The Influence of Inhibitory Control on Alignment of the Head and Neck

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AUTHORIZATION TO SUBMIT THESIS

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ABSTRACT

Background: Forward head posture (FHP) is detrimental, but its causes are not well understood. We examined how attention contributes to acute FHP and related cervical misalignment.

Hypotheses: Anticipating movement could cause the head to get "ahead of" the body, resulting in acute FHP. Postural attention may reduce FHP. Poor inhibitory control, low mindfulness, or high impulsivity may exacerbate FHP.

Method: Participants walked to grasp a bar, at leisurely or rushed speeds, at different heights, or while balancing an object, with and without postural attention.

Results: FHP increased when anticipating movement, decreased with postural attention, and increased with task difficulty. High impulsivity and low mindfulness related to FHP, shortened neck related to neck disability and poor inhibitory control, and backward head tilt related to poor inhibition.

Conclusion: Maintaining neutral posture may require inhibition of an impulse to put the head forward when anticipating movement. With repetition, this may become chronic.

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CHAPTER 1: INTRODUCTION

Posture is an important aspect of daily activity, as it defines how people orient themselves within an environment: while walking, standing, sitting, or lying down, and while interacting with objects such as tools, consoles, switchboards, controls, and seating. *Postural control* is defined as the ability to control the body's position in space for the combined purposes of stability and orientation; postural control requirements relate to the dynamic demands of an environment to maintain both *postural orientation* and *postural stability* (Shumway-Cook & Woollacott, 2012). Measuring postural control often relies on an inverse-pendulum to assess balance, measuring stability based on where the weight rests on the ankles. Poor posture in the workplace is strongly linked to musculoskeletal disorders (DHHS, 1997; Kendall et al., 2005), and is distinct from postural control. *Postural alignment* is task independent, and focuses on measuring the load on the spine from internal sources, particularly appropriate alignment of the vertebrae. To prevent musculoskeletal disorders during work, NIOSH guidelines provide generalized rules about what workers should avoid, such as repetitive work, forceful exertion, static contraction, and constant loads (DHHS, 1997). Recommendations for maintaining good postural alignment are largely similar to the NIOSH general guidelines for reducing compression and spinal loading, but where NIOSH recommendations focus on remaining upright, other recommendations are not as limited (Kendall et al., 2005; Shumway-Cook & Woollacott, 2012).

1.1 What Constitutes Postural Alignment

The spine is the most important factor in determining postural alignment, because it acts as a primary support for the body’s weight. “Neutral” alignment of spinal curves is important for managing constant loads, which are a primary risk for injury (Bruno et al, 2012; Dunk et al, 2005; Griegel-Morris et al, 1992; Hickey et al, 2000; Kapandji, 1974; Kendall et al., 2005; Yip, Chiu, & Poon, 2008). The back and neck are often considered a continuous support structure in spinal health (Kendall et al., 2005). The neck includes the cervical spine: the top seven spinal vertebrae, which are responsible for supporting the head and are not attached to ribs. The cervical segment of the spine also has the greatest nerve density, and damage here poses the greatest risk to mobility.

Postural recommendations generally state that a neutral resting spine is of the greatest importance. Descriptions of this are often vague, but they generally involve balancing the spinal curvature in a way that reduces compression forces (Dunk, Lalonde, & Callaghan, 2005; Griegel-Morris et al., 1992; Hickey et al., 2000; Kapandji, 1974; Kendall et al., 2005; Yip et al., 2008), because this will reduce the stress of mechanical loads on the spine (Kellgren, 1977; Kendall et al., 2005). The importance of this recommendation is well supported, because instances of chronic lower back pain are commonly preceded by increased mechanical loads on the vertebra, caused by postural abnormalities or frequent lifting (Griegel-Morris et al., 1992; Kellgren, 1977; Kendall et al., 2005).

