Effect of Head Orientation on Postural Control during Upright Stance and Forward Lean

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Sensory feedback from the vestibular system and neck muscle stretch receptors is critical for the regulation of postural control. The postural relationship of the head to the trunk is a major factor determining the integration of sensory feedback and can be interfered with by varying head orientation. This study assessed how 60-s of standing with the head neutral, flexed, or extended impacted postural stability during upright stance and during forward lean in 13 healthy participants (26 ±5 years old). During both quiet upright stance and maximal forward lean, head extension increased postural center of pressure (COP) velocity and decreased the COP time-to-contact the anterior stability boundary compared with the head neutral condition. Head flexion did not differ from head neutral for either of the stance conditions. This study demonstrates that interfering with the head-trunk relationship by adopting extended, but not flexed, head orientations interferes with postural control that may impact postural stability during both quiet upright stance and maximal forward lean conditions.

Keywords: biomechanics, functional performance, health behavior, kinesiology, kinetics, motion analysis

The control of standing posture involves coordination of all of the segments of the body and control of the foot center of pressure to keep the body center of mass (COM) within the base of support. Loss of balance or a fall will occur if the motion of the COM cannot be arrested before crossing the stability boundary or a step is not taken to change the base of support. One important index of postural control during prolonged postures, such as upright standing, is the ability to maintain postural sway within the base of support of the feet. This aspect of postural stability is an issue for many populations. In populations that are known to have postural stability problems, such as in the elderly (Horak, Shupert, & Mirka, 1989) or in individuals with Multiple Sclerosis (Van Emmerik et al., 2010), postural sway is increased compared with controls. In both cases, postural instability in upright stance may be related to long-term degradation of sensory and motor functioning. Balance is also critical for people with no sensory-motor impairments. In young,
healthy individuals, accidents involving falls are an increasingly common cause of injury during activities of daily living and occupational tasks (Hu & Baker, 2009).

For both healthy individuals and populations with postural instability, it is critical to identify factors that impact postural control, particularly factors over which there could be some degree of control. Many view the foot-floor interface as a critical area in the regulation of balance (Horak et al., 1989). The importance of lower extremity feedback in the regulation of balance has been highlighted by research showing a degradation of stability when feedback is limited and an enhancement of stability when feedback is increased via biofeedback (Pinsault & Vuillerme, 2008; Vuillerme et al., 2008). Another important area in the regulation of balance is the relationship of the head to the trunk. Housed within the head, the eyes provide visual feedback of the location and movement of the body in space. The vestibular system, in the inner ear, provides feedback about head accelerations and the relation of the head to gravity. Postural muscles in the neck provide proprioceptive feedback that translates lengthening and shortening of the muscles into muscle tone. The integration of feedback about head and body orientations facilitates the regulation of postural control.

Previous research has shown that interfering with sensory feedback by changing the head-trunk relationship can lead to changes in postural control that may impact stability. During the movement from sitting to standing, extending the head backward on the trunk decreases the temporal coordination between torso segments compared with moving with the head neutral on the trunk (Johnson & Van Emmerik, 2010). During upright stance, extending the head backward compared with standing with the head neutral leads to greater postural sway in individuals who are healthy (Tanaka & Uetake, 2003; Vuillerme & Rougier, 2005), have neck trauma (Kogler, Lindfors, Odkvist, & Ledin, 2000), or have vestibular issues (Barin, Seitz, & Welling, 1992; Norre, 1995). Previous research on postural sway with the head extended has generally used a visual target or closed eyes (Paloski et al., 2006; Tanaka & Uetake, 2003; Vuillerme & Rougier, 2005); however, standing with the head extended is a behavior commonly performed with the eyes open (e.g., painting a ceiling). It is unclear what the effect of head extension is when the visual field is not manipulated.

In addition, the impact of other head orientations on postural control is unclear. In young, healthy individuals, with eyes closed, flexing the head forward on the trunk or tilting the head laterally do not increase postural sway as extending the head does (Paloski et al., 2006). However, head flexion appears to be destabilizing in a population that is already posturally challenged, such as the elderly (Buckley, Anand, Scally, & Elliott, 2005) or when there are added sensory challenges (Ledin, Hafstrom, Fransson, & Magnusson, 2003). The lesser effects of head flexion compared with head extension may be caused by head flexion interfering less with vestibular and proprioceptive function than head extension (Paloski et al., 2006). It is unclear whether additional postural challenges would increase postural sway with head flexion.

