Title: **Joint position error after neck protraction-retraction movements in healthy office workers: a cross-sectional study.**

Author's names and affiliations

Helen Pürckhauer[1,2,3], Fabian M. Rast[1], Corinne Nicoletti[2, 4], Markus J. Ernst[1]

[1] Zurich University of Applied Sciences, Institute of Physiotherapy, Winterthur, Switzerland

[2]ETH Zurich, Department of Health Sciences and Technology, Institute of Robotics and Intelligent Systems, Sensory-Motor Systems Lab, Zurich, Switzerland

[3]Schulthess Klinik, Department of Physiotherapy, Zürich, Switzerland

[4] Zurich University of Applied Sciences, Institute of Health Sciences, Winterthur, Switzerland

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Corresponding address:

Markus J. Ernst

Institut for Physiotherapy

Zurich University of Applied Sciences

P.O.Box, Technikumstrasse 71, 8401 Winterthur / Switzerland

Tel.: +41 58 934 6448, Email: markus.ernst@zhaw.ch

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Abstract

Since the upper cervical spine (UCS) has been regarded to be distinct from the lower cervical spine (LCS), joint position error (JPE) needs to be tested separately for both regions. The purpose of this study was to investigate the JPE after cervical protraction/retraction movements, involving opposite movements of extension and flexion for the UCS and LCS. These movements are frequently performed during office work.

Cervical JPEs were tracked in thirty healthy office workers while performing four tests of cervical pro-retraction movements with variations in vision and movement direction, and assessed using the Kinect head tracker (Microsoft Corp), placed in front of each participant. The JPE was expressed in constant (CE), absolute (AE) and variable errors (VE). Multilevel linear models evaluated main and interaction effects of vision, movement direction, cervical region and sex.

Slightly larger JPEs have been found in the UCS. Vision showed no effect on any outcome variable. No effect exceeded typical measurement errors reported for the Kinect head tracker.

This study showed, that JPEs after pro-retraction movements of the head and neck may differ for UCS and LCS. The differences were small and not beyond measurement error reported for the Kinect.

Keywords

proprioception, kinect, measurement technology, office work

Introduction

The sensorimotor system of the neck is mainly affected by proprioceptive inputs of the cervical spine, visual and vestibular information. Afferent information converge in the central nervous system (Treleaven, 2008). Previous studies suggest that the upper cervical spine (UCS) (C0-C2) provides abundant proprioceptive information. Compared to anatomical structures and physiological processes in the lower cervical spine (LCS), far greater amounts of muscle spindles predominate in UCS segments (Kristjansson & Treleaven, 2009). Considering the characteristics of the UCS, recent studies have investigated the contribution of the UCS in the presence of neck pain and headaches in various patient groups. Ernst et al. (2015) showed a strong positive relation between restricted UCS range of motion with frequency and intensity of headaches in working-age patients (Ernst et al., 2015). Compared to patients with LCS pain, significantly greater sensorimotor impairments were demonstrated in patients with UCS pain (Treleaven, Clamaron-Cheers, & Jull, 2011). However, no study has measured UCS and LCS proprioception separatley.

A common assessment to evaluate proprioception in the cervical spine is the joint position sense test (JPT) where usually blindfolded participants reproduce a neutral head position after an active neck movement. The magnitude of the cervical joint position error (JPE) represents the ability to relocate the head precisely back to the starting position. Joint position errors are mostly expressed in absolute (AE), constant (CE) and/or variable errors (VE) (B. Armstrong, McNair, & Taylor, 2008). Previous systematic reviews comparing neck pain patients to healthy people show considerable overlap in JPE between groups (de Vries et al., 2015; de Zoete, Osmotherly, Rivett, Farrell, & Snodgrass, 2017), with pooled values between 1.7 to 5.1° reported for healthy participants, and 2.2 to 9.8° for neck pain patients in the meta-analysis by (de Zoete et al., 2017). To date, studies have only compared JPEs of the whole cervical spine and during uniplanar and angular range of motion (de Vries et al., 2015). As the muscle spindle density in the UCS is extremely high, it is of interest if this will be represented in a smaller JPE compared to the LCS in healthy subjects.