1.2 Negative Effects of Forward Head Posture

Many of the same factors that influence back pain are also involved in neck pain, and mechanical loads that lead to increased compression of the vertebral discs are a primary concern (Ariëns et al., 2000; DHHS, 1997; Griegel-Morris et al., 1974; Kendall et al., 2005; Yip, Chiu, & Poon, 2008). Degeneration of the intervertebral disc environment, accelerated by increased spinal compression (in combination with a number of genetic causes), accounts for nearly 40% of chronic back pain cases (Barrick et al., 2000; Griegel-Morris et al., 1992; Kellgren, 1977; Kuslich, Ulstrom, & Michael, 1991; Luoma et al., 2000). Though there are a number of interacting factors that accelerate intervertebral degeneration, only the level of compression of intervertebral discs is easily modified through daily activity (Adams & Dolan, 2005).

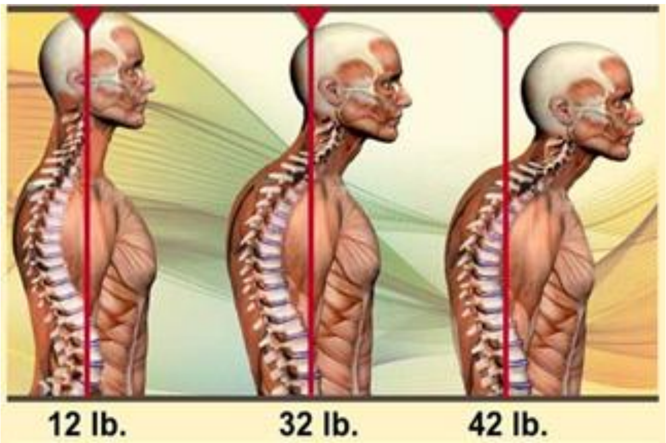

Figure 1 - Progressive load increase with greater FHP

Moving the head forward in relation to the spine results in a stooped posture with an outstretched chin, termed forward head posture (FHP) (Figure 1, Kapandji, 1974). This posture shifts the center of mass of the head forward from its spinal support, increasing shear force on the spinal column and load moment on the cervical spine (Edmondston et al., 2011). This amplified mechanical load on the cervical spine leads to increased musculoskeletal stress (Edmondston et al., 2011; Kapandji, 1974). The mechanical load increases dramatically with greater forward shift of the neck (Kapandji, 1974), leading to a number of chronic health problems.

FHP has been linked to an increased likelihood of chronic neck pain in a number of studies (Ariëns et al., 2001; Ariëns et al., 2000; Chiu et al., 2002; Silva et al., 2009; Watson & Trott, 1993; Yip et al., 2008). It is also believed that FHP leads to reduced postural stability and increased fall risk (Kang et al., 2012; Michaelson et al., 2003). In addition, FHP has been found to affect other systems indirectly, leading to a number of undesirable consequences. For instance, FHP reduces the range of motion in the temporomandibular joint (Visscher et al., 2000), neck joints (Michaelson et al., 2003; Quek et al., 2013) and shoulders (Quek et al., 2013; Szeto, Straker, & Raine, 2002); increases upper torso and shoulder muscle strain (Weon et al., 2010); increases likelihood of cervical headaches (Jull et al., 1999; Page, 2011; Watson & Trott, 1993); and even affects breathing by decreasing maximal respiratory volume (Kapreli et al., 2009). Demonstrated below are several physiological aspects of FHP which lead to these adverse effects.

The most prominent health problem found in conjunction with chronic FHP is long-term neck strain; patients with chronic neck pain are highly likely to exhibit greater FHP than individuals without chronic neck pain (Ariëns et al., 2000; Chiu et al., 2002; Silva et al., 2009; Yip et al., 2008). One study found that the degree of neck pain in middle-aged adults is inversely correlated with the craniovertebral (CV) angle (Yip et al., 2008), an angle between a horizontal line through the spinous process of the seventh cervical vertebra (C7) and a line from C7 to the tragus (small cartilaginous protrusion anterior to the canal) of the ear (Watson & Trott, 1993). Increased FHP decreases this angle, causing shortening of the neck, which is interpreted as compressing the discs between vertebrae, and increasing muscular strain. In studies of head-on-neck postures, FHP has been identified as a risk factor for incidences of increased neck pain both while seated (Ariëns et al., 2001) and while standing (Ariëns et al., 2000; Chiu et al., 2002).