An important aspect of balance is the ability to maintain upright stance within the stability boundary of the feet (Riccio, 1993). The changes in postural control when operating in closer proximity to the stability boundaries formed by the feet can be highlighted by incorporating stance conditions that approach the boundary, such as lean. Healthy individuals show changes in postural sway during a forward lean compared with upright stance (Riley, Mitra, Stoffregen, & Turvey, 1997). It is
unknown how altering the head-trunk relationship by varying head orientation will affect postural sway in relation to the stability boundary. In addition, by calculating the predicted time-to-contact the stability boundary, researchers have highlighted how postural behavior in relation to the stability boundary is associated with falls (Hasson, Van Emmerik, & Caldwell, 2008). Elderly individuals show decreased A/P and M/L time-to-contact during leans in multiple directions compared with controls (Van Wegen, Van Emmerik, & Riccio, 2002). If postural control is decreased in a population with sensory-motor impairment, it is possible that impairing sensory feedback by adopting a challenging head orientation will lead to similar degradations in postural control in healthy, young individuals.

The purpose of this study was to assess how manipulation of the head-trunk relationship impacts the control of stance. These changes in head-trunk relationship were investigated under two conditions, namely (1) during quiet upright standing and (2) during a perturbed posture of forward lean in which greater proximity to the stability boundary was elicited. It was predicted that during upright stance, head extension would induce changes in postural control, as quantified by increased postural sway and velocity and decreased temporal margins (TtC) to the stability boundary. Head flexion during quiet upright standing was not predicted to differ from the head neutral orientation. It was predicted that during maximal forward lean, where posture is challenged more than upright stance, both head extension and head flexion would induce changes in the postural variables compared with head neutral.

Methods

Participants

The study included 13 healthy, young participants (indicated by sample size estimation based on Vuillerme & Rougier, 2005), six male and seven female, mean age: 26 ± 5 years, height: 1.70 ± 0.08 m, weight: 69 ± 11 kg. Approval was granted by the University’s Human Subjects Review Board; all participants gave written informed consent.

Procedure

Participants wore spandex shorts and women wore sports bras. Retro-reflective markers were attached to anthropometric landmarks on each participant’s legs, arms, back, and head (Figure 1). For upright stance trials, participants stood with their arms at their sides. For forward lean trials, participants maintained a maximum forward lean from their ankles. For each stance condition, two trials were collected for each of three head orientations: extended, flexed, and neutral. For the extended head orientation, the head was rotated posterior to the trunk in the pitch plane; for the flexed head orientation, the head was rotated anterior to the trunk in the pitch plane; for the neutral head orientation, the head was aligned with the trunk (Figure 1). For each trial, data were collected for 65 s. Stance conditions and head orientations were maintained for 60 s, after which participants were asked to step off the force plate so a baseline force measurement could be taken. The visual environment was painted off-white and was clear of objects. The floor, wall, and ceiling in view were about 5–7 ft from head level in standing.
Data Collection

Kinematic data were collected at 80 Hz with a six-camera Proreflex Motion Capture system (Qualysis, Gothenburg, Sweden). Ground reaction force data were collected at 240 Hz from dual force plates, one under each foot (AMTI, Newton, MA). All data were filtered at 6 Hz using a fourth order, low pass, zero lag Butterworth filter, based on residual analysis (Winter, 1995). Data were analyzed using custom written software in MATLAB (The MathWorks, Natick, MA, USA).

Data Analysis

Visual 3D software (C-Motion, Kingston, ON, Canada) was used to create a 7-segment model of each subject. Three-dimensional Kinematic data were ana-
lyzed for head, trunk, pelvis, two leg, two foot, and two arm segments. From the kinematic data, anterior/posterior full-body center of mass (COM) locations were averaged across each trial. The full-body COM locations were calculated from the combined COM locations and estimated % body masses of the body segments, projected vertically onto the floor (Figure 1). Positive COM locations indicate anterior displacement and negative locations indicate posterior displacement relative to the average location with head neutral during upright stance. COM locations were assessed to check whether the changes in head orientation altered the full-body COM. In addition, sagittal head-trunk angles were averaged across each trial. Positive head-trunk angles indicate forward flexion of the head on the trunk and negative angles indicate backward extension of the head on the trunk relative to the average angle with head neutral during upright stance. Head-trunk angles were assessed to determine whether the head orientation conditions were different from each other.