Clinical differentiation into UCS and LCS tends to be difficult as ongoing movements occur during classical uniplanar angular movement tests. In contrast, protraction (PRO), retraction (RE) is a combined movement of upper cervical extension with lower cervical flexion and vice versa. As a consequence two opposite movement directions would occur during one measurement (Ordway, Seymour, Donelson, Hojnowski, & Edwards, 1999). However assessement even in research settings has been found difficult, as the attachment of sensors or skin markers to the spine below C2 to measure a JPE tended to be impractical (B. S. Armstrong, McNair, & Williams, 2005). Therefore this study seeks to measure UCS and LCS JPE by using a Kinect sensor with a corresponding algorithm The advantage of the Kinect Sensor is seen in its contact free use, simple implementation, high performance and its low cost. Early cervical JPE studies tested repositioning after flexion/extension, rotation or lateral bending using a laser pointer, while possible deviations in PRO/RE might have remained unnoticed (Chen & Treleaven, 2013; Clark, Roijezon, & Treleaven, 2015; Revel, Andre-Deshays, & Minguet, 1991). In contrast, the Kinect Sensor enables to record three-dimensional PRO/RE positions, and thus the distinction between UCS and LCS movements.

Components such as movement direction and vision suppression are known to influence the accuracy of head repositioning. Therefore these factors need to be taken into account when testing for proprioception in both cervical regions (Feipel, Salvia, Klein, & Rooze, 2006).

In office workers cervical complaints are especially common, with an estimated 1-year neck pain prevalence of 45% (Cagnie, Danneels, Van Tiggelen, De Loose, & Cambier, 2007). In this target group a forward head posture, with a protracted head, was investigated more frequently (Kang et al., 2012; Mohammad, Hamza, & ElSais, 2015). A prolonged forward head posture may cause adaptations towards the lengths of anterior and posterior neck muscles especially in the UCS. Participants with forward head postures have been found with an increased proprioceptive deficit (M. Y. Lee, Lee, & Yong, 2014). If this had primarily been attributed to dysfunctions in the UCS is currently unknown (M. Y. Lee et al., 2014). The current study focuses on office workers as this group is regarded more vulnerable to sustained protracted postures and subsequently to proprioceptive deficits after repositioning from these positions.

The purpose of the present study was therefore to examine JPEs after protraction and retraction movements in asymptomatic office workers and evaluate effects of vision (open and closed eyes conditions), movement direction (repositioning from PRO vs. from RE), cervical region (UCS vs. LCS), sex and age. We hypothesise that no significant effect of region, movement direction, sex and age occur, while closed eyes condition should lead to larger JPEs.

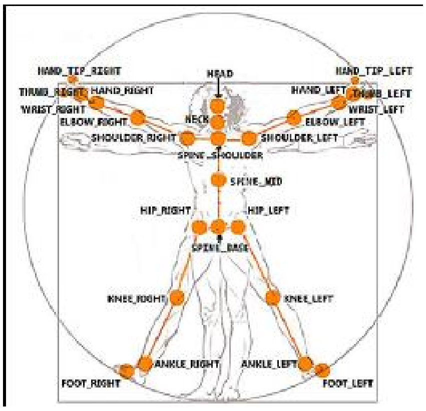
Methods

A cross-sectional study was performed to measure cervical JPE in asymptomatic office workers at the Department of Health Sciences and Technology at ETH Zurich. Before participating, all participants provided written informed consent. The study was approved by the local ethics committee.