Reduced whole body stability may also be related to FHP, but the results are mixed, suggesting the involvement of other factors. A recent study found that heavy computer users tended to have a more forward head and center of gravity while standing than the control group (Kang et al., 2012). However, another study of young individuals with no neck pathology found that inducing 6 degrees of FHP for 30 seconds had no effect on postural stability (Silva & Johnson, 2013). When exposed to whole-body perturbations, healthy older individuals mimicking the stooped posture of Parkinson’s patients showed reduced stability margins, suggesting that a stooped posture or FHP is destabilizing when resting posture is challenged (Jacobs et al., 2005).

As individuals age they are more likely to adopt a stooped posture, which consists of FHP in conjunction with slumping of the entire upper body forward and downward (Griegel-Morris et al., 1992). An investigation of factors that influence range of neck motion in elderly individuals revealed a positive correlation between age and FHP (Kuhlman, 1993), and causes for this association between aging and FHP are not entirely known. Overall, FHP is more common in older adults than in younger adults (Dalton & Coutts, 1994; Kuhlman, 1993; Nemmers & Miller, 2008), and the progressive decline in the resting angle of head posture with increasing age is even greater in those with neck pain (Dalton & Coutts, 1994). Osteoporosis and other known physiological factors presence are not sufficient to explain this association, though they are known to exacerbate its effects (Griegel-Morris et al., 1992; Nemmers & Miller, 2008).

1.3 Possible Causes of Forward Head Posture

Many factors may contribute to increased FHP (Figure 2). The most widely investigated are genetic predispositions to physiological abnormalities in the spine (Adams & Dolan, 2005; Freemont, 2009) and posture related to workplace ergonomics (Griegel-Morris et al., 1992; Kellgren, 1977; Kendall et al., 2005), but these do not provide a satisfying or complete explanation. Aging, which has a strong association with FHP, is a nonspecific factor that does little to explain FHP in itself. In addition, there is growing acceptance that perceptual-motor, psychosocial, and most recently, executive function factors could influence FHP.

