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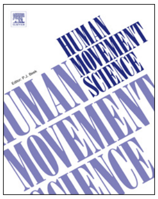

Neck posture is influenced by anticipation of stepping

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ABSTRACT

Background: Postural deviations such as forward head posture (FHP) are associated with adverse health effects. The causes of these deviations are poorly understood. We hypothesized that anticipating target-directed movement could cause the head to get "ahead of" the body, interfering with optimal head/neck posture, and that the effect may be exacerbated by task difficulty and/or poor inhibitory control.
Method: We assessed posture in 45 healthy young adults standing quietly and when they anticipated walking to place a tray: in a simple condition and in conditions requiring that they bend low or balance an object on the tray. We defined FHP as neck angle relative to torso; we also measured head angle relative to neck and total neck length. We assessed inhibitory control using a Go/No-Go task, Stroop task, and Mindful Attention Awareness Scale (MAAS).
Results: FHP increased when participants anticipated movement, particularly for more difficult movements. Worse Stroop performance and lower MAAS scores correlated with higher FHP. False alarms on the Go/No-Go task correlated with a more extended head relative to the neck and with shortening of the neck when anticipating movement.
Conclusions: Maintaining neutral posture may require inhibition of an impulse to put the head forward of the body when anticipating target-directed movement.

1. Introduction

Moving the head and neck forward in relation to the thoracic spine, sometimes called forward head posture (FHP), results in a stooped posture that has been associated with a number of serious chronic health issues (Kapandji, 1974). FHP and related postural deviations increase the gravitational demand on the neck and head (Vasavada, Nevins, Monda, Hughes, & Lin, 2015) and have been linked to an increased likelihood of chronic neck pain in a number of studies (Ariëns et al., 2001; Ariëns, van Mechelen, Bongers, Bouter, & Van der Wal, 2000; Chiu et al., 2002; Silva, Punt, Sharples, Vilas-Boas, & Johnson, 2009; Watson & Trott, 1993; Yip, Chiu, & Poon, 2008). FHP has also been associated with reduced range of motion in the mandible (Visscher, Huddleston Slater, Lobbezoo, & Naeije, 2000), neck (Quek, Pua, Clark, & Bryant, 2013), and shoulders (Quek et al., 2013). In addition, prolonged FHP is associated with increased upper torso and shoulder muscle strain (Weon et al., 2010), increased likelihood of cervical headaches (Jull, Barrett, Magee, & Ho, 1999; Page, 2011; Watson & Trott, 1993), and decreased maximal respiratory volume in breathing (Kapreli, Vourazanis, Billis, Oldham, & Strimpakos, 2009). Finally, postural deviations such as FHP and stooped posture have been associated with reduced postural stability and increased risk of falls and death in older adults (Kado et al., 2007; Kang et al., 2012; Katzman, Vittinghoff, & Kado, 2011).

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Given the health risks associated with carrying one's head forward of one's spine, why do we do it? Existing explanations are primarily physiological, such as genetic predispositions to physiological abnormalities in the spine (Adams & Dolan, 2005; Freemont, 2009), or workplace ergonomics (Ariëns et al., 2001; Griegel-Morris, Larson, Mueller-Klaus, & Oatis, 1992; Kellgren, 1977; Kendall, McCreary, Provance, Rodgers, & Romani, 2005). Aging, which is strongly associated with thoracic hyperkyphosis and a flexed neck (also sometimes referred to as FHP), is a nonspecific factor that does little in itself to explain FHP (Dalton & Coutts, 1994; Kuhlman, 1993; Nemmers & Miller, 2008). Taken together, these explanations do not provide a satisfying or complete account of deviations in cervical posture (Ariëns et al., 2001).

One possible explanation for FHP and related postural deviation rests on an idea from evolutionary theory. A prevailing model is that quadrupeds began to lead with the head during locomotion to enable active predation. Leading with the head facilitates the ability to sense both food sources and threats in the direction of motion (Le Douarin & Kalcheim, 1999; Northcutt, 2005). Importantly, upright posture changes the positional relationship between the head and spinal column (Farley & Ferris, 1998); when a quadruped puts its head forward, the head and spine are still aligned, but when a human puts his or her head forward, the head moves out of alignment with the spine (Edmondston, Sharp, Symes, Alhabib, & Allison, 2011). In itself, putting the head forward to initiate movement only constitutes an acute deviation of alignment; however, this is a situation which is likely to be repeated, leading to a chronic, detrimental habit. This may explain why some populations—for instance, computer workers focused on a screen daily—are predisposed to chronic FHP when this impulse to "lead with the head" is repeatedly managed poorly.

Despite a large body of work on anticipatory postural adjustments prior to gait (e.g. Brenière, Do, & Bouisset, 1987) and a few studies of head stabilization during gait initiation (Maslivec et al., 2017), little is known about changes in head position that may occur *before* gait initiation. We propose that in the presence of a stimulus that evokes activation of a goal (such as reaching to place an object on a shelf), people have an automatic tendency to move their heads toward that stimulus (Moskowitz, 2016), and that inhibitory control is necessary to prevent this head-forward response – especially if the task or stimulus demands significant attention. Prevention of the head-forward response could be the result of automatic lateral inhibition (Aron, 2007) primed by prior experiences (Chiu & Aron, 2014) in which carrying the head out of alignment led to pain or to decrements in balance, range of motion, or breathing capacity.

The biomechanics of the neck are complex (Bogduk & Mercer, 2000; Nevins, Zheng, & Vasavada, 2014). In FHP, neck load increases with an increased moment arm between the head and base of the neck. As the head moves farther forward from supporting vertebrae, the gravitational load of the head on the spine increases. Further, neck load can be compounded by kinematics of the head and neck. For example, if one puts one's head forward of one's body while continuing to look straight forward, the head will be tilted backward relative to the neck (as commonly seen in chronic FHP), this could compound stress on the neck; if one looks downward (as in what is commonly referred to as "text neck,") this may reduce neck stress, but total moment arm may increase even further. Neck loads may lead to prolonged compression of cervical nerves, as well as paresthesia and pain in the neck and shoulder, extending to the arms (Ming, Närhi, & Siivola, 2004). Because these segmental kinematics can exist independently as well as together, we included three measures of postural deviation of the head and neck, as illustrated in Fig. 1: (i) FHP (torso-neck angle), (ii) head flexion/