<u>Participants:</u> Data collection was performed at the Sensory-Motor Systems Lab at ETH Zurich between April 2016 and September 2016. An asymptomatic group of office workers between 18 and 65 years of age, with no shoulder, head, or neck pain, were recruited from the university, the regional employment agency and from different small and middle sized companies. Participants were included if they were asymptomatic office workers using

a computer or laptop several hours daily. Participants who experienced neck pain on more than thirty days within the last twelve months, had shoulder or neck pain the evening before or at the day of measurement, as well as participants who have experienced shoulder or neck pain caused by an accident were excluded from the study. Furthermore, participants were excluded if they had a BMI >30, sleeping disorders, used medication (e.g. psychotropic drugs, muscle relaxants or analgesics) within the last three days prior to measurements or if they were pregnant. During the measurement participants were asked to tie their hair, remove glasses, jewellery and reflectors, if needed, to provide optimal visibility of their face.

Data collection system: A Microsoft Kinect Sensor 2.0 (Microsoft Corp., Bellevue, Washington, USA) was used to assess JPEs in real time. The device consists of a skeletal and face tracking system with a v2 depth sensor. The face tracking was used to record 3D orientation of the head. The face tracking device of the second generation has been shown "robust enough to deal with facial hair or asymmetries" (Schätz, Procházka, Ťupa, Vyšata, & Sedlák, 2016) by using an improved face tracking algorithm (Smolyanskiy, Huitema, Liang, & Anderson, 2014). According to the Kinect terminology, the head pivot point is the computed centre of the head. The Kinect face tracking algorithm calculates total head flexion/extension movements expressed as head angle (HA) around this pivot point. In addition, the head point (nose level) and spine-shoulder point (sternoclavicular joint level) of the skeletal tracking algorithm were recorded to detect translational head movements in relation to the trunk, which are expressed in meter unit (Figure 1) (Oh, Kim, Kim, Hwang, & Lee, 2014). A costum-made software was used to record these outputs of the Kinect skeletal and face tracking algorithms with a sampling frequency of 30 Hz. When tested for reliability and validity, the Kinect Sensor and corresponding algorithms showed good agreement with the CROM™ device (ICC > 0.97, mean angular differences for head up and down: 0.25 - 2.50°) (Oh et al., 2014), good to excellent absolute agreement with an optoelectronic Vicon system (r= 0.99) (Otte et al., 2016), moderate to excellent agreement with electrogoniometry (0.26 and 0.30° mean differences for neck flexion and extension, with SD of 1.2 and 0.80°) (Allahyari, Sahraneshin Samani, & Khalkhali, 2016) and a favourable to excellent test-retest reliability (ICC 0.76 and 0.80 for neck extension and flexion) (Allahyari et al., 2016; Oh et al., 2014). Furthermore one study evaluated the validity of the Kinect towards an inertial measurement unit (IMU) while measuring JPE in the sagittal plane (Elias, Melim, Frizera, Bastos, & Souza, 2012). The authors reported mean differences up to 0.5° degrees between the two measurement devices and for AEs and CEs (Elias et al., 2012). An excellent accuracy of movement signals from Kinect landmarks (skeletal tracking algorithm) against Vicon marker locations of the head and neck (1-2cm) during different task types has been reported recently (Otte et al., 2016). The Kinect Sensor was placed on a tripod at the level of the participant's nose and the distance between the participant's forehead and the sensor was adjusted to one meter, which has been reported as the optimal distance (Oh et al., 2014).



Caption Figure 1

Illustration of locations for the skeletal tracking algorithm within the Kinect

<u>Measurement of UCS and LCS angles</u>: Further data processing was limited to the sagittal plane. Total cervical spine movement was partioned into a rotational and translational component. It was presumed that the LCS contributes to both components, whereas the UCS

contributes only to rotation. This is reasonable as the majority of UCS rotation in the sagittal plane occurs at the junction between occiput and atlas (O-C1) and between atlas and axis (C1-2) (Ordway et al., 1999), which correspond to the measured head point of the Kinect (Figure 1). For the LCS movement an angle between a vertical line through the spine-shoulder point and a line between the spine-shoulder and head point of the Kinect (Figure 1) was calculated which corresponds to the craniovertebral angle (CVA) in Figure 2 (Lau et al., 2010; M. Y. Lee et al., 2014).