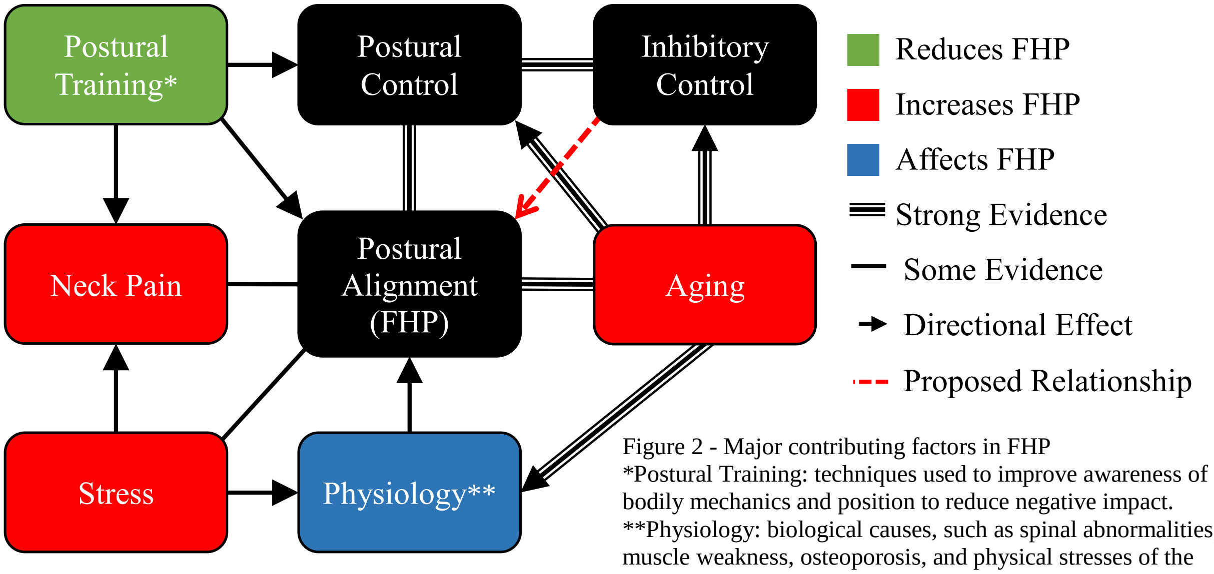

Figure 2 - Major contributing factors in FHP
*Postural Training: techniques used to improve awareness of bodily mechanics and position to reduce negative impact.
**Physiology: biological causes, such as spinal abnormalities, muscle weakness, osteoporosis, and physical stresses of the neck.

a. Perceptual-motor influences

From an evolutionary perspective, a head-first strategy is common. Many sensory organs are located in the head, including the eyes, ears, nose, and mouth. A prevailing theory in evolution is that mobile aquatic animals and terrestrial quadrupeds developed with their heads in front of the body in order to shift from filter feeding to active predation, and to do so it was important to be able to sense food sources and threats in the direction of motion (Le Douarin & Kalcheim, 1999; Northcutt, 2005). Humans also need to know where we are going, but our upright bipedal posture changes the 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 et al., 2011).

Individuals with perceptual misconceptions appear to exaggerate postural corrections, and they are more likely to experience chronic neck pain than those who do not (Edmondston et al., 2007; Lee, Lee, & Yong, 2014). In a recent study comparing sitting postures of otherwise healthy young adults with and without neck pain, there were no differences found between their unattended sitting postures. However, when asked to demonstrate their “best posture”, those with neck pain displayed greater FHP (Edmondston et al., 2007), suggesting that some individuals may not always be aware what good posture consists of. Another study divided healthy young adults into two groups based on whether they displayed FHP while standing. Both groups completed a head-repositioning task to evaluate their proprioceptive sense. Individuals in the FHP group exhibited greater error than those without, and the degree of FHP positively correlated with repositioning error (Lee et al., 2014), suggesting that some individuals are less aware of their neck position, which may lead to FHP; or that chronic FHP may have a negative impact on head proprioception.

b. Psychosocial influences

In addition to the physical and genetic risk factors, psychosocial risk factors may play a major role in the development of neck pain (Adams & Dolan, 2005; Ariëns et al., 2000; Ariëns et al., 2001). Because of the relationship between neck pain and FHP, it is possible that some of these psychosocial factors play a role in FHP as well. A review of psychosocial factors and their relation to neck pain showed that while overall stress is correlated to neck pain, there are certain workplace factors that explain this relationship (Ariëns et al, 2001). The review investigated 29 studies on MSD issues involving the neck in conjunction with a psychosocial factor. Of the workplace factors identified in the review, there was evidence for a positive relationship between neck pain and high work load demands, poor social (coworker) support, low job control, low variety of tasks, and low job satisfaction. Presumably, this increased neck pain is caused because under stress, muscles contract with greater intensity, leading to increased tension and strain (Schleifer et al., 2008). Although this could contribute to FHP, where the muscles contract to pull the head downward, recent findings do not support this association.

Because neck pain is closely related to FHP, several studies of neck pain and stressful work conditions also include measures of FHP. These studies have not found a direct association between FHP and stressful conditions (Chiu et al., 2002; Szeto et al., 2002). A field study of office workers' posture found that computer work significantly increased FHP, both in individuals with neck pain and without (Szeto et al., 2002). Severity of neck pain and changes in posture were related, but the stress introduced from office work did not appear to impact FHP. An epidemiological survey of academic staff's perceived posture, neck pain, and stressful work conditions revealed a strong association between perceived stress and neck pain, and between neck pain and FHP, but no link between stress and FHP (Chiu et al., 2002).

