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The effect of posture on neck proprioception and head/neck stabilization in asymptomatic participants

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Objective: *We sought to determine the effect of different body postures on neck proprioception and head/neck stabilization.*

Methods: *Twelve healthy college students completed a head repositioning task and a 'head still' task while wearing a headpiece (helmet) with laser fixed on top during standing, kneeling, sitting, and sitting with stabilization. Video data of the laser dot coordinates on a projection screen were obtained to examine the accuracy of the two tasks.*

Results: *There was a significant effect of both posture and vision for both vertical and horizontal head movements during the head still task. Standing and kneeling generated more variable head movement than sitting with or without stabilization. Posture did not significantly affect head repositioning accuracy.*

Conclusion: *For healthy young adults, clinicians*

Objectif : *Nous avons cherché à déterminer l'effet de différentes postures corporelles sur la proprioception du cou et la stabilisation tête/cou.*

Méthodes : *Douze étudiants en bonne santé de niveau collégial ont accompli une tâche de repositionnement de la tête et une tâche d'immobilisation de la tête tout en portant un casque avec un laser fixé sur le dessus pendant qu'ils étaient debout, à genoux, assis et assis en état stable. Des données vidéo des coordonnées des points laser sur un écran de projection ont été obtenues pour examiner la précision des deux tâches.*

Résultats : *On a observé un effet significatif de la posture et de la vision pour les mouvements verticaux et horizontaux de la tête pendant l'immobilisation de la tête. Le fait de se tenir debout et de s'agenouiller a généré un mouvement de la tête plus variable que le fait de s'asseoir en étant ou non stable. La posture n'a pas eu d'effet significatif sur la précision du repositionnement de la tête.*

Conclusion : *Pour les jeunes adultes en santé, les*

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and researchers need to be concerned with postural influences on tasks that involve head/cervical spine stabilization, but not head repositioning accuracy.

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KEY WORDS: posture, cervical spine proprioception, head repositioning, motor control, postural balance

cliniciens et les chercheurs doivent se préoccuper des influences posturales pour les tâches qui font appel à une stabilisation de la tête et de la colonne cervicale, mais non de la précision du repositionnement de la tête.

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MOTS CLÉS : posture, proprioception de la colonne cervicale, repositionnement de la tête, contrôle moteur, équilibre postural.

Introduction

Proprioception encompasses the sensation of joint movement (kinesthesia) and joint position (joint position sense).[1-5] Perception of the orientation of our head in space as well as on the trunk demands not only the contribution of vestibular and visual cues but also proprioceptive information from the neck[1] and likely from other body regions.[6, 7] A few reflexes contribute to orientation of the head and trunk including the cervico-ocular (COR), vestibulo-ocular (VOR), vestibulospinal (VSR), vestibulo-collic (VCR) and cervicocollic (CCR).[2, 8] The COR stabilizes the eye in response to trunk-to-head movements, the VOR stabilizes gaze during head motion, the VSR produces compensatory body movements to stabilize the body in space, the VCR stabilizes the head relative to space and the CCR stabilizes the head relative to the trunk.[2, 8] The receptors that are responsible for proprioception are found in muscle-tendon units (e.g., muscle spindles, golgi tendon organs), joints (e.g., Ruffini endings, Pacinian endings) and skin (e.g., hair follicles, Ruffini endings).[9] Proprioception is essential for proper joint function in sports and activities of daily living or work-related tasks.[1, 2, 10]

Tests of proprioception have differentiated between the 2 main proprioceptive functions—detection of static position and detection of motion.[4] Detection of motion can be assessed by the threshold of motion detection (e.g., amount/speed of motion required for detection to occur) and the direction of motion (e.g., flexion or extension), which is considered a discrimination task.[4] On the other hand, tests of neck joint position sense to date have focused on two methods involving the accuracy of: a) position-matching tasks involving relocation of the head to a set point or angle or; b) relocation to the natural (neutral) head posture. The reliability of these tests are good to excellent.[11] Accuracy is derived by calculating the difference between the reference target (e.g. natural head posture) and the reproduced position or angle of the head. This accuracy is frequently reported as the absolute value of the constant error computed along the global (hypotenuse), the horizontal (x), and the vertical components (y) of the reproduced position relative to the natural head position. Some factors shown to reduce the accuracy of neck proprioception include fatigue, and pathology such as whiplash and neck pain.[2, 4, 12, 13]