The HA was extracted from the face tracking algorithm as rotation of the head in the sagittal plane (Figure 2). The LCS spine angle was extracted and calculated from the difference in the skeletal tracking between the trunk (spine-shoulder point of the Kinect) and the head (head point of the Kinect). Since the HA is assumed to be the sum of LCS and UCS movements, the UCS angle was calculated by subtracting the LCS angle from the HA (Figure 2).

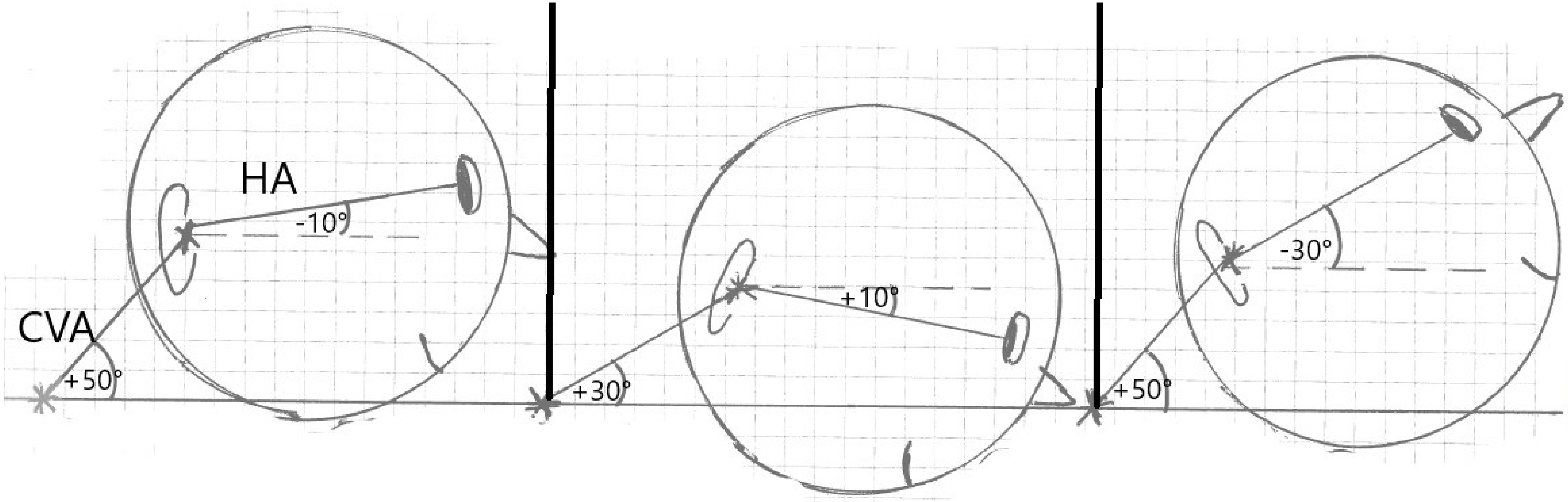


Figure 2a		Figure 2b		Figure 2c	
Normal position	**Kinect: (Off-set)**	**JPE (only LCS)**	**Kinect-measurement**	**JPE (only UCS)**	**Kinect-measurement**
CVA: 50° HA: -10°	CVA: 0° HA: 0° **Calculation UCS (HA-CVA)** **0°-0°= 0°**	CVA: 30° HA: +10°	CVA:+20° HA: +20° **Calculation UCS JPE (HA-CVA)** **+20°-20°= 0°**	CVA: +50° HA: -30°	CVA: +0° HA: -20° **Calculation UCS JPE (HA-CVA)** **-20°-0°= -20°**

Caption Figure 2

CVA= Cranio-cervical angle, HA= head angle, JPE= joint position error, LCS= lower cervical spine, UCS= upper cervical spine