Abnormal inhibitory responses to stress appear to influence muscles involved in neck posture. In response to stressful conditions, motor circuits' evoked potentials increase, indicative of increased excitability. Under normal circumstances, short-interval intracortical inhibition (SICI) accompanies this excitability, mitigating its effects on muscle tension. However, one study showed that within trapezius motor circuits, SICI was absent in individuals with a history of chronic neck pain (Marker et al., 2014). The results of Marker et al. suggest that individuals with a history of neck pain lack compensatory inhibition, leading to increased incidences of painful contraction in the neck. Another study investigated effects of mental concentration and acute stress on cervical muscle activity (Shahidi, Haight, & Maluf, 2013). FHP increased significantly in response to increased mental concentration, but not stress, while upper trapezius muscle activity increased in response to stress, independent of changes to concentration and posture.

As shown above, stress and neck pain are closely related, probably by way of increases in muscle tension, but stress is not directly related to acute presentation of FHP (Ariëns et al., 2001; Marker et al., 2014; Shahidi et al., 2013). This disconnect between acute stress and acute FHP, despite the strong relationship between chronic neck pain and chronic FHP, suggests that other factors are likely to be involved. The link between mental concentration and acute FHP suggests that attentional factors could play a role in FHP (Shahidi et al., 2013); bringing attention to a person's posture can improve their alignment (Westgaard & Winkel, 1997), offering support for this theory.

c. Influences of attention

Theoretically, becoming aware of body position takes active attention, because people do not adjust their posture unless they are experiencing discomfort. On a higher level, this strategy makes sense, because it reduces cognitive load; we don't have to interrupt our thoughts to worry about how we stand unless it hurts. Some interventions to improve attention to posture through awareness of body position have positive effects on musculoskeletal disorders. Little research has been conducted on the underlying reason for their effectiveness, but research suggests that simply instructing individuals to use their best posture or "stay upright" does not produce lasting improvement (Westgaard & Winkel, 1997), and may even prove detrimental to alignment (Edmondston et al., 2007).

Workplace interventions that bring attention to posture can positively influence alignment (Levanon et al, 2012; Park & Yoo, 2012). In one study, experimenters used biofeedback to aid participants in postural maintenance while performing seated computer tasks (Park & Yoo, 2012). EMG feedback from various muscle groups (upper trapezius muscle, L4-erector spinae muscles, both, and none) was presented during 15 minutes of computer operation, and postural angles corresponding to FHP were measured. Under conditions with feedback, subjects maintained a more upright posture. A second study implemented biofeedback in conjunction with ergonomics training across 15 weeks and found that interventions that focused on attending to posture led to a reduction in musculoskeletal pain scores, regardless of the use of biofeedback (Levanon et al., 2012). This evidence suggests that maintaining upright postural alignment requires attention, and computer work may be detrimental to postural alignment because it interferes with this attention.

When rushed, people are compelled more strongly to focus on a singular task, and this imposed time pressure affects inhibitory control and related neural activity. The striatum (part of the basal ganglia) plays a role in action readiness and motor preparation by modulating motor inhibition, and recent research suggests it plays a similar role in decisions (Forstmann et al., 2008). In normal situations, people weigh options and consider consequences carefully, inhibiting a response until an accurate decision is selected; under rushed conditions however, inhibition is decreased, allowing a lower threshold of activation and a more quick response (Forstmann et al., 2008). Inhibitory control is commonly measured by a Go/No-Go task, in which participants respond rapidly to a stimulus unless a certain condition is met, in which case they withhold their response; failure to withhold a response counts as an error, termed a false alarm. In one such study, errors increased significantly while under time pressure; false alarm errors increased dramatically with a response window of 1 second, as opposed to 2 or 3 seconds. This increase in errors is presumably due to participants rushing to act before the response window closes, leading to accidental movements and false alarms (Simpson & Riggs, 2006). This research demonstrates that people have a tendency to give less importance to inhibition when rushed; this tendency may extend to postural alignment. Inhibitory control is a component of executive functions (Miyake et al., 2000), which act as a supervisory component in attention and are influential in postural control.

