Musculoskeletal Science and Practice 43 (2019) 12–17

Contents lists available at ScienceDirect

Musculoskeletal Science and Practice

journal homepage: www.elsevier.com/locate/msksp

Original article

# Internal and external sagittal craniovertebral alignment: A comparison between radiological and photogrammetric approaches in asymptomatic participants

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ARTICLE INFO

*Keywords:*
Cervical kyphosis
Cervical lordosis
Craniovertebral angle
Forward head posture

ABSTRACT

*Background:* Photogrammetric measures are a commonly applied, highly reliable tool for appraising craniovertebral postures during clinical assessments, rehabilitation, and research interventions.
*Objective:* This study aimed to compare and contrast three external measures of postural alignment (EMPA) using photogrammetric and radiological approaches, and to discuss whether the craniovertebral angle (CVA) reflects the shape of the underlying cervical spine.
*Design:* Cross Sectional Correlation Study.
*Method:* Young adults attended three assessment sessions (S1, S2 and S3). S1 involved a standardised photogrammetric protocol. S2 involved radiographic image acquisition. S3 followed the same protocol in S1 but excluded the self-balancing procedure. Each session's EMPA were compared through either paired or independent samples *t*-tests. The different radiographic cervical subtypes and their corresponding CVAs were assessed.
*Results:* There were no significant differences in any EMPA between the two photogrammetric sessions. The CVA was the only EMPA to show a significant difference between photogrammetric (S3) and radiographic approaches. Cervical subtype variability is present throughout the full CVA range.
*Conclusions:* Despite the statistically significant difference in the CVA between approaches, the mean difference was small and unlikely to be clinically meaningful. Accordingly, the quantification of EMPA can be undertaken with high levels of precision and reliability using standardised photogrammetric procedures. The CVA, however, does not provide an indication of the shape of the underlying cervical spine. The distinct radiological differences in the inter-segmental orientation of each vertebral motion segment in conjunction with the differences in the overall global cervical alignment, both within and between participants, negate this possibility.

## 1. Introduction

Radiographic measurements are considered the “gold standard” when evaluating skeletal alignment (Cohen et al., 2017; Harrison et al., 2005). Sagittal plane radiological images can be used to classify the shape of the cervical spine either through visual (Takeshima et al., 2002) or numerical (Ohara et al., 2006) methods, or a combination of visual and numerical methods (Daffin et al., 2017). In this latter multimethod approach, five cervical subtypes - lordotic (L-type), straight (St-type), global kyphotic (GK-type), sigmoidal (S-type) or reverse sigmoidal (RS-type) - were identified with high levels of intra-rater reliability ($_K$ = 0.836–0.918) (Daffin et al., 2017; Daffin et al., 2019). However, due to health concerns associated with repeated radiographic assessments (Ashnagar et al., 2017; Cohen et al., 2017) alternate, less invasive measures of skeletal alignment such as photogrammetry are commonly used throughout clinical practice.

In fact, there is a long tradition within the manual therapies of evaluating cervical postural alignment through photogrammetric approaches (do Rosario, 2014; Raine and Twomey, 1997; Singla et al., 2017). Linear distances and angular measures are routinely evaluated on neutral sagittal and coronal plane photogrammetric images of the craniovertebral region using standardised anatomical landmarks (Silva et al., 2009; Singla et al., 2017). Three commonly assessed external measures of postural alignment (EMPA) are the craniovertebral angle

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https://doi.org/10.1016/j.msksp.2019.05.003
Received 29 April 2018; Received in revised form 28 March 2019; Accepted 2 May 2019

(CVA), upper cervical gaze angle (UCGA) and lateral head tilt angle (LHTA). Once an individual's baseline cervical postural alignment is established, these data can then be compared to normative values or used as part of repeated photogrammetric assessments to evaluate the efficacy of interventions aimed at altering cervical postural alignment (Cohen et al., 2017; Silva et al., 2009; Singla et al., 2017).

