial < 0.20; Small 0.20; Medium 0.50; Large 0.80 [30]. The Wilcoxon Signed Rank test was used to determine differences in CoP parameters between FS and CS types. Statistical analyses were completed using SPSS version 22 (SPSS Inc., IBM, Chicago, Illinois).

## 4. Results

There were significant between group differences in three of the CoP parameters (Table 3). These differences were present on both compliant and firm surfaces. Although not the primary focus of this paper, all of the measured CoP parameters were significantly greater on the CS than on the FS ($p < 0.001$).

## 5. Discussion

The key purpose of this research was to compare and contrast asymptomatic CoP parameters within radiologically determined cervical lordotic and non-lordotic groups. To our knowledge this is the first study of its type, and represents a new perspective on the potential for CoP parameters to be used as novel biomarkers to clinically identify early transitional pathology. Notably, our sample was selected exclusively on their asymptomatic status, without preconception of their prospective group allocation, making our sample typical for a 'control group' within this domain (it is also larger [n = 150] than comparative studies). Finally, rather than focusing on EPM, group allocation was performed radiologically, with 'best practice' methodologies

**Table 2**
Eight reported center of pressure (CoP) based postural sway parameters.

| Category | Measure | Definition |
|---|---|---|
| Distance (mm) | Anterior/Posterior Range (A/P Range) | The maximum distance being the smallest and largest values between any two points on the CoP path in the trials A/P time series [4,28,29]. |
| | Medial/Lateral Range (M/L Range) | The maximum distance being the smallest and largest values between any two points on the CoP path in the trials M/L time series [4,28,29]. |
| | Anterior/PosteriorRoot Mean Square (A/P RMSq) | The square root of the mean of the set of standard deviation values squared within the A/P range time series [4,27,28]. |
| | Medial/Lateral Root Mean Square (M/L RMSq) | The square root of the mean of the set of standard deviation values squared within the M/L range time series [4,27,28]. |
| | Root Mean Square Distance (RMSq Dist) | The square root of the mean of the total number of consecutive data points within the A/P and M/L CoP path directions squared within the time series [29]. |
| | Total Excursion (TEx) | The sum of the total distance traveled between consecutive points of the CoP path (path length) during the duration of the trials time series [4,28]. |
| Velocity (mm/s) | Mean Velocity Total Excursion (MVel TEx) | The average velocity of the consecutive points on the CoP path divided by the total time of the trials time series [4,28,29]. |
| Area ($mm^2$) | 95% Confidence Circle (95% CC) | The area of a circle that covers 95% of all CoP positions during the trials time series. The radius of the circle represents the one sided 95% confidence limit generated from the resultant distance of the time series [28,29]. |

**Table 3**
Mean (SD) center of pressure parameters, with level of significance (*p*) and effect size (*r*) for differences between lordotic and non-lordotic groups.

| Surface | A/P Range (mm) | M/L Range (mm) | A/P RMSq (mm) | M/L RMSq (mm) | RMSq Dist (mm) | TEx (mm) | MVeL TEx (mm/s) | 95% CC ($mm^2$) |
|---|---|---|---|---|---|---|---|---|
| FS Lordotic | 33.6 (7.1) | 36.8 (8.7) | 9.3 (3.6) | 7.4 (1.7) | 12.2 (3.6) | 1758 (401) | 20.9 (4.8) | 1287 (719) |
| FS Nonlord | 37.8 (10.9) | 37.6 (8.2) | 9.6 (3.3) | 7.8 (1.8) | 12.7 (3.3) | 1901 (389) | 22.6 (4.6) | 1412 (707) |
| *p / r* | 0.013*/-0.20 | 0.655/-0.04 | 0.462/-0.06 | 0.340/-0.08 | 0.233/-0.10 | 0.029*/-0.19 | 0.032*/-0.18 | 0.199/-0.10 |
| CS Lordotic | 58.3 (12.2) | 56.4 (11.4) | 12.5 (4.0) | 10.4 (1.9) | 16.5 (3.9) | 3167 (822) | 37.7 (9.8) | 2434 (1129) |
| CS Nonlord | 62.7 (10.9) | 57.7 (10.9) | 12.9 (3.4) | 10.7 (2.0) | 17.0 (3.4) | 3563 (893) | 42.4 (10.6) | 2545 (1020) |
| *p / r* | 0.023*/-0.19 | 0.299/-0.08 | 0.275/-0.09 | 0.754/-0.03 | 0.400/-0.07 | 0.005*/-0.23 | 0.004*/-0.23 | 0.338/-0.08 |

FS: firm surface, CS: compliant surface, Nonlord: non-lordotic, A/P Range: anterior/posterior range, M/L Range: medial to lateral range, A/P RMSq: anterior /posterior root mean square, M/L RMSq: medial to lateral root mean square, RMSq Dist: root mean square distance, TEx: Total Excursion, MVeL TEx: mean velocity total excursion, 95% CC: 95% confidence circle, SD: standard deviation, *r*: *effect size*, *p*: *p* - value, *: significant differences *p* - value < 0.05.

incorporated throughout the postural control testing.