One factor that has not been well studied is the contribution of different body postures to the accuracy of head-neck position sense. A recent study looking at the effect of different induced head-neck-jaw postures on head-neck position sense among healthy subjects did not find any significant difference between postural configurations.[14] Specifically, this study evaluated cervicocephalic kinesthetic sense while standing, habitual sitting, habitual sitting with clenched jaw and habitual sitting with forward head posture during right rotation, left rotation, flexion and extension.[14] Likewise Teng *et al*.[15] considered the most frequently adopted posture during daytime (sitting or standing) as self-reported data in three groups of individuals, a control group of 20 asymptomatic young adults and two groups of middle-aged adults (20 subjects in each group) with or without a history of mild neck pain. While Teng *et al*.[15] collected self-reported differences in daytime posture between these groups, their study was not designed to prospectively test the differences between groups as a function of posture. However, a study investigating the effect of different sitting postures on cervicocephalic kinesthetic sensibility found that sitting with arms supported decreased head-neck repositioning error.[16] In this study[16], cervicocephalic kinesthetic sensibility was measured in healthy young adults while in a habitual slouched sitting position with arms hanging by the side, a habitual slouched sitting position with arms unloaded (supported) and during upright sitting position with arms hanging by the side during maximum and 30 degree right, left rotations, flexion, and extension. The authors hypothesized that the sitting posture with supported arms, provided a direct mechanical relaxation of muscles allowing the proprioception receptors of the neck to perform in an optimal manner.[16]

Proprioceptive information from cervical muscles is known to play a major role in the control of posture and gait in humans.[11] When neuromuscular function at the neck is impaired either by pathology[17], trauma[12], or by experimental manipulations in healthy subjects (such as neck fatigue[18]), balance and movement control have been shown to decrease.[11] Similarly, individuals with non-traumatic neck pain perform with longer movement times then healthy control participants during a rapid head movement aiming task when task conditions are adequately challenging.[19] In addition, the gain values of the COR were significantly increased in a whiplash associated disorders population.[20] Accordingly, accurate assessments of neck function and proprioceptive abilities appear to be of great importance. The need to conduct the current study stems from the fact that there is no consensus concerning the best method of assessing neck proprioception in the literature.[1] A systematic investigation of the contribution of how motion or position at various joints contributes to the sense of head position and/or neck proprioception has not been performed.

The current study sought to determine the role of body postures on two tasks – a head repositioning task as well as a head still task. We are not aware of any previous study that has looked at the effect of body postures on these two tasks. Head repositioning appears to be a common outcome measure in the literature for proprioception.[2, 11] Likewise, the ability to maintain our head still is also important since postural control functions in a manner that facilitates other higher order (suprapostural) tasks[21] such as looking and reading[22] which require stabilization of the head. These studies, while showing that postural sway is modulated in a task specific manner also show that postural adaptation involves more than basic reduction or increase of motion; it involves multi-segmental coordination of body segments to achieve a particular goal.

We hypothesized that both joint position error during the head repositioning task as well as variability of head position during the head still task would be reduced when segments other than the neck can contribute to the perception of the orientation of our head in space. Participants performed these tasks in different postures including standing, kneeling, sitting, and sitting with the trunk stabilized under eyes open and eyes closed conditions. We further hypothesized that the more unconstrained/unsupported body segments that participated in accomplishing these two tasks, the less the head position error or variability would be. Our hypotheses assumed that the central processing of proprioceptive inputs that arise from numerous muscles and joints contribute to both the overall awareness and control of body posture.[6, 7] The representation of body geometry is based on proprioceptive inputs (primarily from muscle) that convey information about the position of a given segment with respect to the others. Accordingly, all movements of our multi-joint body are calibrated within the proprioceptive field of a postural space.[7] This has led to the notion that there exists a form of "proprioceptive chain" which functionally links the eye muscles to the foot muscles.[6] Therefore, our study assessed how the proprioceptive chain affects head and neck position sense.