Whilst EMPA are a simple, safe, and cost effective approach (Ashnagar et al., 2017; Cohen et al., 2017) that has demonstrated moderate to excellent reliability (Ashnagar et al., 2017; Cohen et al., 2017), potential difficulties in identifying anatomical landamarks through manual palpation may lead to errors when measuring EMPA using photogrammetry compared to radiography (Cohen et al., 2017; do Rosario, 2014; Robinson et al., 2009). Furthermore, it is unlcear whether the CVA, a commonly reported EMPA within musculoskeletal literature for professions such as physiotherapy and chiropractic (Silva et al., 2009; Singla and Veqar, 2017), reflects the shape of the underlying cervical spine or is limited to being a simple measure indicating the presence ($< 50^{\circ}$) or absence ($> 50^{\circ}$) of forward head posture (Ruivo et al., 2014). Accordingly, the purpose of this research is to (1) compare and contrast three EMPA using photogrammetric and radiological approaches, and (2) discuss whether the CVA measure taken form radiological images reflects the shape of the underlying cervical spine.

## 2. Methods

### 2.1. Participants

The sample consisted of 150 participants aged between 18 and 30 years: 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). Participant eligibility was assessed with a 36-item Short-Form Health Survey (Ware Jr and Sherbourne, 1992), the Neck Disability Index (Vernon and Mior, 1991), a project specific self-reporting questionnaire and a physical examination as described in (Daffin et al., 2019). All participants were asymptomatic for neck related problems at the time of testing. 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. All aspects of this study were performed by the same researcher, a board-certified Chiropractor experienced in surface palpation and assessment of postural alignment.

## 3. Data collection

Participants attended 3 sessions - 2 photographic (S1 and S3) and 1 radiographic (S2) over a period of 3–4 weeks. In S1, data collection was conducted in a sequenced order in accordance with published procedures (Straker et al., 2009). Participants stood barefoot on a large sheet of paper, assuming a natural relaxed stance while looking towards the horizon. A foot tracing was then created for each participant in order to standardize the position of the feet during the postural assessments.

Two Fujifilm Finepix JX550 digital cameras mounted onto Manfrotto 161MK2B tripods and levelled with the tripods' inbuilt spirit level were used to obtain the photographic images. The left sagittal plane camera was located 2.25 m from the wall (Shaheen and Basuodan, 2012) whereas the anterior coronal plane camera was located 2.5 m from the wall (Ferreira et al., 2011). Adjustable tripods permitted the optical axis of each camera to be aligned with the C7 vertebra (Ruivo et al., 2014). In order to determine true vertical, a plumb line was positioned within the fields of view of both cameras (Ferreira et al., 2011). Lines projecting from the optical axes of each camera lens were marked on the floor using adhesive tape. These lines were aligned with a cross that was marked at the centre of the base of support of the foot tracing of each participant and the paper for the tracing was fixed to the floor with blue tack. This ensured that participants were positioned perpendicular to the optical axis of each camera and neutral craniovertebral posture was not affected by changes in foot placement (Fig. 1) (Ferreira et al., 2011; Gadotti and Magee, 2013; Silva et al., 2011).

**Fig. 1.** Foot tracing overlayed on a central cross representing the optical axes of both cameras. Ledger: Sagittal Plane: A. Upper Cervical Gaze Angle (UCGA), B. Craniovertebral Angle (CVA). Coronal Plane: C. Lateral Head Tilt Angle (LHTA).

Five key anatomical landmarks were identified - the tip of the C7 spinous process, the left tragus of the ear, the left lateral canthus of the eye, and the inferior margins of both ear lobes - and small (7 mm) retroreflective markers adhered to rubber pads were attached using double sided tape (Silva et al., 2011). The prominent C7 spinous process was identified during cervical extension as the C6 spinous process translated anteriorly (Yip et al., 2008). Each participant was then instructed to stand barefoot on his/her foot tracing and adopt a neutral relaxed position with the arms placed at the side of the body. A self-balancing procedure was performed to determine each participant's natural head posture. This is a commonly used procedure that relies on the participant's inherent proprioceptive and vestibular apparatus information to achieve a natural head balance in which the visual axis of the eyes is horizontally orientated (Cassi et al., 2016). It requires participants to close their eyes and perform large amplitude neck flexion and extension movements that gradually decrease in amplitude until a stationary balanced head position is achieved (Cuccia and Carola, 2009; Gadotti and Magee, 2013). Upon completion, participants opened their eyes and verbally indicated their preparedness to remain stationary during image acquisition from both cameras. Three images were obtained in quick succession from each camera.