From the ground reaction force data, the range, average velocity, and average time-to-contact the stability boundary of the net center of pressure (COP) were calculated in the anterior/posterior (A/P) and medial/lateral (M/L) directions across each trial (Winter, 1995). Time-to-contact (TtC) was calculated from the instantaneous COP velocity \( v \), acceleration \( a \), and position \( p \), and the stability boundary locations \( p_{max} \) (Equation 1) using the calculation from Hasson et al. (2008), which was based on Slobounov, Slobounova & Newell (1997) and Riccio (1993). The stability boundary locations were defined at the toe and heel in the A/P direction and by the 5th metatarsals in the M/L direction.

\[
TtC = -v \pm \sqrt{v^2 - 2a(p_{max} - p)}/a
\]

**Statistical Analysis**

After confirming that the data were normally distributed, repeated measures analysis of variance was used to compare all dependent measures between the three head orientations (extended, flexed, neutral) and two stance conditions (upright stance, forward lean). Two trials were included in the analysis for each condition. Tukey’s post hoc tests were used to compare means between head orientations within each stance condition. Significance was determined by a cutoff of \( p < .05 \) and trends were identified for measures with \( p < .07 \).

**Results**

**Head-Trunk Angle**

The head-trunk angles did not differ significantly between upright stance and forward lean (\( p = .41 \)). Within both stance conditions, the head orientations were significantly different from each other (Table 1). During both upright stance and forward lean, the average sagittal head-trunk angle was more extended with the head extended and more flexed with the head flexed compared with the head neutral.
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Center of Mass Location

The average COM location differed between upright stance and forward lean ($p < .01$). With the head neutral, the COM was shifted 9.3 cm in the anterior direction during the forward lean compared with upright stance. Within each stance condition, there were small shifts in the average A/P location of the COM between the different head orientations ($p < .01$). During upright stance, the COM locations for extended and flexed were different from each other, but neither differed significantly from neutral. During upright stance, compared with the average COM location with the head neutral, the COM was shifted 0.2 cm backward with the head extended and 0.4 cm forward with the head flexed. During forward lean, the COM locations differed between all three head orientations. During forward lean, compared with the average COM location with the head neutral, the COM was shifted 0.8 cm backward with the head extended and 0.6 cm forward with the head flexed.

Stance Condition

For the postural control measures, there were no significant interactions between the stance condition and head orientation ($p > .15$). For all measures, there were significant differences between upright stance and forward lean (all $p < .03$). COP ranges were greater, average COP velocities were faster, and average COP TtC were shorter during forward lean than during upright stance (Tables 2 and 3). All subsequent results present the differences between head orientations within each stance condition.

Center of Pressure Range

During upright stance, the differences in COP range between head orientations were not significant in the M/L direction, but approached significance in the A/P direction (Table 2). During forward lean, there were no significant differences in COP range in the M/L or A/P direction between head orientations (Table 3).

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Table 1  Mean values with standard deviations (in parentheses) for sagittal head-trunk angles (degrees) during upright stance and forward lean with head extended, flexed, and neutral. Positive values indicate angular flexion and negative values indicate angular extension. Tukey’s mean separation results are presented for measures with $p < .05$: mean values followed by the same letter are not significantly different from each other.

<table>
<thead>
<tr>
<th>Head-trunk Angles</th>
<th>Head Orientation</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Extended</td>
<td>Flexed</td>
</tr>
<tr>
<td>Upright Stance</td>
<td>-40.3° (21.9°) a</td>
<td>49.7° (21.3°) c</td>
</tr>
<tr>
<td>Forward Lean</td>
<td>-37.5° (13.9°) a</td>
<td>46.8° (9.7°) c</td>
</tr>
</tbody>
</table>
During both upright stance and forward lean, there were no significant differences in COP velocity in M/L direction between head orientations, but there were significant differences in the average COP velocity in the A/P direction (Tables 2 and 3).
and 3). For both upright stance and forward lean, the A/P COP velocity with the head extended was significantly faster than with the head neutral, but the A/P COP velocity with the head flexed was not significantly different from the head extended or neutral conditions.