This study has practical significance in that it will help inform clinicians and researchers as to the magnitude to which different body postures contribute to head repositioning accuracy and head stabilization. Secondly, it will provide evidence as to which posture(s) need to be included during neck proprioception testing. Lastly, it may provide a framework from which to assess the effect (if any) of various conditions (e.g. hip arthritis) on neck proprioception.

Methods

Participants

Twelve participants (4 males, 8 females) ranging in age from 20-31 (22.2 ± 2.9, Mean±SD) years participated in this study. Participants were recruited from undergraduate and graduate classes in the Department of Kinesiology and Health at Miami University. The study protocol, all forms used and the informed consent documents were approved by the Human Subjects Institutional Review Board at Miami University. All participants read and voluntarily signed a written informed consent document and completed a health history questionnaire. Exclusion criteria included a history of neck pain, neurological or vestibular impairment, injury or operation to the cervical spine, injury or illness of ankle(s), knee(s), hip(s), back within the last six months, inability to stand, kneel, or sit, and vision that was not corrected to normal.

Design and procedure

Each participant came to the biomechanics laboratory once for a 60-minute session. Participants wore athletic shorts and a t-shirt during the test to minimize the effect of extra clothing on proprioception. Each participant completed two tasks: head repositioning task and the head still task. These tasks are described in detail below. Participants wore an adjustable bicycle helmet and blindfold (sleeping style mask) during the eyes closed conditions of both the head repositioning task and the head still task.

We used a within-subjects study design to determine the influence of posture on each of the tasks and to control for the potential influence of individual differences. Given the within-subjects design, the sample size was estimated based on similar studies involving clinical and asymptomatic populations.[18, 23-26] Both tasks incorporated four postural conditions (standing, kneeling, sitting, sitting with stabilization). Each task, and each postural condition were counterbalanced. To do so, we created four separate orders of conditions (pseudorandom order) between participants to minimize the potential of order and carryover effects. The order of trials (e.g., eyes open first then eyes closed) within a task condition was the same for every participant.

Head repositioning task

For this task, participants were fitted with an adjustable bicycle helmet with laser pointer fixed on top, while wearing a blindfold. The helmet was placed on the head such that the laser pointer was facing directly forward. The laser was fixed to the top of the helmet. Participants confirmed comfort before participating. A high-speed video camera (capturing at 30 frames per second) with SIMI motion software (Unterschleissheim, Germany) was used to track and determine the coordinates of the

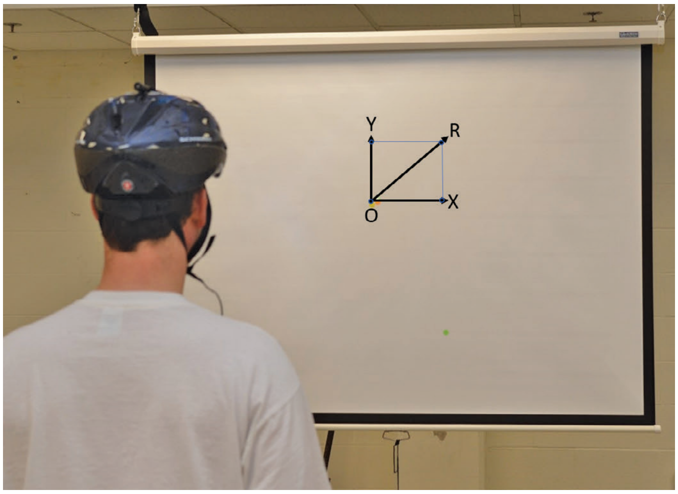

Figure 1.
Experimental setup. Participants wore an adjustable bicycle helmet with a laser pointer on top for both the head repositioning task and the head still task. Head repositioning accuracy (HRA) data involved the measurement of laser dot coordinates. Point O represents the center of the target (coordinates 0,0). Point R represents the position that the laser dot stopped when the head was repositioned after a near-maximal movement. The distance O–R represents the global error of positioning converted into degrees (R) and serves as the outcome of HRA in this study. The horizontal projection (O–X) and the vertical projection (O–Y) indicate the horizontal and vertical components of the global error. Each component was assigned a positive or negative sign according to its position below or above zero on the corresponding axis.