Three angles were generated using the landmarks described previously, two sagittal and one coronal (Fig. 2). The UCGA is the acute angle formed at the intersection between a horizontal reference line and a line connecting the marker on the left tragus of the ear and the marker on the left lateral canthus of the eye. The UCGA describes the horizontal inclination of the head in the sagittal plane and is related to the relative position of the upper cervical spine (Mo et al., 2013; Singla et al., 2017; van Niekerk et al., 2008). A decrease in the UCGA suggests that the upper cervical spine is relatively more flexed. The CVA is the acute angle formed at the intersection between a horizontal reference line and a line connecting the marker on the left tragus of the ear and a point at the skin-marker interface at the spinous process of the seventh cervical vertebra. The CVA describes the inclination of the head with respect to the lower cervical spine (Mo et al., 2013). A CVA $> 50^{\circ}$ theoretically represents an 'ideal' head on trunk alignment while a CVA $< 50^{\circ}$ is considered to indicate the presence of forward head posture (Singla et al., 2017; van Niekerk et al., 2008). The LHTA is the acute angle formed at the intersection between a horizontal reference line and a line connecting the inferior margins of both ear lobes at the skin-marker interface. Positive values indicated right lateral flexion and negative values indicated left lateral flexion. The LHTA describes the lateral flexion of the head in the coronal plane (Silva et al., 2011; Singla et al.,

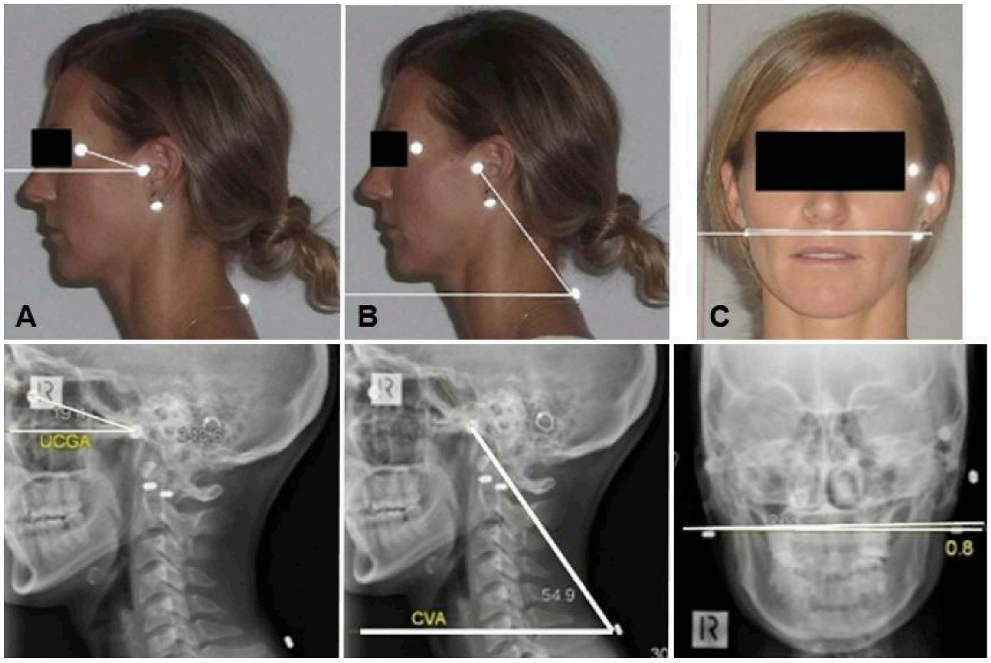


**Fig. 2.** Anatomical landmarks, photogrammetric and radiographic image digitization. Ledger: Sagittal Plane: A. Upper Cervical Gaze Angle (UCGA), B. Craniovertebral Angle (CVA). Coronal Plane: C. Lateral Head Tilt Angle (LHTA).