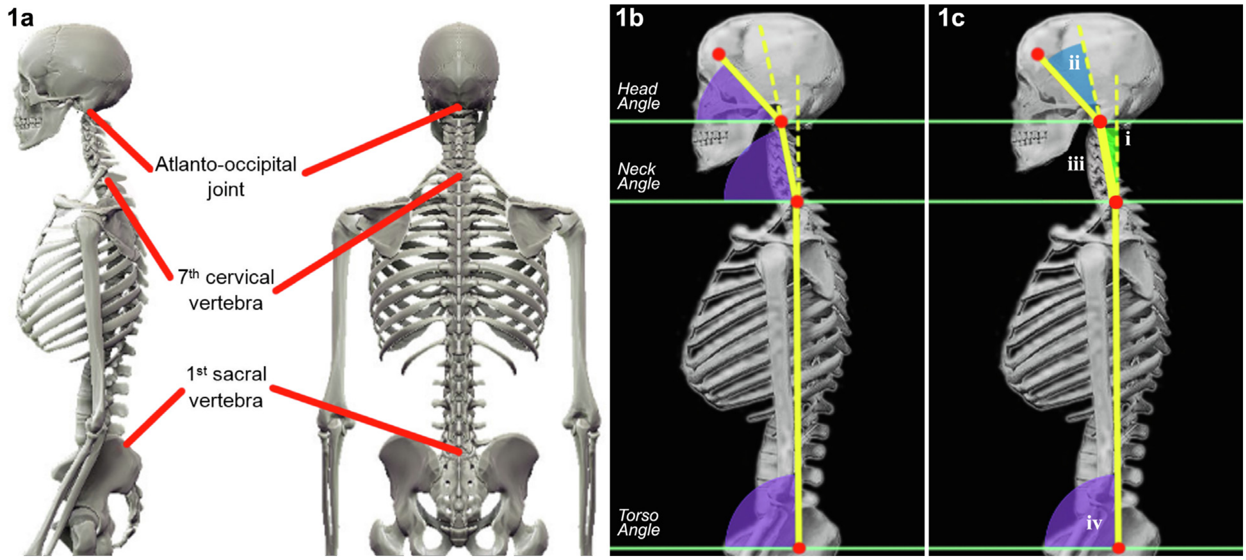


Fig. 1. Anatomical landmarks. a. Bony landmarks used in digitization of composite skeleton. The MotionMonitor composite skeleton. Digitized points for head segment, atlanto-occipital (A/O) joint, C7/T1 joint, and S1 (listed from top to bottom) are shown in red; corresponding extrinsic angles for the head, neck, and torso are shown with purple shading. c. Dependent measures used in data analysis: torso-neck angle (i, green shaded area), neck-head angle (ii, blue shaded area), neck length (distance between AO joint and C7T1 joint, iii, yellow line), and torso angle (relative to horizontal, iv, teal shaded area). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

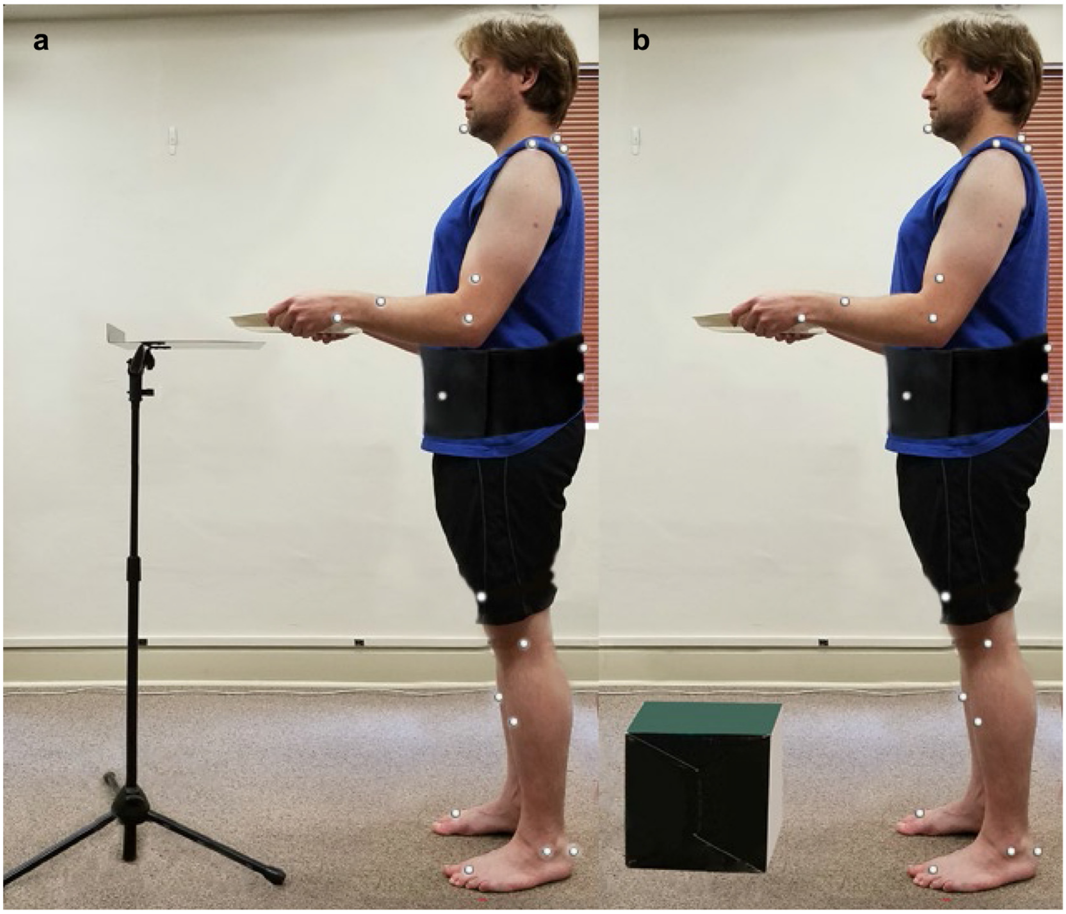


Fig. 2. Reflective markers. Participant wearing reflective markers (a) while holding the tray and balancing the rolling object, before placing the tray at elbow height, and (b) before placing the tray at low height.

extension (neck-head angle), and (iii) total neck length. The figure also shows (iv) torso angle, for reference.

The present study investigated changes in postural alignment of the head and neck when preparing for target-directed gait initiation, compared to baseline standing. Participants stood holding a tray awaiting a cue to walk forward several steps and set the tray down on a shelf at standing elbow height. To examine the influence of making the anticipated task more difficult, we included a condition in which the tray needed to be balanced carefully to prevent an object on it from rolling. To examine effects of target height, we included a condition in which the tray needed to be placed on a low shelf. We hypothesized that people tend to lead with the head when anticipating movement, causing FHP and related postural deviations (head forward from the rest of the torso, with or without jutting of the jaw and shortening of the neck), and that this tendency is modulated (reduced) by inhibitory control. We predicted that: (1) Postural deviation would be greater when preparing to move than when not preparing to move. (2) Postural deviation would be greater before more difficult movements than before easier movements and before movements with lower target heights than neutral target heights. (3) Habitually poor postural alignment would be associated with poor inhibitory control and low mindfulness. (4) The effects of anticipating movement and of increasing task difficulty would be stronger in subjects with poorer inhibitory control.

2. Methods

2.1. Equipment

Three-dimensional motion capture data were collected using eight Vicon Bonita motion capture cameras (Oxford, UK) and processed using The MotionMonitor software by Innovative Sports Training (Chicago, IL). We placed 33 reflective markers on bony landmarks of the body (Fig. 2), tracked by Vicon Nexus software with data streaming to The MotionMonitor for processing at a rate of 100 frames/second. The arrangement of these reflective markers produced 14 body segments in Vicon: head, torso, trunk, pelvis, left and right upper arm, left and right lower arm, left and right thigh, left and right shank, and left and right foot. Based on these Vicon segments, The MotionMonitor produced a composite model of each participant's skeletal structure for analysis.

2.2. Participants

We tested 45 participants (16 men and 29 women) aged 18–29 years (M = 20.2, SD 5.1), recruited from psychology courses at the University of Idaho. Participants received course credit for a two-hour data collection session. Participants were excluded from the study if they reported current musculoskeletal injuries (pain in any part of the body while standing or walking), neurological issues (diagnosed mental disorder), or any condition that could interfere with their ability to perform the task comfortably.