Assessment of cervical joint position error: Participants performed four randomized test conditions regarding vision and movement direction. These conditions included neck movements in PRO followed immediately by RE (=PRO/RE) or RE followed immediately by PRO (=RE/PRO), both with open and closed eyes. During the familiarization phase participants were enabled to practice required head movements, while the examiner provided feedback and corrections. To standardize the starting position, participants sat upright on a chair with arms by their side, the head in line with the shoulders and the forehead kept perpendicular. Once the participants achieved their reference position and signalled it verbally, the recordings were started. According to the procedure by Revel et al. (1991), participants stayed for three seconds in the reference position, performed a maximal PRO/RE or RE/PRO movement with open or closed eyes and tried to relocate the starting position as accurately as possible (Revel et al., 1991). Each of the four different test conditions was repeated three times in a self-selected speed. After each test condition, participants have been asked for their current neck pain intensity using a visual analogue scale. JPE was calculated for both, the LCS and UCS angle by subtracting the angle of the starting position from the angle of the end position. In previous studies, the variables CE, AE and VE were used to express the JPE in more detail. The CE provides information about the average magnitude and direction (under- or overshooting) of errors, and can contain positive or negative values. As PRO and RE are performed by opposite movements for the UCS and LCS, positive values indicate a position in more flexion of either the UCS or LCS, negative values a position of extension respectively. The AE does not include the direction of the error but represents the general accuracy of repositioning. The VE is a measure of the variance around the CE and reflects the variability in the data (Schmidt & Lee, 1999).

Data processing and analysis: Characteristics of participants including maximal range of motion of the UCS and LCS during PRO/RE and RE/PRO movements were calculated. Mean JPEs for each participant and test condition were expressed in the dependent variables. For each JPE variable, a multilevel linear model has been calculated, taking into consideration the dependency (repeated measures) in the data. Additionally sex and age have been added to the models. All within-subject factors, vision (open and closed eyes), movement direction (PRO/RE and RE/PRO) and cervical region (UCS and LCS) and between-subject factors (age and sex) have been tested for main-, and interaction effects on the outcome variables.

Data were analysed by the software R with ggplot2 for R. The level of significance was set to $p<0.05$ (Wickham, 2009).

Results

Thirty healthy office workers (15 male and 15 females) participated in the study. Two participants had missing values. One due to difficulties performing the PRO/RE and RE/PRO movements, another one due to technical issues. The final dataset consisted of 28 participants aged between 21 and 50 (mean 29.4; SD 8.1) years. Both sexes were of comparable age (p= 0.51), with women 30.1 years in mean (SD 9.1) and men 28.6 years (SD 6.7). Participants characteristics and clinical features are presented in Table 1.

Table 1 Participant characteristics and clinical features

	Participants (N=28)	**Mean**	**SD (±)**	**Min./Max.**
Sex (female/male)	14/14			
Age (years)		29.4	8.1	21/50
Cervical ROM during pro-retraction movements				
LCS angle (°)		28.1	7.4	
UCS angle (°)		26.0	9.9	
Neck pain VAS *		0.5	0.8	0.0/2.8

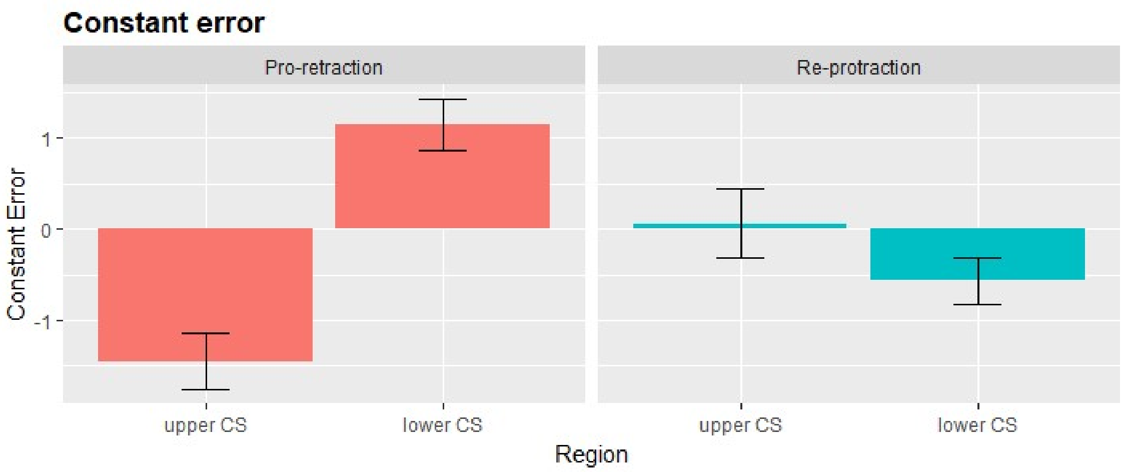
*average pain ratings during four test conditions;
N = number of participants; SD = standard deviation; ROM = range of motion; LCS = lower cervical spine; UCS = upper cervical spine; VAS = 100 mm visual analogue scale of pain.