laser pointer that was calibrated to a white large projection screen located 2.6 meters in front of the participant (Figure 1). SIMI camera based motion software has demonstrated very good agreement with a sensor-based gait analysis system[27] and has been used in a variety of motion analysis[28-30] applications.

The head repositioning task described below was performed in each of these postures using a counterbalanced order: standing, kneeling, sitting, sitting with stabilization. The support surface for each posture was the hard floor of the laboratory. Standing involved normal upright standing with feet shoulder width apart and arms by their sides. Kneeling involved shoulder width apart knee posture and an upright trunk. Sitting was on a high back chair with their arms hanging by their sides but their back not touching the backrest. Sitting with stabilization was performed on the same high back chair but their back was touching the backrest. In addition, a Velcro© strap was placed around the subject's trunk and arms (at mid-arm level) and securely fastened to the seatback so as to stabilize the subject and only allow head and neck movements.

Blindfolded subjects with eyes closed, wearing the laser mounted helmet were placed 2.6 meters from the projection screen which was adjustable in height to accommodate all postures. Participants were instructed to: a) memorize their neutral head position, 'put your head into what you think is a straight ahead position' and hold for two seconds; b) perform a near maximal head rotation to the left (or right) for approximately two seconds; and c) to relocate the head to the initial neutral reference head position with maximum precision but without speed instruction and to hold the position for 2 seconds (to allow experimenters to register the position on the screen[31]). Five trials were performed with head repositioning after a right head rotation and five trials after a left rotation under each of the postural conditions. Other authors have found that the greatest test-retest reliability for joint position error testing was obtained with five or more trials.[26] No feedback was given to the subjects regarding their relocation performance. Video capture of the laser defined neutral head and relocated head positions (x, y) on the projection screen was performed. Error distance in centimeters (cm) was derived from the difference between neutral and relocated head positions. This error in centimeters was converted to head repositioning error in degrees (Ø).

Head still task

The same postures and equipment used for the head repositioning task were also used for the head still task. While located 2.6 meters in front of the projection screen, participants were instructed to maintain the laser dot on a colored target circle that was 1.91 cm in diameter for 30 seconds. Two trials were performed in each of the four postures, one trial with eyes open and no mask, the other with eyes closed wearing the mask. No feedback was given to the subjects regarding their performance during eyes open condition. Feedback was given to the subject during eyes closed condition only until the subject achieved placement of the laser dot in the target circle. Once this was achieved, no further feedback was provided. The laser dot positions (x, y) during each trial were determined using video analysis. The variability in position (standard deviation) of the laser dot from the center of the target was determined as the measure of accuracy during this task and represented a proxy for head sway.

Data analysis

For head repositioning accuracy, the laser dot coordinates in x, y dimensions were determined for both the initial starting head neutral position and for the return head position following head rotation right or left. Each x and y dimension of the coordinate pair was given positive or negative values according to its position relative to the calibrated projection screen axes. Using the two coordinate pairs of values, the distance (hypotenuse) between the laser dots of the initial starting position and the relocated position was calculated using the formula of Pythagoras.[25] Negative signs were removed by calculating the root mean square values. We then converted the hypotenuse data into an angle in degrees (Ø) representing repositioning accuracy. To do so, we divided the hypotenuse distance (described above) by the distance of the screen to participant (2.6 m) in order to calculate the arctangent. This provided the angle of the person's head relative to the error position in radians. We then converted radians to degrees. This hypotenuse distance O–R (Figure 1) represents the global error of positioning converted into degrees and serves as the outcome of HRA in this study. The global error of positioning was recorded in centimeters from the target and was converted into degrees by the following formula: Angle θ (degrees) = 57.3 * $\tan^{-1}$ [global error component (cm)/distance to screen (260 cm)], where 57.3 is the conversion factor from radians to degrees. For every subject, the mean angle (degrees) of the five repetitions in each direction of head rotation for each postural condition served as the values that were entered into the statistical analysis. One subject's data was inadvertently not recorded for the knee and seated conditions. To eliminate cells with no data in the analysis, the mean of the other 11 participants' data served as the data point for each of these conditions.