2.3. Protocol

Participants provided informed consent as approved by the Institutional Review Board of the University of Idaho. To minimize participant expectation effects on neck posture *before* gait initiation, we informed participants that we were performing a study on how people walk toward something. Reflective markers were applied while the equipment was calibrated. Data collection consisted of two components: motion capture trials and cognitive testing.

2.3.1. Motion capture data collection

Each participant completed three walking trials for each of three separate conditions (Simple, Down, and Rolling). During all trials, participants stood grasping a small tray (8 × 12 in.) lengthwise by its rim (a 3-cm lip, Fig. 2a). For the walking trials, we asked participants to walk forward 2 m and place the tray either at standing height (the Simple condition), at a low height (the Down condition) or at standing height while balancing a cylindrical object (12 cm long × 2 cm diameter) on the tray (the Rolling condition). Before beginning, experimenters adjusted the height of the target location for each participant to ensure that the participant's forearm would be horizontal when placing the tray in Simple and Rolling conditions (Fig. 2b). For the Down condition, the tray was placed on a 20-cm high box (Fig. 2c). Participants were instructed to look straight ahead while standing, and to wait for the experimenter to count off three seconds ("one…two…three") before stepping forward; data for step anticipation were sampled at the start of this count (as the experimenter said "one"). We wanted to capture a brief impulse that occurs prior to preparing to step, so we used a median of 5 frames, at least two full seconds before the stepping foot was lifted from the floor.

Prior to the walking trials we recorded a Baseline trial, using the median of all frames while participants stood still for 10 s, holding the tray with no expectation of stepping. We compared the anticipation data against this Baseline. During pilot testing, the head was still up until the last second before the step (presumably when participants were making necessary postural adjustments to take a step). Participants then performed three trials in each of the three experimental conditions in a blocked counterbalanced order: each participant was assigned one of six possible condition orders and performed all three trials for each condition before moving on to the next condition according to their assigned order.

2.3.2. Go/No-Go task

Each participant completed a pair of short computer tasks that measured reaction time and inhibitory control (Donders, 1969). In the simple reaction time (SRT) task, participants sat at a computer, watched the screen for a letter to appear, and pressed the space bar as quickly as possible when one appeared. For each trial, a random letter was presented once every 1–2 s and remained visible for 250 ms. Each participant completed 108 trials. The purpose of the SRT task was to prime participants to move quickly and make errors in the Go/No-Go task. The Go/No-Go task was identical to the SRT task, except that participants were instructed to withhold responses to the No-Go stimulus, which was the letter "X." If a participant responded to a presented "X," their response was counted as a false alarm. The probability of a No-Go stimulus appearing on any given trial was 18%. Response time was measured from the moment of letter presentation: responses faster than 500 ms were counted as hits; slower responses were counted as misses. Response times and hit rates were collected, as well as false alarm rates for Go/No-Go trials.

2.3.3. Stroop task

Each participant also completed the Stroop task (Stroop, 1935). This consisted of three speeded oral tasks, each with 50 items. Any time a participant made an error, they were required to correct their mistake before continuing. First, the participant named the color of 50 ink squares printed on paper. Then they read 50 words: color names corresponding to the ink colors used in the first task (in a different order), written in black ink. The third task (the conflict condition) consisted of a series of 50 color names written in different colored ink; participants were instructed to name the ink color. This third task requires inhibition of the well-established habit of reading words. The faster a participant could complete the conflict condition (including correcting any errors), the better their inhibitory control.

2.3.4. Mindful Attention Awareness Scale

Inhibitory control has been linked with mindful management of attention (Greenberg, Reiner, & Meiran, 2013). The Mindful Attention Awareness Scale (MAAS) is a 15-item scale designed to assess participants' beliefs about their awareness of and attention to what is taking place in the present (Brown & Ryan, 2003; Chambers, Lo, & Allen, 2008). Each item describes an example of mind wandering or inattentiveness. Participants indicate how frequently they experience the described example on a scale of 1 (always) to 6 (never). The scores are summed; a higher total score indicates greater self-reported mindfulness.

2.4. Motion capture data

In postural assessment, body segment angles are the most commonly used type of measure, but these do not translate directly to skeletal angles, particularly in the neck. To our knowledge, cervical vertebral angles can only be accurately measured using visualization of internal tissue (Vasavada, Hughes, Nevins, Monda, & Lin, 2018). To address this limitation, we assessed segment angles and also computed a measure of neck length to indirectly assess compression. Head, neck, and torso angles relative to the horizontal plane were collected for use in data analysis. We used three surface landmarks to approximate joint positions in our analysis (Fig. 1a): the joint center between C7 and T1 vertebra (7.18 cm forward and 3.35 cm down from the spinous process of the C7 vertebra), the mastoid processes (bony protuberances directly below the ear), and the glabella of the brow. The MotionMonitor allows tracking of these digitized landmarks relative to reflective markers on the participant. To verify that our measures were sensitive enough to assess differences in alignment, we conducted pilot tests in which eight participants (who were not part of our main study) assumed different postures: leaning forward and backward at the torso, pushing the head forward and pulling it back, and extension or flexion of the head.

We used these anatomical landmarks first to generate angles with an extrinsic frame of reference. Each angle consisted of the union of a line connecting two body landmarks and a line from the lower landmark forward in the horizontal plane (Fig. 1b, images adapted from https://washamscience.edublogs.org). The head angle was based on a line between the brow and the midpoint of the mastoid processes (approximately in line with the atlanto-occipital joint (AO), where the spine connects to the head); the neck angle was based on a line from the midpoint of the mastoid processes to the joint below the seventh cervical vertebra (C7/T1); the torso angle was based on a line from C7/T1 joint to the spinous process of the first sacral vertebra (S1). In all cases, a larger angle indicates extension, or greater tilt backwards. As can be seen in Fig. 1, these extrinsic angles are additive in nature (the neck is influenced by the position of the torso, and the head is influenced by the position of the neck and torso).

Based on these extrinsically measured points and angles, we computed our three dependent variables, defined in an intrinsic frame of reference: torso-neck angle (FHP), neck-head angle (head flexion/extension), and neck length.

We calculated the torso-neck angle (Fig. 1c (i)) by subtracting the neck angle from the torso angle. This yields a positive value: a more positive result indicates a more flexed neck relative to the torso, or greater FHP. This measure primarily reflects the increasing moment arm as the head moves forward relative to the torso. During pilot testing, participants' torso-neck angles averaged 35 degrees when looking straight ahead, 75 degrees when looking down at the feet, and 70 degrees when jutting the jaw to imitate extreme FHP.

We calculated the neck-head angle (Kang et al., 2012, Fig. 1c (ii)) by subtracting the head angle from the neck angle. This also yields a positive value: a more positive value indicates flexion (tilting the head forward relative to the neck), and a more negative angle indicates extension (tilting the head back relative to the neck). During pilot testing participants' neck-head angles averaged 5 degrees when looking straight ahead, 20 degrees when looking down at the feet, 0 degrees when jutting the jaw to imitate extreme FHP, and -15 degrees when tilting the head back.

Because compression is known to be particularly detrimental to nerves in the neck (Bogduk & Mercer, 2000), we also included a measure of neck length (Fig. 1c (iii)), defined as the estimated total distance between the joint center of the C7/T1 vertebra and AO. A smaller linear distance would suggest greater compression in the neck. During pilot testing, participants' neck lengths averaged 8.5 cm when looking straight ahead or when looking down at the feet, 7.5 cm when jutting the jaw to imitate extreme FHP, and 8 cm when tilting the head back.