For all JPE outcome models, including vision, movement direction, age and sex the UCS showed larger errors compared to the LCS, with differnces between cervical regions of 0.37° for CE (p= 0.08), 0.45° for AE (p= 0.06) and 0.48° for VE (p= 0.03). AE values for the UCS were 2.75° (SD 1.86); -0.70° (SD 2.68) for CEs and 2.14° (SD 1.45) for VEs. Values for the LCS were for AEs 2.30°; (SD 1.31), for CE 0.29°; (SD 2.18) and for VE 1.75°; (SD 1.03).

There was consistently more overshooting (CE) after PRO/RE movement compared to RE/PRO in both UCS (into Extension) and LCS (into Flexion), which was not significant after correction for leading signs (negative values reflect extension movement, positive values reflect flexion movement) (Figure 3). There was no significant main effect for vision, sex or age, nor any other interaction effect on any JPE outcome variable.

Discussion

The purpose of the study was to evaluate the effect of cervical region, vision and movement direction on cervical JPE in healthy office workers after PRO/RE and RE/PRO movements in the sagittal plane, and to test for any effects of sex or age. We mainly found small differences of less than 0.5° degrees in relocation accuracy between UCS and LCS region, which would not be regarded clinically meaningful. Furthermore, results should be interpreted with caution as effects are close to measurement errors reported for the Kinect V2 (Allahyari et al., 2016; Oh et al., 2014). With respect to the validity of our model, we however suppose that a consistent and opposing overshooting for UCS and LCS as depicted in Figure 3 after PRO/RE would not have been expected by measurement error alone. Overshooting after PRO/RE means UCS extension and LCS flexion, while after RE/PRO the opposite movements is regarded overshooted. For statistical comparisons CE values of every subject were transformed to positive ones and compared subsequently. Otherwise differences between regions after PRO/RE and RE/PRO as depicted in Figure 3 would have been inflated.



Caption Figure 3

Plots show bar charts and standard errors separately for the Constant error and for Pro-retraction (left in red) and Re-protraction (right in turquois). Negative values reflect extension movement, positive values reflect flexion movement.

Overshooting in the UCS after PRO/RE might be attributed to the additional stretch on the suboccipital muscles after RE, leading to an increased forward movement into PRO via the gamma loop (Holm, Indahl, & Solomonow, 2002; McCloskey, 1978). No studies so far exist which examined the effect of PRO/RE or RE/PRO movements on JPE and especially separated for UCS and LCS. As the sample consisted of asymptomatic office workers the small differences of less than 0.5° between UCS and LCS values, are regarded as within normal variation.

Standard error of the measurements (SEMs) of approxiamtely 2° have been found in reliability studies of angular JPE tests (Alahmari et al., 2017; Strimpakos, Sakellari, Gioftsos, Kapreli, & Oldham, 2006; Wibault, Vaillant, Vuillerme, Dedering, & Peolsson, 2013). Values below that threshold might be regarded as normal variability between studies, subjects or testers. However, as no reliability study on pro-retraction movments has been conducted we cannot be sure whether that SEM applies for these JPE tests too.