Our findings indicate that decreased postural control is associated with non-lordotic subtypes within an asymptomatic sample. Specifically, *Small* but significant differences in A/P Range, TEx and MVeL TEx were found between subtypes on both surfaces. Research within this domain typically assesses differences between control and pathological groups, with differences in postural control being exaggerated as a function of the underlying pathologies within the symptomatic groups. In our study we were able to identify differences within an otherwise asymptomatic sample, emphasising the sensitivity of the significant CoP parameters for assessing decreases in postural control. Regardless of the group or surface type all the participants demonstrated comparable postural control within the sway area covered by the 95% CC. While this common measure of postural control has been used to record differences between groups of asymptomatic and pathological samples [5,6,31], it does not appear to be sensitive enough to determine the influence of cervical subtypes on postural control in an asymptomatic population. Combined, our results show that both the lordotic and non-lordotic subtypes maintain a comparable sway area, but the later have greater A/P Range, TEx and MVeL TEx.

We identified 99 non-lordotic participants radiologically comprising straight, global kyphotic, sigmoidal, and reverse sigmoidal subtypes. Similar studies within this domain have been limited to assessing only FHP determined by EPM [7,8]. However, the association between non-lordotic subtypes and the biological mechanisms responsible for a multitude of cervical osseous and neurological degenerative conditions [18–20], provides support for the direct assessment of cervical alignment via radiography. A potential shortcoming can arise when allocating straight, global kyphotic, sigmoidal and reverse sigmoidal subtypes via EPM. Although this gross criterion can characterise postural conditions associated with craniovertebral sagittal plane translation, it fails to determine the precise cervical vertebral alignment. The cervical spine's sagittal plane translation encourages the different underlying vertebral patterns to develop within every subtype [16,18–20]. Clearly, the detrimental long-term effects of non-lordotic subtypes warrants greater attention than indirect measures such as EPM. The latter is particularly important in asymptomatic samples, where greater measurement precision is required to accurately allocate participants into correct cervical subtypes.

Due to the asymptomatic samples similarities we suggest concentrating on those CoP parameters shown to be significant (A/P Range, TEx and MVel TEx) coupled with the sway area (95% CC). Consolidating the choice of CoP parameters investigated will reduce over representation and enhance reporting consistency [1], a factor strongly supported when initially developing preliminary novel biomarkers [32]. Moreover, our data may contribute to the standard CoP descriptors required to develop novel biomarkers capable of identifying early pathology. For example, the biological mechanisms associated with NSNP and the pathological predisposition of the non-lordotic state need to be considered. NSNP sufferers display decreased postural control [5,6] and the non-lordotic state promotes degeneration [18–20]. Accordingly, through continued research, postural control analysis may have the capacity to identify the transitional state within the nervous system that results in individuals developing NSNP. Future research is essential within the asymptomatic postural control domain, to propagate comparable standardised CoP data collection capable of being used to develop clinically valid biomarkers.

## 6. Limitations

A potential limitation of the current study may be the assumptions made from a single lateral cervical radiograph. The cervical spine is highly mobile and so it's plausible that several slight natural alignment variants exists during stance. One lateral radiograph of an assumed natural cervical posture is only a representation of the adopted posture at that instant in time, but multiple image analyses are extremely rare in this field.

## 7. Conclusion

We believe our study is the first to use a multi-method radiographic approach to examine the relationships between sagittal cervical subtypes and postural control within a young adult asymptomatic population. Our findings demonstrate that decreased postural control is present in asymptomatic participants across all non-lordotic subtypes and is not isolated exclusively to FHP. In light of the present findings, the authors believe that A/P Range, TEx, MVel TEx in association with a comparable 95% CC represent the key measures within the asymptomatic domain. The rigorous protocols adhered to throughout this study provide an opportunity for developing a normative database of biomarkers for the early detection of cervical degeneration.


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## Conflict of interest

None.

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## Appendix A. Supplementary data

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