2.5. Statistical analysis

We used Microsoft Office Excel 2013 for generating graphs and analyzing correlations and SPSS Version 22 for conducting ANOVAs. We verified that data met statistical assumptions using the Shapiro/Wilk test of normality on residuals and Mauchly's test of sphericity for homogeneity and equality of variance. Effect size estimates are reported using partial eta-squared (ηp^2). We used an alpha of 0.05 for significance testing. Significant effects were followed with post hoc tests using Tukey's Honestly Significant Difference. Because the correlations between cognition and anticipation of movement were exploratory in nature, we used a Bonferroni correction (Dunnett, 1955) to account for three postural measures which were compared to each cognitive measure ($\alpha = 0.05/3 = 0.0167$). Because our interest in the relation between cognition and anticipation did not depend on task condition, we used the average posture value across task conditions.

To analyze the effects of anticipating movement, we used a 1x4 repeated measures ANOVA to compare posture during (1) Baseline (when participants did not immediately anticipate walking), and when participants were anticipating walking (at the start of the countdown, 3 s prior to stepping) in (2) Simple (waist height, empty tray), (3) Down (low box, empty tray), or (4) Rolling (waist height, balancing an object), conditions.

To determine whether inhibitory control or mindfulness was associated with postural alignment, we tested for correlations between each participant's inhibitory control (Go/No-Go false alarm scores and Stroop conflict time scores) and self-reported mindfulness (MAAS score) with postural measures assessed during Baseline and when anticipating walking in Simple, Down, and Rolling conditions.

To determine whether effects of our manipulations on our postural measures (FHP, head flexion/extension, and neck length) were associated with inhibitory control or mindfulness, we calculated the difference in posture for each manipulation from Baseline (Baseline-Simple, Baseline-Down, and Baseline-Rolling) and correlated those differences with Go/No-Go false alarm scores, Stroop conflict time scores, and MAAS scores.

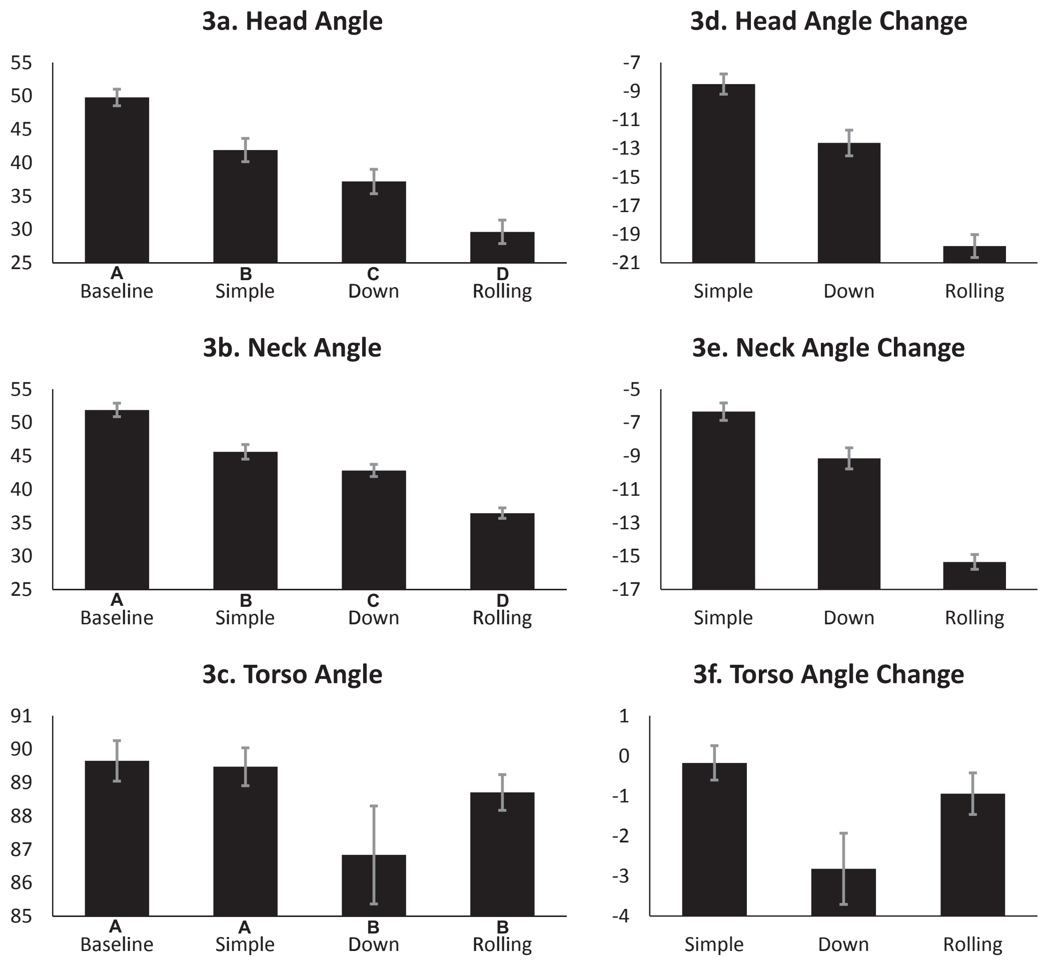


Fig. 3. Extrinsic angle values. Graphs of (a) head angle, (b) neck angle, and (c) torso angle relative to the horizontal plane during baseline and anticipating simple, down, and rolling tasks. Lettering indicates contrast groups for significant main effects. Error bars represent within-subjects standard error. Change in (d) head, (e) neck, and (f) torso angles from baseline.

2.6. Exclusion criteria

No participants were excluded due to existing musculoskeletal issues or neurological disorders. One subject's kinematic data were excluded due to missing trials. Go/No-Go results from five subjects, Stroop results from two subjects, and MAAS results from one subject were excluded from correlations due to missing data.

3. Results

3.1. Kinematic data

3.1.1. Analysis of extrinsic angles

Anticipation of movement resulted in significant differences in head, $F(3, 129) = 60.9$, $p < 0.001$, ($\eta p^2 = 0.61$); neck, $F(3, 129) = 61.1$, $p < 0.001$, ($\eta p^2 = 0.61$); and torso angle, $F(3, 129) = 3.5$, $p = 0.02$, ($\eta p^2 = 0.08$). Differences between each condition for extrinsic angles are shown in Fig. 3. Post-hoc comparisons revealed that head angle was greater during the Baseline condition than the Simple, $t(43) = 3.9$, $p < 0.001$, Down, $t(43) = 6.7$, $p < 0.001$, or Rolling conditions, $t(43) = 9.1$, $p < 0.001$; head angle was also greater during the Simple condition than the Down, $t(43) = 3.1$, $p < 0.001$, or Rolling conditions, $t(43) = 9.1$, $p < 0.001$; and head angle was greater during the Down than the Rolling condition, $t(43) = 4.4$, $p < 0.001$. Neck angle was greater during the Baseline condition than the Simple, $t(43) = 4.3$, $p < 0.001$, Down, $t(43) = 8.1$, $p < 0.001$, or Rolling conditions, $t(43) = 11.8$, $p < 0.001$; neck angle was also greater during the Simple condition than the Down, $t(43) = 2.8$, $p = 0.007$, or Rolling conditions, $t(43) = 12.4$, $p < 0.001$; and neck angle was greater during the Down than the Rolling condition, $t(43) = 6.4$, $p < 0.001$. Torso angle was smaller in the Down condition than during the Baseline, $t(43) = 2.2$, $p = 0.03$, and Simple conditions, $t(43) = 2.0$, $p = 0.047$, and smaller during the Rolling condition than the Baseline, $t(43) = 2.5$, $p = 0.02$, and Simple conditions, $t(43) = 2.2$,

$p = 0.03$. Fig. 3 summarizes changes in (3d) head, (3e) neck, and (3f) torso angles from baseline to anticipation.