d. Executive function

Executive function is a term used to refer to organizational processes responsible for coordinating cognitive sub-systems to achieve a particular goal, such as interrupting planned movements, switching between tasks, and maintaining postural control during movement (Elliott, 2003). Executive function is instrumental in goal-directed behavior and in integrating multiple system inputs when performing actions (Verbruggen, McLaren, & Chambers, 2014). There is extensive evidence that executive functions play a key role in postural stability; studies have found links between postural correction and inhibitory activity within the motor cortex (Elliott, 2003; Mirelman et al., 2012; Muir-Hunter et al., 2014; Oliveri et al., 2012). Variability in gait and increased fall risk is also associated with executive function and attention deficits (Hawkes et al, 2012; Mirelman et al., 2012; Yogev-Seligmann, Hausdorff, & Giladi, 2008). The link between executive function and postural control has been studied mostly in the context of aging, and the prevailing method is a dual-task methodology, where a participant performs both a primary and secondary task simultaneously. How a person prioritizes these two tasks allows assessment of attention and inhibition. The concept behind this approach is that human processing resources are limited and shareable, and if performance on one and/or both tasks is lower when done simultaneously, they must be drawing on the same limited resources.

Recent studies of balance performance during dual task experiments link executive function to postural control. One such study showed that decreased executive function correlated with poor balance function in older adults, especially when walking while completing a secondary cognitive task (Muir-Hunter et al., 2014). Another study showed that balance-impaired adults had poorer task switching performance than healthy adults (Hawkes et al., 2012). A third study showed that the relation between cognitive distraction and balance is non-linear, where focus on just the task has little impact on balance, focusing on a related simple external task improves balance, and a complex task reduces performance. During a simple balancing task both young and healthy older adults showed decreased postural sway compared to when just focusing on posture. During an additional protocol, sway increased in conjunction with numerical recall tasks of increasing complexity in older adults but not in young adults (Huxhold et al., 2006).

The dual task studies constitute a link between executive functions and postural *control*, but they do not directly link executive function to postural *alignment* (such as FHP). Postural control, as stated previously, is control of stability and orientation for dynamic tasks (Shumway-Cook & Woollacott, 2012), while postural alignment is the task independent ability to maintain a neutral spine (Kendall et al., 2005). While these two aspects of posture are typically considered separately, some evidence above suggests they may be linked. We believe it is plausible that the inhibitory regulation and attentional influences in executive functions that correlate with postural control also extend to alignment. If inhibitory control in executive functions is related to postural alignment, we would expect to see one or both of the following: (1) a failure to hold the head up, perhaps due to competing cognitive resources and/or inadequate motivation (failing to actively attend to posture); (2) actively pulling the head forward, possibly in response to compelling stimuli (such as motivation to rush toward a target, manipulating the location of the target, or complicating the task with multiple goals). This thesis will address both of those possibilities.

1.4 Summary

As reviewed above, the negative *effects* of FHP are well-documented, but the *causes* are not yet clearly understood. There are evolutionary reasons for adopting FHP for a short period. Spinal abnormalities, workplace physiology, errors in body schema, perceptual differences, and psychosocial factors explain some cases of chronic FHP, but they do not fully explain the prevalence of FHP, or its acute presentation during certain tasks. Executive function has been linked to postural control, and postural control has been linked to FHP, but nobody has yet explored the possible connection between FHP and executive control. Based on previous research relating postural control with cognitive factors such as attention, compelling conditions, and executive function, it is likely that the link between executive functions and postural control also extends to FHP alignment issues.

1.5 Hypotheses

We hypothesized that people have a tendency to lead with the head when preparing to move, causing acute FHP, and that this tendency is modulated by attention and inhibitory control. With repetition, this tendency could lead to chronic FHP. In study 1 we predicted that: (1) Acute FHP would be greater when preparing to move than when not preparing to move. (2) Acute FHP would be reduced when attending to posture, except in subjects with poor inhibition. (3) Acute FHP would be greater under time pressure than in leisurely conditions, particularly in subjects with poor inhibition. (4) Chronic FHP would be more pronounced in participants with poor inhibition.