2017). Studies assessing the intra-rater reliability of these EMPA when incorporating the self-balancing procedure have reported ICC values ranging from 0.93 to 0.99 (Silva et al., 2011; Yip et al., 2008).

S2 involved the collection of single lateral and anterior-posterior cervical radiographs, taken by the same radiographer and digital capturing unit, using established radiological procedures (Daffin et al., 2017; Harrison et al., 2003). Participants were instructed to adopt a relaxed neutral erect stance position with their head looking toward the horizon. The participant's trunk was stabilised against the bucky (wall mounted x-ray/digital cassette holder) while the shoulder girdles and arms hung relaxed by their sides. The 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 (Daffin et al., 2017). Neither foot tracings nor the self-balancing procedure could be used during S2. The photogrammetric procedures in S3 were identical to those outlined in S1. However, the self-balancing procedure was not performed so that data from S2 and S3 could be compared. Instead participants were instructed to look forward as if they were looking at the horizon.

## 4. Data reduction

The photogrammetric images were imported and digitized on the Able Image Analyser software programme (version 3.6; http://able.mulabs.com) (Shaheen and Basuodan, 2012). The use of a vertical plumb line allowed a correction procedure to be performed that ensured that all measurements were taken relative to a 'true' horizontal (Ferreira et al., 2011). The radiographic images were imported and digitized on standard radiographic software (Genesis OmniVue® Genesis Digital Imaging, Inc. Los Angeles, CA). All measurements were recorded to the nearest 0.1° (Shaheen and Basuodan, 2012).

The images of 50 randomly selected participants from the total cohort were assessed two weeks apart to determine the intra-rater reliability of the principal researcher when measuring each of the three postural alignment variables on both photographic and radiological images. A two-way mixed effects model ($ICC_{3,k}$) was used for the measures on the photographic images and a two-way mixed effects model ($ICC_{3,1}$) was used for the measures on the radiological images (Table 1).

**Table 1**
Measures of intra-rater reliability for the key photogrammetric and radiographic variables.

| Angle | Photogrammetric Measures | | | External Radiographic Measures | | |
|---|---|---|---|---|---|---|
| | $ICC_{(3,k)}$ | $SEM_{95}$ | $MDC_{95}$ | $ICC_{(3,1)}$ | $SEM_{95}$ | $MDC_{95}$ |
| UCGA | 0.99 | 0.4° | 1.0° | 1.0 | 0.2° | 0.5° |
| CVA | 1.0 | 0.1° | 0.4° | 1.0 | 0.1° | 0.3° |
| LHTA | 0.99 | 0.1° | 0.4° | 0.99 | 0.1° | 0.4° |

*Notes.* ICC: Intraclass correlation coefficient, SEM: Standard error measurement, MDC: Minimal detectable change, UCGA: Upper cervical gaze angle, CVA: Craniovertebral angle, LHTA: Lateral head tilt angle, S1: Session 1, S2: Session 2, S3: Session 3.

A multi-method sagittal cervical subtyping classification protocol was used to determine the cervical subtype of all 150 participants from the radiographic images (Fig. 3) (Daffin et al., 2017). The breakdown of the different cervical subtypes and the corresponding CVAs were then assessed (Table 3).

## 5. Statistical analysis

The three postural alignment measures taken on the photographic images across sessions 1 and 3 were compared using paired t-tests. The three postural alignment measures taken on the photographic and radiological images across sessions 2 and 3 were compared using independent samples t-tests. The alpha level was set 0.05. All statistical analyses were conducted using the Statistical Package for the Social Sciences (Version 22.0 for Windows, SPSS Inc., USA).