Since the UCS provides a considerably higher amount of muscle spindles and reveals stronger connections to the central nervous system compared to LCS segments, we expected smaller JPEs in the UCS region (Kulkarni, Chandy, & Babu, 2001; Richmond, Singh, & Corneil, 1999). However, Wang et al. investigated the reposition accuracy of each cervical joint after cervical flexion/extension in healthy participants. Significantly larger JPEs were identified in UCS segments compared to LCS segments (Wang, Lindstroem, Carstens, & Graven-Nielsen, 2017). Their JPE values for UCS and LCS segments were comparable to ours, (Wang et al., 2017). Furthermore our AE values (2.75° for the UCS, and 2.3° for the LCS) are within that range reported by the meta-analysis of de Zoete et (1.66 to 5.1° for asymptomatics) for angular movements (de Zoete et al., 2017). In contrast, Treleaven et al. reported larger JPEs of the whole cervical spine following head rotations in patients with UCS pain conditions compared to LCS pain conditions which had been associated to the importance of the UCS in proprioception (Treleaven et al., 2011). Both studies suggest, that the cervical spine should not be considered as a single unit of motion when investigating proprioception of the neck, but as a complex region with varying sensorimotor functions in UCS and LCS segments. No study so far examined the proprioceptive accuracy for the UCS and LCS separately, which might explain the often non-significant and/or non-meaningful differences found in so many studies (de Zoete et al., 2017).

The lack of impact of vision on JPE might be surprisingly at first sight. Former studies which examined the JPE after axial rotational movement like rotation or flexion/extension typically blindfolded their participants to prevent them from relying on visual cues while relocating their head (Artz, Adams, & Dolan, 2015; Chen & Treleaven, 2013; Revel et al., 1991). However, a visual anchor for returning to neutral head position after translational movement is much more challenging to find and requires a distinct ability of occular accomodation to distinguish between milli-to centimetres distances. Additionally, participants sat infront of a camera and a plain wall, which limited visual feedback. As the cervical JPT does not measure solely the proprioceptive function of the cervical spine but might contains vestibular information, it is a test widely used to evaluate the sensorimotor functioning of the cervical and head region (Artz et al., 2015; M. Y. Lee et al., 2014; Revel et al., 1991; Treleaven et al., 2011).

No main effect of age or sex on JPE were found either. Most of former cervical JPE studies, predominantly case control studies, either did not match for age or sex or could not find any effect on cervical JPE too. (Artz et al., 2015; Demaille-Wlodyka et al., 2007; H. Lee, Wang, Yao, & Wang, 2008).

Pain during the tests need to be considered as it might have an impact on the JPE data in this study. Since previous studies found an effect of neck pain on reposition accuracy (de Vries et al., 2015; Revel et al., 1991), neck pain was assessed by a VAS after each test condition. According to the classification of Jensen et al., measured pain values ranged from “no pain” to “mild pain” (<4.4cm) and never persisted after the test (Jensen, Chen, & Brugger, 2003).

Impaired cervical range of motion showed a negative correlation with cervical JPE in an earlier investigation (H. Lee, Nicholson, Adams, & Bae, 2005). However, the average cervical mobility found in this study is comparable to the PRO/RE range of motion in healthy participants reported by Braun et al. (mean 33.62°) and Park et al. (mean 24.20°) (Braun & Amundson, 1989; Park, 2015).

Habitual seated positions typically decrease cervical range of motion and increase forward head posture, which again is associated with larger JPE (Dunleavy & Goldberg, 2013; M. Y. Lee et al., 2014). Recent findings found also close associations between a “forward head posture”, a typical protracted head position, that is frequently seen in office workers and impaired proprioception (M. Y. Lee et al., 2014). Accordingly the current study enabled participants a comfortable but still erect seated posture.

In JPE studies concomittant positional changes in two-dimensional measurements were reported, either as single values for each movement plane or as “global error”, often the resultant of x- and y-error values (Heikkila & Wenngren, 1998; Rix & Bagust, 2001; Sajjadi, Olyaei, Talebian, Hadian, & Jalaie, 2014; Vuillerme, Pinsault, & Bouvier, 2008). Joint position errrors occuring in the secondary plane were approximately half of those reported for the primary plane (Heikkila & Wenngren, 1998; Rix & Bagust, 2001; Sajjadi et al., 2014; Vuillerme et al., 2008). Most studies did not account for the third dimension, as measurement technology were technically not mature in the early years of JPE assessments (Heikkila & Wenngren, 1998; Vuillerme et al., 2008).