For the head still task, thirty second trials were transformed to 20 second trials by removing the first 5 seconds and the last five seconds of data collection. With a data collection rate of 30 frames per second this yielded 600 data points of analysis per trial. Out of the 96 head movement variability trials (8 trials per person) in this experiment, three trials (each by different participants) were not recorded or incompletely recorded by the video camera. To eliminate cells with no data in the analysis, the mean of the other 11 participants' data served as the data point for each of these three error trials. The standard deviation of the mediolateral (ML) (x) and vertical (y) laser dot positions generated by head movements for each 20 second trial was calculated and formed the basic unit of head sway analysis.[22] The mean standard deviations for ML and vertical laser dot positions were computed for each experimental condition.

Statistical analyses for head repositioning task accuracy were performed using separate one-way, within-subjects ANOVA's after right and left head rotation respectively. For the head still task, the statistical analyses for head movement variability in mediolateral (ML) (x) and vertical (y) axes were conducted with separate 2x4 factor, repeated measures ANOVA's with the two factors being visual condition (eyes closed, eyes open) and posture (kneeling, seated, standing, seated stabilized). Post hoc tests were performed using Bonferroni pairwise comparisons. All analyses were conducted using IBM SPSS Statistics for Windows, Version 21.0. Statistical significance was set at an alpha value of 0.05.

Results

Head repositioning task

Separate one-way, within-subjects ANOVA's were run for repositioning after right and left head rotation respectively. Mauchly's test of sphericity indicated that the assumption of sphericity was met for repositioning with left head rotation, $\chi^2(5) = 3.581$, $p = 0.613$ as well as right head rotation, $\chi^2(5) = 6.135$, $p = 0.295$. With left head rotation, there was no significant effect of posture on head repositioning accuracy, $F(3,33) = 1.024$, $p = 0.395$. Similarly, after right head rotation, there was no significant effect of posture on head repositioning accuracy, $F(3,33) = 1.943$, $p = 0.142$. See Table 1 for descriptive statistics of head repositioning accuracy (error) following left and right head rotation.

Head still task

ML (x) Head Movements

Mauchly's test of sphericity indicated that the assumption of sphericity was met for x-axis variability in terms of the main effect of posture, $\chi^2(5) = 5.818$, $p = 0.326$ as well as the interaction between posture and visual condition, $\chi^2(5) = 2.714$, $p = 0.863$. There was a significant main effect of posture on ML position (x) variability defined as the mean standard deviation, $F(3,33)= 4.63$, $p =0.008$,

Table 1.
Descriptive statistics for head repositioning accuracy in degrees after left and right head rotation.
MHRA = Mean head repositioning accuracy (error) in degrees based upon the global error of positioning, distance O–R (Figure 1).

	Left Head Rotation		Right Head Rotation	
Posture	**MHRA (∅)**	**Standard Deviation**	**MHRA (∅)**	**Standard Deviation**
Knees	2.602	0.752	3.200	1.267
Seated	3.138	1.686	3.100	0.786
Seated Stabilized	2.994	1.205	2.702	0.692
Standing	3.291	1.132	3.312	1.125