3.1.2. Descriptive statistics for intrinsic angles and neck length

Histograms for Baseline data of each computed measure (intrinsic angles and neck length) are shown in Fig. 4. Residuals were normally distributed for all variables and sphericity was not violated for any of the variables.

3.1.3. Effects of anticipating movement

Anticipation of movement resulted in significant differences in torso-neck angle, $F(3, 129) = 88.3$, $p < 0.001$, ($\eta p^2 = 0.67$); and neck-head angle, $F(3, 129) = 12.4$, $p < 0.001$, ($\eta p^2 = 0.23$), but not neck length; these differences are shown in Fig. 5. Post-hoc comparisons revealed that torso-neck angle was lower during Baseline than Simple, $t(43) = -5.2$, $p < 0.001$; Down, $t(43) = -6.0$, $p < 0.001$; and Rolling conditions, $t(43) = -13.4$, $p < 0.001$, and greater during the Rolling condition than during Simple, $t(43) = 10.8$, $p < 0.001$, or Down conditions, $t(43) = 12.0$, $p < 0.001$. Neck-head angle was lower during Baseline than in the Simple, $t(43) = 2.2$, $p = 0.02$, Down, $t(43) = 3.7$, $p < 0.001$, and Rolling conditions, $t(43) = 6.3$, $p < 0.001$, and greater during the Rolling condition than during Simple, $t(43) = 4.4$, $p < 0.001$, and Down conditions, $t(43) = 2.2$, $p = 0.02$. Fig. 5 summarizes changes in (5d) neck-head angle, (5e) torso-neck angle, and (5f) neck length from baseline to anticipation.

The effect of anticipation on torso angle presented a potential confound. To investigate this possibility, we included torso angle as a time-varying covariate in a 1x4 repeated measures MANCOVA. Effects of the experimental conditions on torso angle did not correlate with the effects on torso-neck angle, $F(3, 129) = 0.13$, $p = 0.23$, neck-head angle, $F(3, 129) = 0.48$, $p = 0.49$, or neck length, $F(3, 129) = 1.45$, $p = 0.23$; thus torso angle was not a significant covariate.

3.2. Cognitive data

3.2.1. Go/No Go

On average, SRT was 312 ms (SD = 35 ms), with a hit rate of 98.1% (SD = 5.3%); Go/No-Go RT was 386 ms (SD = 46 ms), with a hit rate of 92.0% (SD = 6.7%) and a false alarm rate of 44.4% (SD = 20.6%). This indicates that participants responded more slowly, $t(37) = 23.5$, $p < 0.001$; and less accurately, $t(37) = 16.92$, $p < 0.001$; for the Go/No-Go task than for the SRT task.

3.2.2. Stroop

On average, participants completed the ink-color naming task in 25.9 s (SD = 5.5) with an average of 0.26 errors (SD = 0.58), the word condition in 21.4 s (SD = 4.2) with an average of 0.19 errors (SD = 0.45), and the conflict condition in 59.0 s (SD = 9.4) with an average of 1.5 errors (SD = 1.6). This indicates that participants responded more slowly during the conflict condition than during the ink condition, $t(42) = 8.46$, $p < 0.001$, or the word condition, $t(42) = 11.9$, $p < 0.001$, but had no difference in accuracy.

3.2.3. MAAS

Average score on the MAAS was 59.05 (SD = 9.45).

3.3. Correlations between cognitive and kinematic data

3.3.1. Correlations within conditions

Only correlations that were significant after correcting for multiple comparisons are reported. There was a negative correlation between number of Go/No-Go false alarms and neck-head angle; $r(37) = -0.44$, $p = 0.01$. Fig. 6a shows the correlation between false alarms and neck-head angle averaged across conditions. Participants with worse inhibitory control had a smaller neck-head angle (greater head extension) compared to those with better inhibitory control. There were no significant correlations between other postural measures and Go/No-Go performance.

There was a positive correlation between time to complete the Stroop conflict task (Stroop score) and torso-neck angle; $r(41) = 0.42$, $p = 0.01$. Fig. 6b shows the correlation between conflict time and torso-neck angle averaged across conditions. Participants with worse Stroop scores had higher torso-neck angles (more FHP) compared to participants with lower Stroop scores. There were no significant correlations between other postural measures and Stroop performance.

There was a negative correlation between MAAS score and torso-neck angle; $r(42) = 0.42$, $p = 0.01$. Fig. 6c shows the correlation between MAAS score and torso-neck angle averaged across conditions. Participants with lower self-reported mindfulness had a higher torso-neck angle (more FHP) compared to those with higher self-reported mindfulness. There were no significant correlations between other postural measures and MAAS scores.

3.3.2. Across-condition correlations

We found a significant correlation between number of Go/No-Go false alarms and change in neck length when anticipating walking; $r(37) = 0.40$, $p = 0.01$. Fig. 7 shows the correlation between false alarms and change in neck length when anticipating walking, averaged between Simple, Down, and Rolling conditions. Participants with fewer false alarms on the Go/No-Go task had less shortening of the neck when anticipating movement compared to those with more false alarms. There were no significant correlations between inhibitory control measures and the effect of anticipation on other postural measures.