For our cervical spine model, we assumed that the LCS contributes to rotation and translation of the head, whereas the UCS contributes only to rotation. This assumption might be a simplification of cervical spine movements. However, this affected the starting and end position equally and we, therefore, expect only a minimum influence on the calculation of the JPE.

In accordance to similar studies and due to a tight timeframe in measurement procedure, all participants repeated each movement condition only three times (Artz et al., 2015; Treleaven et al., 2011). As previously investigated by several authors, a number of three repetitions might be regarded not sufficient, and five to eight trials are recommended (de Vries et al., 2015; Pinsault et al., 2008; Swait, Rushton, Miall, & Newell, 2007). As the focus of the current study was not test-retest reliability, we can only speculate if future investigations on cervical JPE using PRO/RE movements should consider a higher amount of repetitions to increase test-retest reliability.

One limitation of our study is the small sample size. Studies which demonstrate reference or normal values are usually larger by either matching sexes for age or by sampling many more subjects of different age groups.

A further limitation of the study might be the unreported measurement validity of the Kinect head tracker for PRO/RE movements. Examining JPEs of both UCS and LCS have only been possible by using both the head and face tracking devices of the Kinect, with the latter to especially measure the UCS JPE. As the face tracking device needs to ongoingly capture the face of the participant, no rotational movements could have been performed and tracked. The Kinect head tracker showed satisfactory agreement with other common assessment tools in uniplanar neck movements like the CROM™, an optoelectronic Vicon system and with electrogoniometry (Allahyari et al., 2016; Oh et al., 2014; Otte et al., 2016). The calculated Kinect tracking points for measuring the LCS and UCS do not exactly correspond with anatomical landmarks of the frequently used CVA and HA (see Figure 2).

Therefore an accurate anatomical classification in UCS and LCS segments was limited, as were comparisons to postural and range of motion values frequently reported for the CVA and the cervical spine respectively (Amiri, Jull, & Bullock-Saxton, 2003; Braun & Amundson, 1989; Ordway et al., 1999; Park, 2015).

Furthermore, in the literature the CVA is usually calculated by a horizontal line through the spinal process of C7 and a line drawn from C7 to the tragus of the ear and provides an estimation of the angle of the LCS in the sagittal plane and as depicted in Figure 2 (Watson & Trott, 1993). The HA is assessed by measuring an angle formed of a horizontal line through the tragus of the ear and a line joining the tragus of the ear and the corner of the eye (see also Figure 2) (Hande, Shinde, Khatri, & Dangat, 2012). Considering the modified angle calculations, comparisons of UCS and LCS range of motion as outlined in Table 1 with those reported in the literature are limited.

Next, although all participants were asymptomatic at the time of measurement, they might not be regarded as healthy participants who have never suffered from any neck pain before. However, only participants with neck pain of not more than thirty days within the last twelve months have been included and participants with a history of traumatic neck pain were excluded.

Finally, the aforementioned study by Wang et al. used video fluroscopy, which allowed them to visualize JPEs of single cervical segments (Wang et al., 2017). However, the exposure to radiation makes their procedure impractical for clinical use. Armstrong et al. in contrast, attached external sensors to the skin onthe forehead, C3 and T1 to assess JPE differences in the UCS and LCS and during rotational movements in healthy participants and whiplash patients mentioned primarily constrained extension movements in participants with shorter necks as the “receptors would abut” due to their set up (B. S. Armstrong et al., 2005).

The Kinect head tracker in contrast is practical and can overcome some of the short-comings of the aforementioned studies.

Acknowledgments

The study was approved in October 2015 by the Ethic Committee of ETH Zurich (EK 2015-N-23).

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