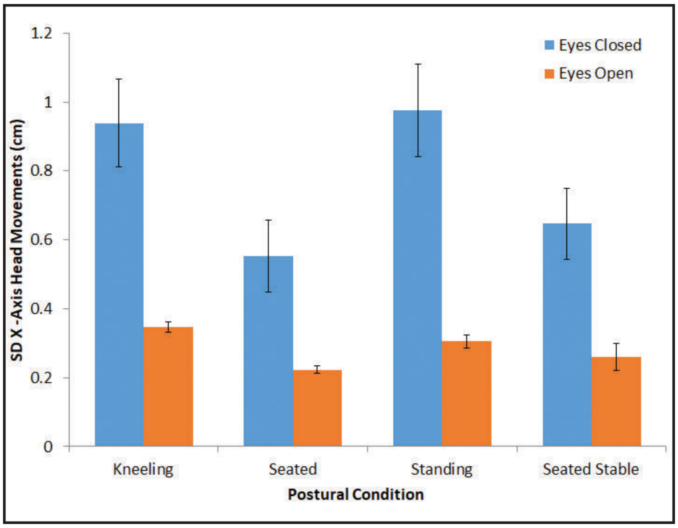

Figure 2.
Mean standard deviation (±SE) of head movements in the x axis for head still task.

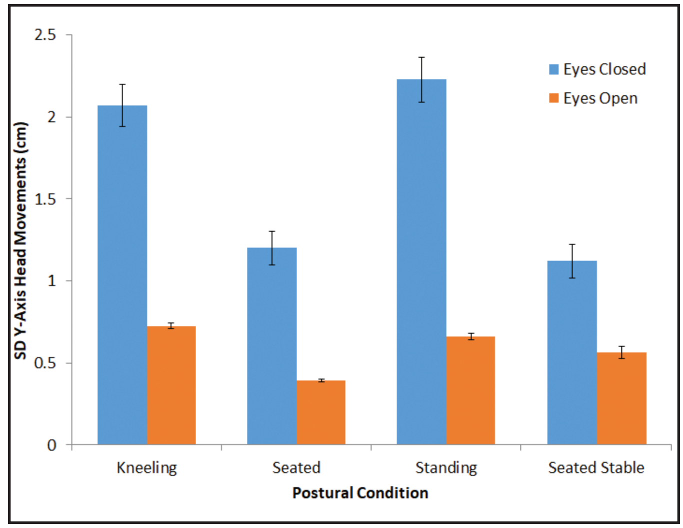

Figure 3.
Mean standard deviation (±SE) of head movements in the y axis for head still task.

$\eta_p^2 = 0.296$ (Figure 2). In general, kneeling and standing conditions generated more ML head movement than seated and supported conditions, however Bonferroni post hoc analyses failed to show any significant differences in pairwise posture comparisons. There also was a significant main effect of vision on ML (x) variability, F(1,11)= 97.63, p <0.001, $\eta_p^2 = 0.899$. ML head movement variability was significantly greater in the eyes closed condition (M=0.778 cm, SE=.056 cm) than in the eyes open condition (M=0.284 cm, SE=0.0095 cm). There was no significant interaction between posture and eye condition for ML head movement variability.

Vertical (y) Head Movements

Mauchly's test of sphericity indicated that the assumption of sphericity was met for y-axis variability in terms of the main effect of posture, $\chi^2(5) = 2.265$, p = 0.812, but it was not met for the interaction term between posture and visual condition, $\chi^2(5) = 12.910$, p = 0.025 so we used the Greenhouse-Geisser correction for the interaction. There was a significant main effect of posture on vertical position (y) variability as defined as mean standard deviation, F(3,33)= 8.688, p <0.001, $\eta_p^2 = 0.441$. Post hoc analyses of pairwise comparisons showed kneeling exhibited significantly greater y position variability than seated (p=.030) and supported (p=.012) conditions respectively. In addition, standing exhibited significantly greater y position variability than seated (p=0.050) and supported (p=.014) conditions respectively. There was also a significant main effect of vision on vertical (y) variability, F(1,11)= 55.13, p =0.000, $\eta_p^2 = 0.834$. Vertical head movement variability was significantly greater in the eyes closed condition (M=1.65 cm, SE=.15 cm) than in the eyes open condition (M=0.587 cm, SE=0.045 cm). There was a significant interaction between posture and eye condition for vertical (y) head movement variability, F(2.134, 23.469)= 4.883, p =0.015, $\eta_p^2 = 0.307$. Post hoc pairwise comparisons for the interaction revealed that for all four postures, the eyes closed condition led to significantly greater y variability than for eyes open (p<.05). Figure 3 indicates the greatest differences between eyes open and eyes closed conditions appeared for kneeling and standing.