**Center of Pressure Time-to-Contact**

During upright stance, there were no significant differences in M/L COP TtC (Table 2). During forward lean, the differences in M/L COP TtC approached significance (Table 3). There were significant differences in the average A/P COP TtC between head orientations during both upright stance and forward lean. TtC was generally shortest with the head extended. The A/P COP TtC with the head extended was significantly shorter than with the head flexed during upright stance. During forward lean, the A/P COP TtC with the head extended was only significantly shorter than with the head neutral.

**Discussion**

This study demonstrated changes in postural control due to head extension during upright stance and under a more challenged posture, forward lean. These postural control changes were most clearly evident in the postural variables that reflect dynamic changes in the COP (velocity and TtC). As in previous research, during upright stance, head flexion did not affect any of the assessed postural control variables compared with the neutral orientation (Paloski et al., 2006). However, contrary to predictions, head flexion also did not impact the postural variables during forward lean, when posture was challenged with respect to the stability boundary.

**Directional Instability**

The impact of head extension compared with head neutral was mostly seen in the A/P direction, as highlighted by greater COP velocity during both upright stance and forward lean and shorter TtC during forward lean. In addition, head extension showed a greater impact on A/P TtC during upright stance compared with head flexion. These results support previous research that found greater peak-to-peak COP sway in the A/P, but not M/L direction with head extension, but not flexion (Paloski et al., 2006). However, the results of another study paint a less clear distinction between A/P and M/L postural stability, showing an impact of head extension compared with head neutral in both the A/P and M/L directions for force-derived COP-COG difference spatial and mean frequency parameters, but an impact only in the A/P direction for spatial characteristics of COP-COG difference transition points (Vuillerme & Rougier, 2005).

Potentially, the greater impact of head extension on A/P compared with M/L postural sway in the current study is because the head orientation change is in the A/P direction. However, research suggests this is not the case. In the current study, flexing the head, an A/P head orientation change, did not increase sway compared with head neutral. Previous research supported an effect on A/P postural sway of head extension, but not head flexion, and additionally demonstrated that adopting head orientations tilted in the M/L direction also did not increase either A/P or
M/L sway compared with head neutral (Paloski et al., 2006). Future work should address whether A/P and M/L result differences are due to different mechanisms affecting the directions of sway.

**Stability Boundary**

The reduced time-to-contact the stability boundary with head extension compared with flexion, even during the posturally challenging forward lean, highlights the importance of assessing postural control in relation to the stability boundary. Previous research has suggested that the time-to-contact the stability boundary is an important predictor of stepping that may need to occur to avoid loss of stability and falling (Hasson et al., 2008). In this study, the TtC measure was the only measure that suggested differences in postural sway in the M/L direction with head extension. These findings support previous research highlighting the usefulness of stability boundary relevant measures to assess postural control (Van Wegen et al., 2002). In addition, despite overall decreased time-to-contact the stability boundary during forward lean compared with upright stance, head extension during the maximal forward lean condition still resulted in further increases in COP velocity and decreases in time-to-contact. These results demonstrate that the impact of head extension does not get overshadowed by additional challenges to stability, such as by approaching the stability boundary.

**COM Location**

It is possible that differences in the average location of the COM were responsible for the differences in findings attributed to head orientation. During upright stance, head extension could have shifted the COM behind the ankle joint, creating greater difficulty to control posture and increasing the likelihood of postural instability. During maximal forward lean, however, a backward shift of the COM due to head extension would have facilitated postural control to counteract the overall forward shift of the COM. Given that the COP velocity also increased and TtC decreased during forward lean, it is likely that the COM location was not responsible for the effects of head extension. In fact, it is interesting that during a forward lean, despite the smaller overall forward COM shift with the head extended compared with neutral or flexed, there were still changes in the postural variables with head extension compared with neutral, but not with head flexion, as shown in the A/P COP velocity and TtC. When viewed together, the similar results during upright stance and forward lean suggest that head extension affects postural control through mechanisms that are not purely mechanical responses to body weight distribution.

**Sensory Contributions**

It is possible that the results are due to differences in the visual field between head orientations despite a neutral visual field, free of visual landmarks. However, previous research found similar changes in A/P postural control while standing with the head extended compared with neutral when visual effects were controlled for by occluding vision or using a consistent target between conditions (Buckley et al., 2005; Jackson & Epstein, 1991; Paloski et al., 2006; Tanaka & Uetake, 2003; Vuillerme & Rougier, 2005). In both this study with eyes open and previous work
with eyes closed, (Paloski et al., 2006), greater A/P, but not M/L postural sway was also elicited with the head extended compared with the head flexed, indicating that vision did not play a major role in the differences found between head orientations. In addition, studies that varied visual feedback, head orientation, and lower extremity proprioceptive information found decreased stability with head extension compared with neutral that was independent of the visual or proprioceptive effects in both young and elderly subjects (Jackson & Epstein, 1991; Buckley et al., 2005).