The biomechanics of the neck are complex. 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. This will lead to compression of the intervertebral discs, and shortening of the neck (Bogduk & Mercer, 2000). This shortening of the neck is likely to lead to prolonged compression of cervical nerves, paresthesia and pain in the neck, shoulder, and extending as far as the arms (Ming, Närhi, & Siivola, 2004). It is possible that some of the negative effects of FHP might be caused by neck compression, perhaps due in part to this backward head/neck angle. Therefore, in addition to our primary outcome measure of FHP, we examined the effects of all manipulations on head/neck angle and total neck length.

CHAPTER 2: STUDY 1 METHODS

2.1 Equipment

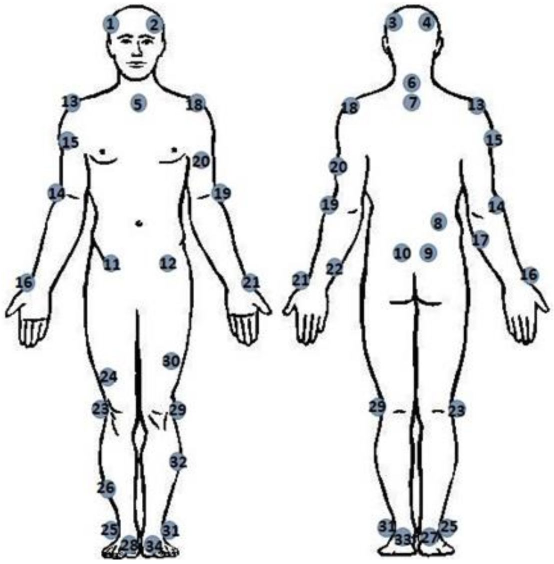

Figure 3 - Vicon marker placement chart

Three-dimensional motion capture data were collected using 8 Vicon Bonita motion capture cameras (Oxford, UK) and processed using The MotionMonitor® software by Innovative Sports Training (Chicago, IL). We placed 34 reflective markers on bony landmarks of the body (Figure 3), 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 (Figure 4a). Based on these Vicon segments, the MotionMonitor produced a composite model of each participant's skeletal structure for analysis (Figure 4b).