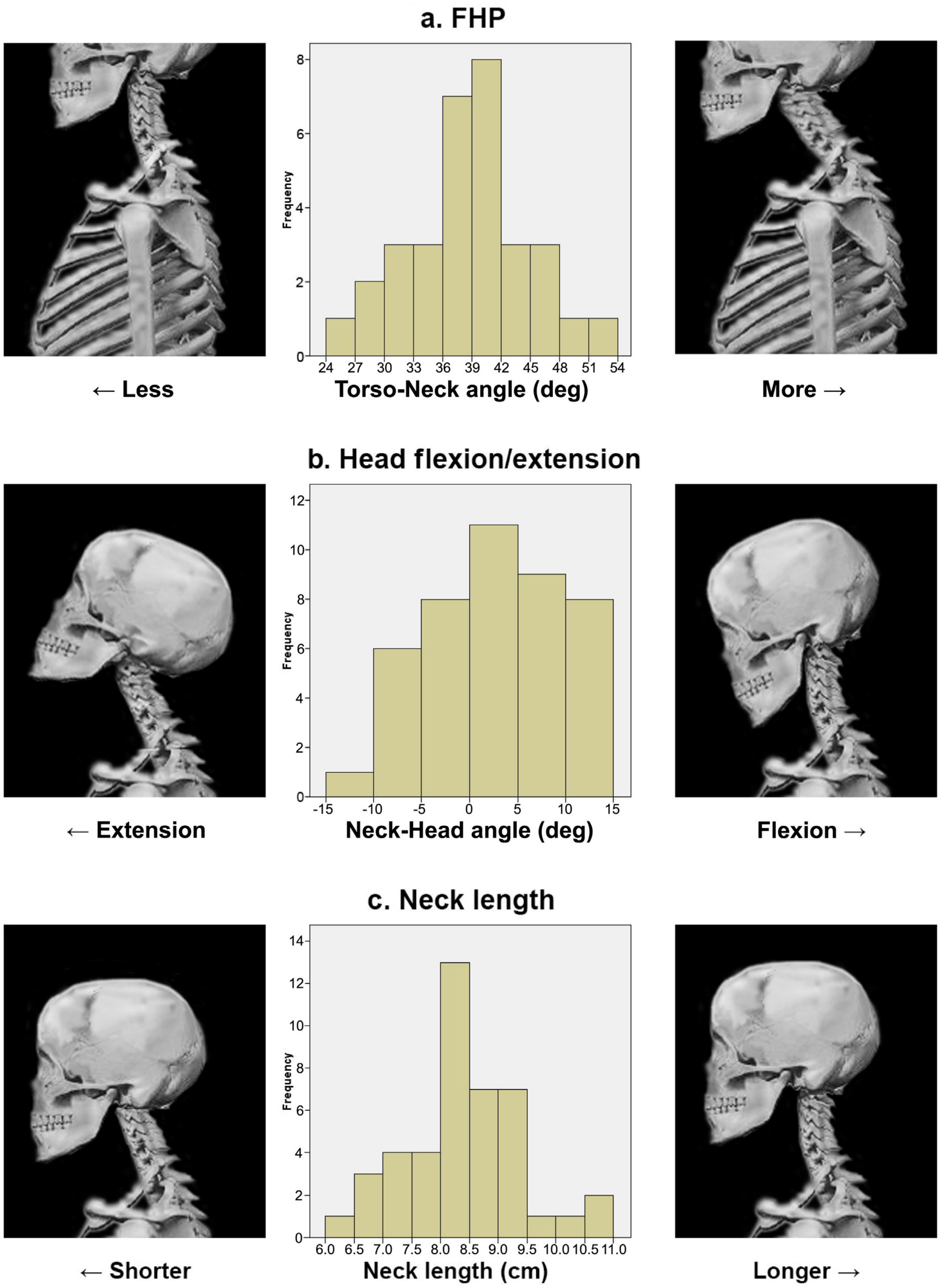


Fig. 4. Histograms of baseline posture measure. Histograms of values during baseline for (a) torso-neck, (b) neck-head angle, and (c) neck length; accompanied by images of extreme postures.

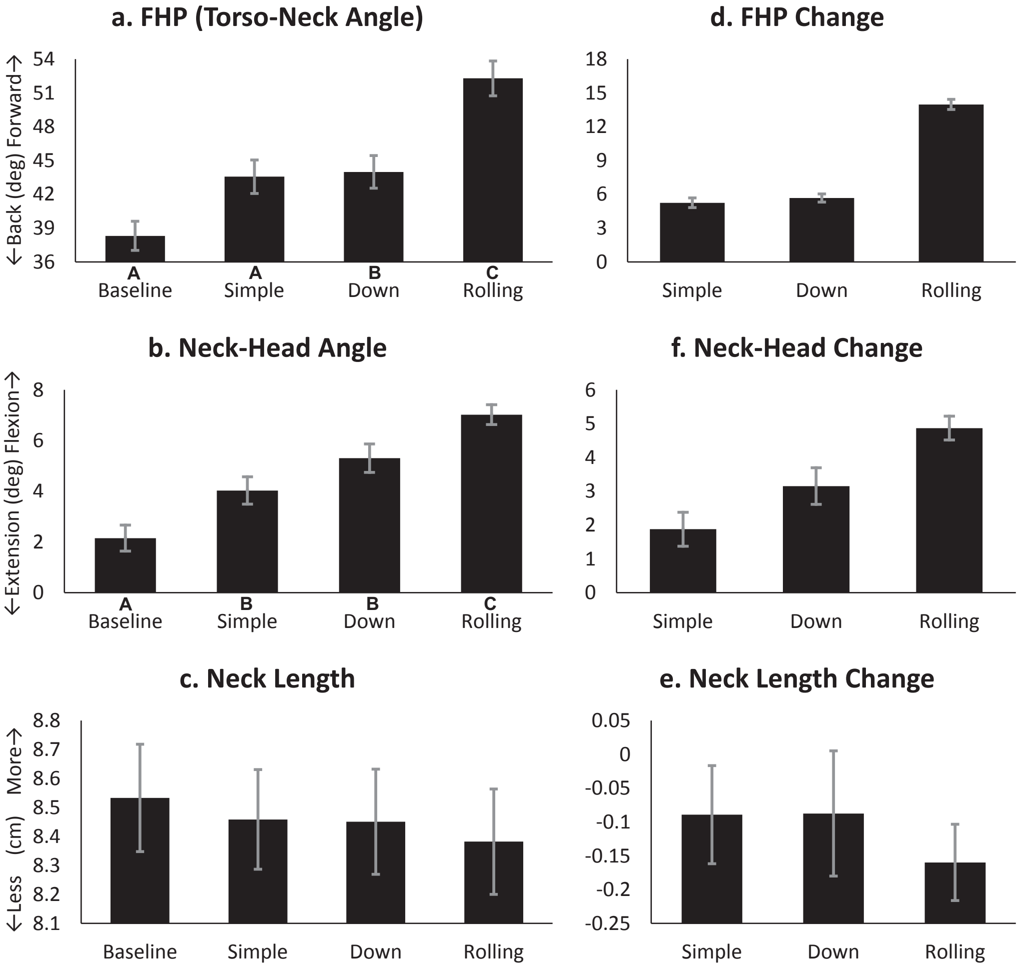


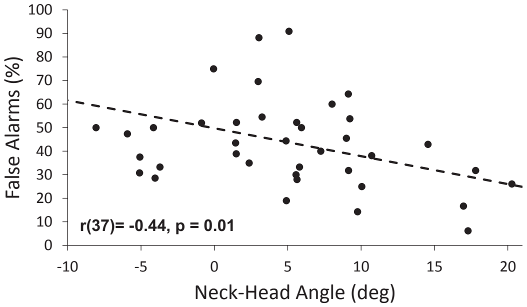
Fig. 5. Effects of anticipating movement. Graphs of (a) torso-neck angle (FHP), (b) neck-head angle, and (c) neck length during baseline and anticipating simple, down, and rolling tasks. Lettering indicates contrast groups for significant main effects. Error bars represent within-subjects standard error. Change in (d) torso-neck angle, (e) neck-head angle, and (f) neck length from baseline.

4. Discussion

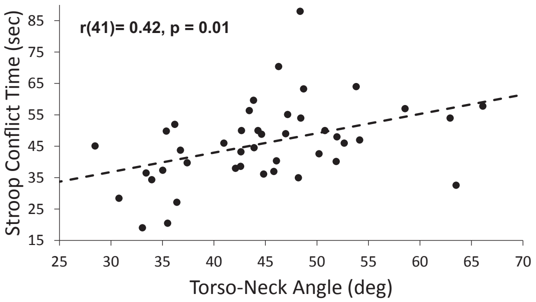
The goal of this study was to investigate possible links among anticipation, inhibitory control, and postural alignment of the head and neck during the initiation of walking. Our central findings were that torso-neck angle was greater when participants were anticipating walking toward a target than when not anticipating walking, weaker inhibitory control and lower mindfulness were associated with greater postural deviation, and weaker inhibitory control was associated with shortening of the neck when anticipating movement. With respect to our initial predictions: (1) FHP was greater when anticipating movement than when not anticipating movement. (2) Anticipating more difficult movement (balancing a rolling pen on a tray) increased FHP, while lower target position increased forward torso lean but had no effect on head or neck posture. (3) Weaker inhibitory control (as assessed by false alarms on the Go/No-Go task) was associated with a habitual head extension in all conditions. (4) Weaker inhibitory control was associated with shortening the neck when anticipating movement. The implications of these findings are explored in depth below.