## 6. Results

The standard error of measurement and minimal detectable change for the UCGA, CVA and LHTA showed *excellent* reliability (Table 1). There were no significant differences in any EMPA between the two photogrammetric sessions (S1 and S3). The CVA was the only EMPA to

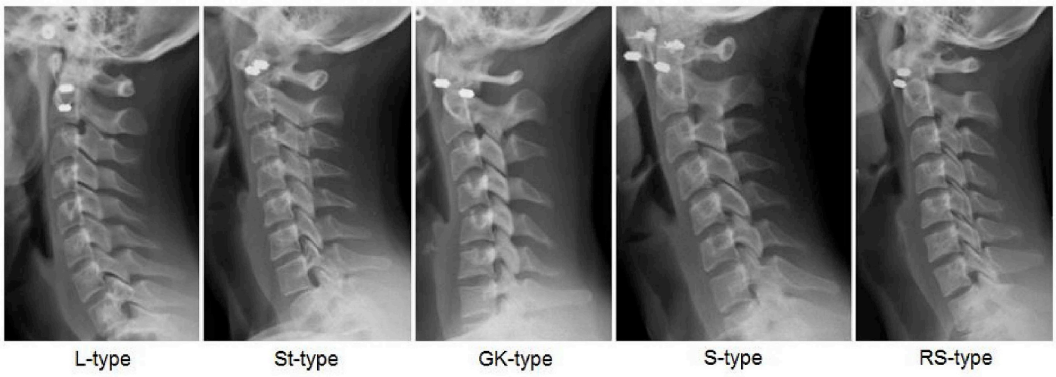


**Fig. 3.** A radiographic representation of the typical alignment patterns observed within each cervical subtype classification: Lordotic (L-type), Straight (St-type), Global Kyphotic (GK-type), Sigmoidal (S-type), and Reverse Sigmoidal (RS-type) subtypes.

**Table 2**
Paired *t*-test results comparing photogrammetric session 1 and 3/independent samples *t*-test results comparing radiographic session 2 and photogrammetric session 3.

| Angle | Mean S1 (SD) | Mean S3 (SD) | Mean difference (S1–S3) | 95% CI difference | *P*-value |
|---|---|---|---|---|---|
| UCGA | 20.5° (5.2°) | 20.8° (5.4°) | −0.3° | −1.1–0.4° | *0.408* |
| CVA | 50.4° (5.2°) | 50.2° (5.3°) | 0.2° | −0.3–0.6° | *0.417* |
| LHTA | 0.4° (2.1°) | 0.5° (2.0°) | −0.1° | −0.3–0.1° | *0.391* |
| Angle | Mean S2 (SD) | Mean S3 (SD) | Mean difference (S2–S3) | 95% CI difference | *P*-value |
| UCGA | 19.8° (5.1°) | 20.8° (5.4°) | −1.1° | −2.3–0.1° | *0.073* |
| CVA | 51.6° (5.2°) | 50.2° (5.3°) | 1.4° | 0.2–2.6° | *0.022** |
| LHTA | 0.3° (1.8°) | 0.5° (2.0°) | −0.2° | −0.7–0.2° | *0.288* |

*Notes*. UCGA: Upper cervical gaze angle, CVA: Craniovertebral angle, LHTA: Lateral head tilt angle, (SD): Standard deviation, S1: Session 1, S2: Session 2, S3: Session 3, *: significant differences $p < 0.05$.

**Table 3**
A breakdown of the different cervical subtypes and the corresponding craniovertebral angles.

| S2 CVA° | Lordotic | Nonlordotic-type | | | | | | Incremental % | | Cumulative % | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | L | St | GK | S | RS | Total N-L | Total | Lordotic | N-L | Lordotic | N-L |
| 30 to 34.9 | 1 | | | | | | **(1)** | 100 | 0 | 2.0 | 0 |
| 35 to 39.9 | | 1 | | 1 | 1 | 3 | **(3)** | 0 | 100 | 2.0 | 3.0 |
| 40 to 44.9 | 9 | 3 | 3 | 1 | 1 | 8 | **(17)** | 52.9 | 47.1 | 19.6 | 11.1 |
| 45 to 49.9 | 15 | 12 | 7 | 5 | 7 | 31 | **(46)** | 32.6 | 67.4 | 49.0 | 42.4 |
| 50 to 54.9 | 17 | 16 | 14 | 3 | 6 | 39 | **(56)** | 30.4 | 69.6 | 82.4 | 81.8 |
| 55 to 59.9 | 8 | 3 | 4 | 2 | 5 | 14 | **(22)** | 36.4 | 63.6 | 98.0 | 96.0 |
| 60 to 64.9 | 1 | 1 | | 1 | 1 | 3 | **(4)** | 25 | 75 | 100 | 98.9 |
| 65 to 70.0 | | 1 | | | | 1 | **(1)** | 0 | 100 | | 100 |
| Total | **(51)** | 37 | 28 | 13 | 21 | **(99)** | **(150)** | | | | |