Discussion

The main findings of this study were that body posture did not influence head repositioning accuracy (either with head rotation to the right or to the left) but did influence head stabilization (head still) performance. There was a significant effect of both body posture and vision on both horizontal (x) and vertical (y) head movements during the head stabilization task with the two seated conditions yielding the least amount of head movement.

The connections between vestibular, visual and proprioceptive afferent information are responsible for postural stability and accuracy of orientation of the head as well as visual balance.[32, 33] Knowledge of higher-order proprioceptive circuitry lags far behind other sensory systems, such as vision, audition, and olfaction.[34] A possible reason for this discrepancy is that proprioceptive sensing is distributed throughout the body, and therefore lacks a single central organ such as an eye or nose.[34] In this light, Roll and Roll[35] suggested that muscle-spindle inputs might form a continuous "proprioceptive chain" from the feet to the eyes. We sought to manipulate this chain by altering posture and thus, the mechanical and proprioceptive degrees of freedom during two different tasks, head repositioning and trying to keep the head still.

We hypothesized that joint position error during the head repositioning task would be reduced when segments other than the neck could contribute to the perception of the orientation of the head in space. We failed to find evidence to support this hypothesis. Rather, it appears that the participants were equally successful at repositioning their heads in space regardless of the number of joints allowed to contribute towards their performance. We take this to mean that for our healthy participants' head repositioning task to be effective, only the cervical spine need be operational. Adding further degrees of segmental freedom is not required, nor helpful in the task of head repositioning accuracy. Our results call into question the hypothesis of a proprioceptive chain – at least with respect to this task and in a healthy population.

Muscle spindle density is very high in the deep muscles of the human neck compared to elsewhere.[36, 37] This high cervical muscle spindle density along with the limited lever action of these muscles suggest that the deep neck muscles allow not only great precision of movement but also adequate proprioceptive information needed both for control of head position and movements and for eye/head movement coordination.[37] For comparison, the deep neck (suboccipital) muscles have almost five times higher the spindle content of the splenius capitis, three times that of the semispinalis capitis, 30 times that of the gluteus maximus and medius, and 75 times that of the gastrocnemius.[38] These histological findings and our behavioral findings suggest there may not have been additional benefit of proprioceptive input from any region other than the neck towards accomplishment of the repositioning task. It may also be possible that healthy participants do not tap into these additional proprioceptive resources.

Clinically, any deterioration of the afferent information received by the senses might lead to inadequate spatial representation, postural alterations and functional impairment of daily activities. Impaired cervical spine proprioception has been demonstrated following fatigue, and pathology such as whiplash and neck pain.[32] In addition, these factors along with neck muscle vibration have also been shown to alter postural stability.[39] Previous evidence has documented that the head repositioning test is a simple and effective method to analyze cervical proprioceptive deficiencies or alterations.[32] In this manner, Dugailly *et al*.[32] studied 36 healthy subjects and 35 chronic neck pain patients (age 30–55 years). Subjects performed the head repositioning test at two different speeds and at two different distances. For each condition, six consecutive trials were sampled. Dugailly *et al*.[32] reported horizontal, vertical and global errors of positioning whereas our current study reports global errors of positioning. Normative values by Dugailly *et al*.[32] of the head repositioning error of 3.3° and 5.4° were identified for asymptomatic and symptomatic subjects (neck pain), respectively. Our subjects fall well within the normative values of the head repositioning error of 3.3° for asymptomatic people. Based upon our results, clinicians can be confident that performing head repositioning accuracy tasks in a variety of postures will not change their results for asymptomatic young subjects. Since many symptomatic subjects have decreased head repositioning accuracy, we suggest repeating our present study with these populations (e.g., whiplash, neck pain) to determine whether they might benefit from greater degrees of postural and proprioceptive degrees of freedom. Posture may be a factor that could bring about improvement in symptomatic patients' cervical spine proprioception in addition to mental training[40], neck muscle vibration[39], exercise and rehabilitation[41], and manual therapy including cervical spine manipulation[31, 41]. Interestingly, spinal manipulation may lead to normalization of afferent input and restoration of appropriate sensorimotor integration and spinal function which has shown improvement in both spinal and limb proprioception.[42]