4.1. Effect of movement anticipation on postural alignment

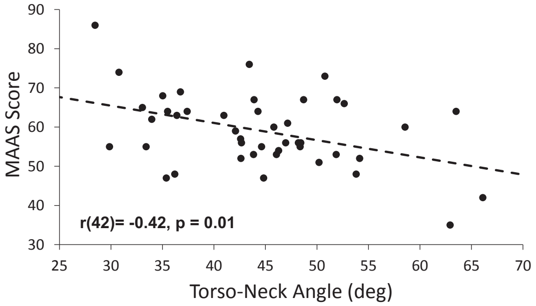
Our first hypothesis was that people “lead with the head” when anticipating movement, leading to FHP and related postural deviations. This hypothesis was supported. When participants anticipated taking a step in three seconds, they shifted their heads forward in relation to their torsos, leading to increased FHP. Comparison of the Baseline and Simple conditions in Fig. 3 confirms that this anticipatory forward movement occurred at the neck, not at the hips or ankles. This novel finding supports the idea that people tend to “lead with the head” when they intend to move forward, perhaps in order to attend closely to a task or to a target they plan to approach.



a. Head extension relates to poor inhibitory control



b. Greater FHP relates to poor inhibitory control



c. Greater FHP relates to lower mindfulness

Fig. 6. Backward head tilt and increased FHP relate to poor inhibitory control. Correlations between Go/No-Go false alarms and neck-head angle (a), Stroop conflict times and torso-neck angle (b), and MAAS scores and torso-neck angle (c). Values for average neck-head angle and torso-neck angle across all conditions were used, as the relationship is consistent between conditions.

This study showed that head and neck posture in the sagittal plane changes *prior* to locomotion; previous research has shown that *during* locomotion, the head orients in the horizontal plane prior to the body in anticipation of turns. (Grasso, Prévost, Ivanenko, & Berthoz, 1998; Hicheur, Vieilledent, & Berthoz, 2005; Imai, Moore, Raphan, & Cohen, 2001; Spildooren et al., 2013). This orientation occurs approximately one second prior to the turn (Imai et al., 2001), regardless of the angle of the anticipated turn (Hicheur et al., 2005), even with the eyes closed (Grasso et al., 1998). This suggests that the act of “leading with the head” in anticipation of movement is part of a general orienting process in which we plan for action by attending to the path ahead and sending our heads in that direction.

4.2. *Effects of compelling conditions on postural alignment*

Our second hypothesis was that FHP and related postural deviations would be greater in conditions that are compelling (such as

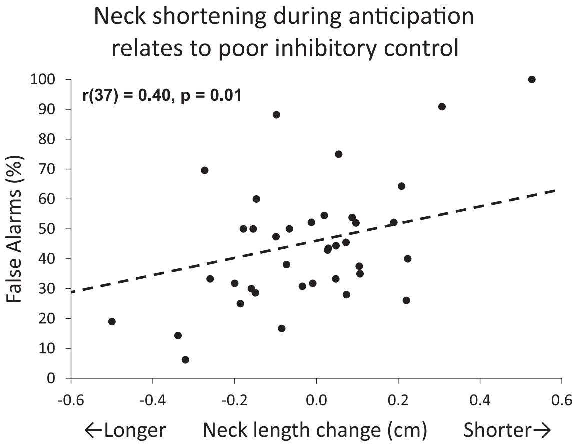


Fig. 7. Change in neck length due to preparation. Correlation between Go/No-Go false alarms and change in neck length from baseline to anticipating simple movement. Values for average neck length changes across all walking conditions is used, as the relationship is consistent between conditions.

when trying to balance an object on a tray) than in less compelling conditions (such as simply holding a tray). The results are consistent with this hypothesis. FHP increased more during the Rolling condition (which required careful attention to stabilize the motion of the tray) than during the Simple and Down conditions, while torso lean increased in both the Down and the Rolling conditions, relative to the Simple condition. This dissociation suggests that target height and task difficulty had separate effects on posture; torso lean was equally sensitive to target height and task difficulty, but FHP was more affected by task difficulty. However, it should be noted that we did not fully cross the factors of target height and task difficulty.

Another possible explanation for these results is that participants may have adjusted their alignment to improve visibility of the target. Although participants were instructed to look straight ahead, it is likely that balancing an object created a temptation to look down at the tray, which could have influenced results. Additionally, when participants expected a more downward movement, they may have leaned forward more at the torso because the goal was below their normal line of sight. The resulting changes in alignment could still be considered maladaptive, as the head and neck move out of alignment with the torso; future studies should investigate this alternative hypothesis.

4.3. Relationships between upright posture and inhibitory control

Our third hypothesis was that deviations in head and neck posture would be more pronounced in individuals with weaker inhibitory control (as indexed by false alarms on the Go/No-Go task and time to complete the conflict condition of the Stroop task) and lower self-reported mindfulness. This hypothesis was supported, but not in as simple a way as we expected. FHP was associated with slower performance on the Stroop task and lower self-reported mindfulness but not with false alarms on the Go/No-Go task; Go/No-Go false alarms, in contrast, were associated only with extension of the head relative to the neck. All three of these correlations were significant whether posture was considered during simply standing or when anticipating movement in any of the three conditions. In addition, both the relationship between false alarms and backward head angle, and the association between FHP and poor Stroop performance were replicated in separate, unpublished pilot studies in our lab.

Why might a postural variable correlate with one measure of inhibitory control but not with another? The answer could lie in the different aspects of inhibition that are challenged by the two tasks (Aron, 2011). Go/No-Go is primarily a test of reactive inhibitory control, in which the participant does not know in advance whether the next trial will call for inhibition or not (Aron, 2011). The Stroop task, in contrast, calls primarily on proactive control; participants know in advance that they will need to inhibit their automatic tendency to read the words (Kalanthroff, Avnit, Henik, Davelaar, & Usher, 2015). We do not currently have an explanation for why proactive control would be more associated with neck angle while reactive control would be more related to head angle.

We also note that FHP and head extension are not completely independent. Logically, if your head is pushed forward, you will need to tilt your head back relative to your neck in order to look forward. This was confirmed by a post-hoc examination of our data revealing a correlation of 0.75 between FHP and backward head extension at Baseline.

4.4. Relationships between inhibitory control and anticipatory effects

Our final hypothesis was that poor inhibitory control is associated with greater deviation in neck posture when anticipating movement, especially under compelling conditions. Poor inhibition was associated with shortening of the neck when anticipating movement, whereas subjects with better inhibitory control were more able to maintain their neck length when faced with compelling demands. This correlation was also present during a similar (unpublished) pilot study. Previous evidence has indicated that poor inhibitory control is associated with ineffective stress management (Li & Sinha, 2008) and that stressful situations often lead to an increase in muscle activity in the upper torso (Yoshie, Kudo, Murakoshi, & Ohtsuki, 2009). Perhaps subjects with weaker inhibitory control had greater difficulty coping with the stress of increasing task demands, and the increased stress resulted in an increase in neck muscle activity, leading to neck shortening. Future studies should combine the neck length measure with electromyography to further investigate this possibility.