*Notes*. N-L: Nonlordotic; CVA: Craniovertebral angle; L: Lordotic; St: Straight; GK: Global Kyphotic; S: Sigmoidal; RS: Reverse Sigmoidal, S2: Session 2.

show a significant difference between photogrammetric (S3) and radiographic (S2) approaches (Table 2). Table 3 is a breakdown of the different cervical subtypes and the corresponding CVAs obtained from the radiological images. The CVA data are presented in 5° increments from 30° to 70°. The percentage of lordotic or non-lordotic subtypes within each increment is also displayed.

## 7. Discussion

External measures of postural alignment (EMPA) are often used in both research and clinical settings. However, potential difficulties in identifying anatomical landamarks through manual palpation may lead to errors when measuring EMPA using photogrammetry compared to radiography (Cohen et al., 2017; do Rosario, 2014; Robinson et al., 2009). Furthermore, it is unlcear whether the CVA, a commonly reported EMPA within musculoskeletal literature for professions such as physiotherapy and chiropractic (Silva et al., 2009; Singla and Veqar, 2017), reflects the shape of the underlying cervical spine or is limited to being a simple measure indicating the presence or absence of forward head posture (Ruivo et al., 2014). Therefore, the purpose of this study was to (1) compare and contrast three EMPA using photogrammetric and radiological approaches, and (2) discuss whether the CVA measure taken form radiographic images reflects the shape of the underlying cervical spine using a recently developed multi-method sagittal cervical subtyping classification protocol. The results provide information that may help practitioners determine the most appropriate measurement tool to support their decision-making processes.

An important finding from this research was that the CVA was the only EMPA that was significantly different when comparing photogrammetric (S3) and radiological (S2) approaches. It is important to note, however, that the mean difference in the CVA between the two measurement approaches was 1.4° and the confidence interval of the difference was 0.2°–2.6° (Table 2). Even though the minimal detectable change (0.4°) is smaller than the mean difference it is within the

boundary of the confidence interval of the difference. Based on these data and the clinical experience of the lead author, we do not believe that the mean difference in the CVA is of sufficient magnitude to considerably alter decision making processes. Therefore, there appears to be little evidence to justify referring patients for radiological assessment to determine EMPA such as the CVA given the financial cost, time, and exposure to radiation. Furthermore, it is important to note that some of the mean difference in the CVA between the two measurement approaches may be explained by minor differences in the testing protocols (e.g. in S2 foot tracings were not used and the trunk was stabilised). In general, this finding supports previous research on young healthy people by van Niekerk et al. (2008) who reported moderate to good correlations between photogrammetric and radiological approaches when measuring sagittal plane EMPA while participants were seated.

Whilst this finding, in association with the excellent intra-rater reliability reported earlier, supports the use of photogrammetry for the quantification of these key EMPA, the second part of this project has shown that clinicians need to be cognisant that the CVA, an important EMPA, does not provide an indication of the shape of the underlying cervical spine. Our results indicate that 25 (37.3%) participants with a CVA < 50° (forward head posture) actually displayed a normal lordotic cervical alignment. Furthermore, of the 83 participants with a CVA > 50° ('ideal' head on trunk alignment), 57 (67.5%) displayed a non-lordotic cervical alignment as represented by the other subtypes. In particular, there were a large number of St-types (19) and GK-types (18) in the 50°–59.9° range. Interestingly, the only CVA range in which there were more examples of a lordotic subtype than a non-lordotic subtype was the 40°–44.9° range.