Regarding the head still task, posture significantly affected performance of the task, but not in the way we hypothesized. We predicted that error during the head still task would be minimized when joints other than the neck can contribute to the perception of the orientation of our head in space. Rather, the seated position generated the least movement variability as measured by standard deviation compared to the other postures. Standing postures generated the most variability in both x and y directions during the eyes closed condition, while kneeling yielded the most variable movement with eyes open, although there was no significant difference observed between standing and kneeling postures. It is also interesting to note that there was no significant difference between sitting with support (being strapped to the chair) and sitting without support. Perhaps a reason why posture significantly affected the head still task is that trying to fixate on a dot has been found to be more cognitively demanding than other tasks, both in relaxed and steady stances.[43] Such a stationary-gaze task is constraining and may lead to higher cognitive workload and higher attention. It is noteworthy that this contrasts to research on an external focus of attention (e.g., focus on the intended movement effect) versus internal focus of attention (e.g., focus on body movements). An external focus of attention would predict better movement effectiveness, efficiency and automaticity (e.g., less cognitive load) than an internal focus.[44] The stationary task also led to significantly larger interindividual postural sway variability.[43] The larger postural sway variability is supported in theory by the idea of "hypercontrol" during stance which could create postural inefficiency.[21]

In general, our results from the head still task seem to indicate that more degrees of freedom led to increased movement variability, not less as predicted and this effect was magnified in the absence of vision. It is entirely possible that factors other than proprioception contributed to the magnitude and variability of sway during this task. Such factors might include the mechanical nature of sway. Given the inverted pendulum nature of human stance, torques generated at the ankles and knees could lead to larger amplitude deviations of the head accounting for the greater sway variability compared to the seated postures. During seated postures, head sway might be minimized mechanically simply because there is less movement of distal (inferior) structures.

There are several limitations and/or ways to improve this study. Firstly, we used five trials for each direction of the head repositioning task. Authors have found stable estimates of performance were obtained when data from six or more trials was included although, the greatest test-retest reliability was obtained with five or more trials for joint position error.[26] It is possible that more trials could have improved performance estimates, although a practice and/or (attentional or physical) fatigue effect might be at play with further repeated trials. It is also a possibility that even with 5 trials for each direction and for each position that we tested that subjects may have had some degree of muscle fatigue. Second, the number of postures in this study could have been expanded, for example to include standing but restricting ankle movement such as with a boot – this would have the effect of allowing knee and hip joint contribution to stance. Another consideration for future studies would be to measure actual head motion as opposed to laser dot movement. Although this might prove less feasible given current technological constraints, it would mitigate any contribution of laser dot measurement error as a proxy for head sway. Finally, an a priori sample size estimate could have reduced the risk of an underpowered result.

Conclusion

For healthy young adults, clinicians and researchers need to be concerned with postural influences on tasks that involve head/cervical spine stabilization. Contrary to our hypothesis, we provide evidence that during the head still task, more joint degrees of freedom led to increased movement variability of the head. Clinicians can be confident that performing head repositioning accuracy tasks in a variety of postures will likely not change their results for healthy, young asymptomatic subjects. We suggest repeating our present study with both neck pain and whiplash populations to determine whether their head repositioning accuracy might benefit from greater degrees of postural and proprioceptive degrees of freedom.

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