4.5. Advantages and disadvantages of FHP

We return now to the question of *why* we would put our heads forward. Previous work suggests that neck position can affect the threshold for sensory processing and muscle activation (Fujiwara, Tomita, & Kunita, 2009). Fujiwara and colleagues presented participants with auditory, visual, and somatosensory stimuli while controlling their head and neck positions. When participants assumed a position combining FHP and increased head extension (called "flexed neck" in those studies), neuroimaging revealed reduced latency for sensory evoked potentials and increased oxidative hemoglobin in relevant sensory regions compared to neutral neck posture (Fujiwara, Kunita, Kiyota, Mammadova, & Irei, 2012). In addition, a flexed neck position improved reaction time during a bilateral arm flexion task (Fujiwara et al., 2009). It is possible that this posture primes "go" networks in preparation for anticipated action, lowering the response threshold in the motor areas of the brain or spinal cord. This would account for both Fujiwara's finding of faster reaction times and our finding of increased false alarms in the Go/No-Go task. A similar phenomenon has been observed with deep brain stimulation of the subthalamic nucleus of people with Parkinson's disease (Ballanger et al., 2009).

The studies cited above only examined acute head and neck posture. However, if *habitually* pushing the neck forward and tilting the head back relative to the neck leads to a chronic bias toward action, this could account for the poorer inhibitory control we observed in participants with these postural habits. Indeed, another study from Fujiwara's group indicated that the association between faster reactions and FHP does not arise until eleven years of age, suggesting that the association is learned, not innate (Kunita, Fujiwara, Kiyota, Yaguchi, & Kiyota, 2018). Yet another study from the same group demonstrated that practicing a speeded task with FHP leads to faster performance on that task with FHP than in neutral posture (Kunita & Fujiwara, 2009). An intriguing question that follows is whether this association can be *unlearned* with sufficient practice in a neutral posture.

4.6. Relating the present work to research on postural control

Numerous studies have demonstrated a connection between cognition and postural *control*, defined by (Shumway-Cook & Woollacott, 2012) as control of body position for stability and orientation (Hawkes, Siu, Silsupadol, & Woollacott, 2012; Huxhold, Li, Schmiedek, & Lindenberger, 2006; Mirelman et al., 2012; Muir-Hunter et al., 2014; Yogev-Seligmann, Hausdorff, & Giladi, 2008). However, only a few studies have investigated associations between cognition and postural *alignment*, which is defined by (Kendall et al., 2005) as aligning the lobe of the ear, the seventh cervical vertebra, the acromion process, the greater trochanter, the joint of the knee, and the ankle joint with a central line from the head to the feet, to balance weight distribution and increase joint stability. Most studies relating cognition to alignment (including the current study) focus on alignment of the head and upper torso. For instance, recent research has demonstrated associations between cognition and postural alignment in healthy older adults (Cohen, Vasavada, Wiest, & Schmitter-Edgecombe, 2016) and in people with Parkinson's disease (Ninomiya et al., 2015).

Though postural control and postural alignment are typically considered separately, some recent studies suggest that they are linked. For instance, one study found that heavy computer users tend to habitually carry their heads and necks farther forward than light computer users, and that heavy computer users also have worse balance than light users (Kang et al., 2012). In another study, healthy older adults mimicking the stooped posture of Parkinson's patients had reduced stability margins in response to whole-body perturbations (Jacobs, Dimitrova, Nutt, & Horak, 2005). These results suggest that stooped forward postural alignment decreases postural control. An intriguing possibility raised by this finding is that there may be a connection between the decline in inhibitory control seen with aging (Muir-Hunter et al., 2014) and the concurrent increase in stooped posture (Nemmers, Miller, & Hartman, 2009).

4.7. Strengths, limitations, future directions

This was the first study to examine the influence of anticipation of walking on head and neck posture, and the first study to correlate inhibitory control to head/neck posture across individuals. The study only included healthy young adults, but it is well known that both postural alignment and inhibitory control decline as people age (Dalton & Coutts, 1994; Kuhlman, 1993; Nemmers & Miller, 2008). Further, it is known that past instances of neck pain are associated with changes in postural alignment; unfortunately, the present study did not gather data about past neck pain alongside information about current health. Future studies could investigate whether the effect of anticipation on FHP or the relation between poor inhibitory control and head extension is stronger or weaker in older subjects, children, those with a history of neck pain, or neuroatypical populations, such as people with ADHD, mild cognitive impairment, or Parkinson's disease.

Methodological issues limit the conclusiveness of some our results. For instance, we used a visual-manual task to attempt to challenge attention during the rolling task; it's possible that a non-visual cognitive task would more clearly isolate the effect. Additionally, though participants were instructed to look forward, the use of a tray with an unstable object may have tempted participants to glance down, affecting their head position in the Rolling condition. Future studies could investigate other ways of manipulating task difficulty or instruct participants to always look at the tray. Other manipulations might have different effects on posture. Previous research suggests that time pressure (Birch, Graven-Nielsen, Christensen, & Arendt-Nielsen, 2000; Szeto, Straker, &

Raine, 2002) and increased stress (Bloemsaat, Meulenbroek, & Van Galen, 2005; Chou, Chen, & Chiou, 2011; McLean & Urquhart, 2002) may elicit changes in trapezius activity. Thus, future studies could examine the effects of more stressful conditions and could include EMG measures.

The MotionMonitor assumes standardized anthropometric values in conjunction with the surface measurements to approximate skeletal structures, which may not be accurate for all participants. To address this, we performed pilot testing on 8 additional participants (not part of the study) to verify that data fell within acceptable parameters prior to testing. Additionally, in a subsequent study (Baer & Cohen, n.d.) we used The MotionMonitor as a biofeedback device based on minimal detectable differences in neck length, neck-head angle, and torso-neck angle. Pilot results indicated that a change of 0.24 cm in neck length was easily detectable by all eight (young, healthy) pilot subjects; a change of 3 degrees was detectable for head angle and neck-head angle, and a change of 5 degrees was detectable for neck angle and torso-neck angle. These values are about half the size of the effects we demonstrated in the current study, suggesting that our findings are robust.

The present study investigated acute changes in posture in anticipation of movement. While we have theorized about how acute FHP may relate to chronic FHP (for instance as a result of computer work), this study did not address that question directly. Future studies will address the relation between acute and chronic FHP.

The discrepancy in correlations between postural measures and cognitive measures suggests that further research is needed to understand the complexity of the head/neck/torso relationship. Some interesting modifications would be to measure posture concurrent with a measure of inhibitory control and to assess inhibitory control while controlling posture. Finally, future work could build on the insights gained here by testing interventions that use mindfulness (such as Yoga, or Tai Chi) and/or inhibition (such as Alexander technique) to improve postural alignment and motor function (Cacciatore, Horak, & Henry, 2005; Cohen, Gurfinkel, Kwak, Warden, & Horak, 2015; Crow, Jeannot, & Trewhela, 2015; Lauche et al., 2016; Loram, Bate, Harding, Cunningham, & Loram, 2017; MacPherson et al., 2015; Preece, Jones, Brown, Cacciatore, & Jones, 2016).

4.8. Conclusions

We hypothesized that maintaining a neutral head and neck posture may require inhibition of an impulse to put the head forward of the body when anticipating goal-directed walking. We found that anticipating walking led people to shift their heads forward from neutral, and that poor inhibitory control was associated with a forward thrusted head during all conditions and with shortening of the neck when anticipating walking. Our inclusion of several different measures of head, neck, and trunk alignment provides some initial insight into the complexity of postural alignment and cognitive control. This is the first study to show that alignment of the head and neck is altered in anticipation of stepping, and to relate this effect to inhibitory control. Thus, the results offer the possibility to considerably broaden the study of the relations among cognition, anticipation, and motor behavior.

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