As can be seen in Table 3 different cervical subtypes existed within every CVA 5° range. The distinct radiological differences in the inter-segmental orientation of each vertebral motion segment in conjunction with the differences in the overall global cervical alignment negates the possibility of relating any CVA to a particular underlying cervical subtype. Our findings build on previous research which has reported that the CVA does not provide an indication of the underlying alignment of the upper cervical spine (Johnson, 1998) and supports concerns on this issue raised by key researchers in this domain (do Rosario, 2014; Oliveira and Silva, 2016). Recent evidence indicates that the number of people displaying non-lordotic subtypes is increasing in the young adult population (Daffin et al., 2017; Le Huec et al., 2015) and this may well have implications for the pathogenesis and rate of progression associated with cervical degenerative conditions (Ames et al., 2013; Iyer et al., 2016; Nouri et al., 2015). Nevertheless, clinicians need to be mindful of the inherent risks associated with frequent use of radiographs to assess postural alignment and should only proceed with this approach when justified by the clinical presentation.

There were no significant differences in any EMPA between the two photogrammetric sessions (S1 and S3). The key difference in the methodologies between these sessions was that in S1 the self-balancing procedure was used whereas in S3 the participants were instructed to look forward as if they were looking at the horizon. The use of the self-balancing procedure is considered to be an important preparatory component when establishing a natural head posture prior to image acquisition (Cassi et al., 2016) and has been incorporated into the methodologies of numerous previous studies (e.g. Cuccia and Carola, 2009; Gadotti and Magee, 2013; Silva et al., 2011; Yip et al., 2008). The findings of the current study, however, would seem to indicate that the use of the self-balancing procedure did not affect the EMPA, suggesting that the central nervous system may determine a natural head balance regardless of any preceding movements. Therefore, the use of the self-balancing procedure as part of a strict standardised protocol is questionable.

A key strength of the current research lies in the strict adherence to the standardised testing protocols. Although inter-rater reliability was not assessed, intra-rater reliability data have been provided to support the value of this process. There were, however, some minor differences between the methodologies of S2 (radiology) and S3 (photogrammetry) that may have affected the results. For example, in S3 foot tracings were used, the trunk was not stabilised by equipment thereby allowing postural sway, and the mean of three images per view were reported, thus taking into account small amounts of postural sway. In S2 no foot tracings were used, the trunk was stabilised against the bucky thereby eliminating postural sway, and only one image per view was produced and analysed. While there are some clear advantages for the use of radiography for the assessment of the shape of the underlying cervical spine, some common postural conditions can be adequately quantified using photogrammetry. Clinically, postural interventions and rehabilitative procedures typically require the collection of repeated measurements in order to evaluate true progression. However, clinicians need to be mindful of the limitations inherent in photogrammetry and the requirement to stringently adhere to standardised protocols during both data acquisition and analysis.

## 8. Conclusions

The findings from this study support the use of photogrammetry for the quantification of the three key EMPA – CVA, UCGA and LHTA – providing that standardised protocols are followed. However, clinicians need to be cognisant that the CVA does not provide an indication of the shape of the underlying cervical spine. Substantial cervical subtype variability is present throughout the full CVA range. An increasing number of non-lordotic cervical subtypes are being observed in young populations and while nonlordotic subtypes have been linked with numerous degenerative conditions, the use of radiographs to assess postural alignment should only occur when justified by the clinical presentation. At this stage conclusively validating a single sagittal external measure of postural alignment that reflects the distinct radiological differences in the inter-segmental orientation of each vertebral motion segment in conjunction with the differences in the overall global cervical alignment, both within and between participants, remains elusive.

## Acknowledgements

The Authors would like to thank.

- Dr David Shahar D.C for his radiographic services.
- Participant consent was obtained for the use of the all images.

## Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.msksp.2019.05.003.

## Conflicts of interest

There were no conflicts of interest associated with this manuscript.

## Ethical approval

The Acting Chairperson of the Human Research Ethics Committee of the University of the Sunshine Coast granted Expedited ethics approval for this research project: HREC: (S/14/607).

## Funding

No funding was provided for this research project.

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