Previous research has suggested that postural control changes induced by head extension is due to impairment of vestibular and neck proprioceptive sensory systems (Anand, Buckley, Scally, & Elliott, 2003; Buckley et al., 2005; Jackson & Epstein, 1991; Vuillerme & Rougier, 2005) and that the sensory impairment with the head extended is greater than with the head flexed (Paloski et al., 2006). However, head extension may interfere with proprioceptive more than vestibular feedback. Previous research showed that individuals with vestibular dysfunction and healthy individuals demonstrated similar postural responses to head extension during upright stance (Barin et al., 1992; Norre, 1995). In contrast, another study found that individuals with neck trauma demonstrated greater instability with head extension than healthy individuals (Kogler et al., 2000). It is possible that part of the effect on the proprioceptive stretch receptors in the neck muscles may come about as a result of the modulation of tonic muscle activity in the neck and trunk from muscle shortening (Gurfinkel et al., 2006). Therefore, there may be inseparable sensory and motor consequences of head extension leading to substantial changes in the postural control of upright stance (Vuillerme & Rougier, 2005).

### Modifying Head Orientation

Head orientation can be voluntarily manipulated, as shown by this study. However, in healthy, young individuals, head extension is also a common automatic response to certain daily activities, such as entering a car (Andreoni, Rabuffetti, & Pedotti, 2004) and moving from sitting to standing (Johnson, Cacciatore, Hamill, & Van Emmerik, 2010). In the elderly, typical postures involve more head extension compared with healthy, young individuals (Kuo, Tully, & Galea, 2009). It is unclear whether these short-term impairments of the head-trunk relationship in young populations are factors in occupational health risks or whether habitual extended head postures in elderly populations are related to decreased postural stability and falls. However, the current study demonstrates a link between head extension and postural control that warrants further exploration.

If postural changes that may result in instabilities can be induced by head extension, it is possible postural stability can be improved by enhancing the head-trunk relationship. Promising methods are being developed to counteract the impact of sensory loss on postural stability through biofeedback of head orientation (Vuillerme & Cuisinier, 2009). However, head orientation is potentially modifiable even without biofeedback. Impairment of the vestibular and neck proprioceptive systems can be avoided simply by not adopting head-trunk relationships that are destabilizing. Research has demonstrated how sensory impairment has a cumulative effect, such that interfering with multiple sensory systems in healthy individuals or increasing sensory interference in individuals with existing sensory issues compounds the instability (Anand et al., 2003). Addressing head orientation as a means to improve
stability might be a useful tool in the education and clinical treatment of populations with multiple sensory-motor impairments. Research has shown that training elderly or individuals with Multiple Sclerosis to improve head stability has led to improvements in postural stability (Cattaneo, Ferrarin, Frasson, & Casiraghi, 2005; Cromwell, Newton, & Forrest, 2001). In addition, alternative indexes of postural control, such as functional reach in elderly individuals and modulation of trunk tone in people with low back pain have been shown to improve as a result of training in a novel method of motor reeducation that emphasizes the importance of the head-trunk relationship in modulating posture and coordination (Dennis, 1999; Cacciatore et al., 2011). Future research should address the postural impact of modifying work environments, such as overhead work exposure, to limit unnecessary head extension during occupational tasks and of training people to avoid impairing the head-trunk relationship, as occurs with head extension, during daily activities.

**Conclusion**

During both upright stance and forward lean, head extension impacted postural control compared with head neutral, as indicated by increased COP velocity in the A/P direction and a reduction in the time-to-contact the A/P stability boundary. Head flexion, in contrast did not impact the postural variables in any of the stance conditions. Consistent differences in postural stability between head orientations between upright stance and forward lean, despite an overall forward shift of the COM during forward lean, suggest that results are not due to the location of the COM in relation to the ankle joint. These findings highlight the negative impact of head extension on postural control with potentially major implications for postural stability in various populations. It is suggested that impairing the head-trunk relationship through head extension be viewed as an occupational hazard and as a behavior to avoid in activities of daily living, particularly for populations with sensory-motor impairment.

**References**