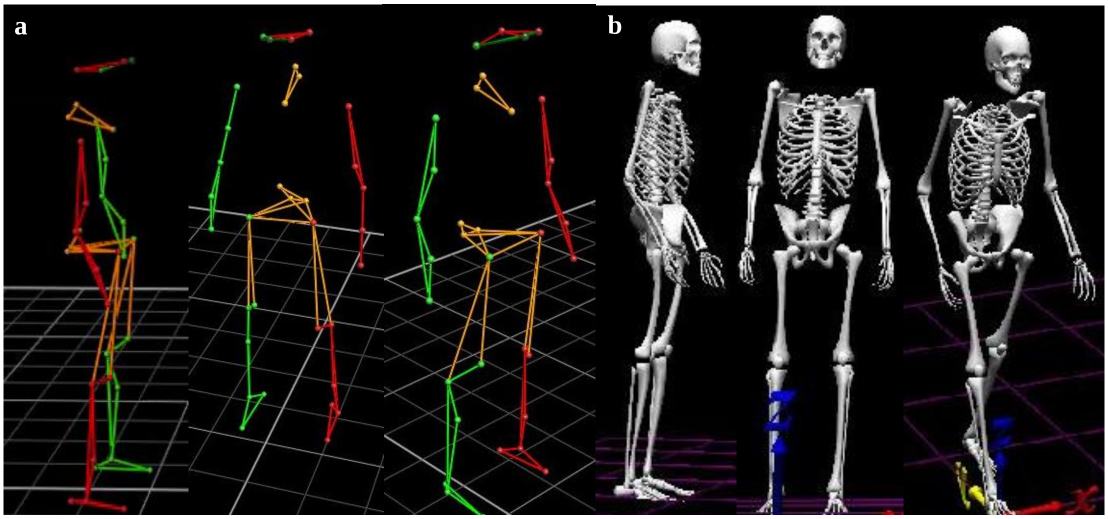

Figure 4 - (a) Vicon marker segments (b) The MotionMonitor composite skeleton

2.2 Participants

We tested 32 participants (21 men and 11 women) between the ages of 18 and 25, recruited from psychology courses at the University of Idaho. Participants were offered course credit through SONA Systems for a two-hour data collection session. Data from four subjects were excluded due to missing trials, and data from one subject were excluded because results for multiple motion capture angles were greater than four standard deviations above or below the mean (suggesting experimenter error).

2.3 Protocol

Participants provided informed consent as approved by the Institutional Review Board of the University of Idaho, in accordance with the Declaration of Helsinki. Reflective markers were applied while the equipment was calibrated. Participants were screened for musculoskeletal injuries, neurological issues, or movement disorders that could interfere with their ability to perform the task comfortably. Data collection consisted of two components: motion capture trials and Go/No-Go testing.

a. Motion capture data collection

Each participant completed five walking trials in an incomplete 2x2x2 design; the factors were postural attention (habitual and attended), instructed walking speed (slow and fast), and time of data capture (baseline and preparation). The manipulation of postural attention applied to both data capture periods. Walking speed was a factor for preparation, but not for baseline. For each walking trial, we asked participants to walk forward 2 meters and take hold of a bar. Before beginning, the experimenters adjusted the height of the bar for each participant, ensuring that when grasping the bar, the participant’s forearm was horizontal.

For the postural attention manipulation, participants performed all trials with their usual posture and no additional instruction (habitual) first, and were then instructed to use their "best posture" (attended) and repeat all conditions. No specific instructions were provided about what that best posture should entail. The participants always performed the attended posture conditions last, to avoid carry-over effects from being instructed to attend to one's posture.

For the speed manipulation, participants were asked to move either at a leisurely pace beginning when they were ready (slow), or at a brisk but comfortable pace beginning when the experimenter said "go" (fast).

Time of data capture referred to when during each trial the data were sampled. Baseline trials, in which participants simply stood still for 5 seconds, were sampled twice: once before walking trials under each attention condition. Preparation was defined as the recorded frame one second prior to the first frame where the participant's horizontal foot displacement exceeded a threshold of 0.5 cm.

b. Simple reaction time and Go/No-Go tasks

In addition to the motion capture trials, each participant completed a short pair of computer tasks that measured reaction time and inhibitory control. In the simple reaction time (SRT) task, participants would sit at a computer, watch the screen for a letter to appear, and press the space bar as quickly as possible when one appeared. For each trial, a random letter was presented once every 1-2 seconds and remained visible for 250 ms; each participant completed 108 trials. 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. 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,” it was counted as a false alarm. The probability of a No-Go stimulus appearing on any given trial was 18%. Response times and hit rates for SRT and Go/No-Go trials were collected, as well as false alarm rates for Go/No-Go trials.

2.4 Motion Capture Data

In postural assessment, body angles are the most commonly accepted measure, but these do not translate directly to spinal compression. In order to address this discrepancy, we measured angles and also computed a measure of neck length. Head, neck and torso angles relative to the horizontal plane were collected for use in data analysis. Each raw angle is oriented towards the front of the participant, and consists of the union between a line connecting two body landmarks and a line from the lower landmark forward in the horizontal plane (Figure 5a, images adapted from http://anatomybodyblog.com/). The head angle uses a line between the Vicon head segment’s center of mass (resulting in a point midway between the temples) (Figure 5b) and the mastoid of the head (a bump behind the ear analogous to the atlanto-occipital joint (AO), located just behind the ears, midway between the left and right mastoid processes, where the spine connects to the head), the neck angle uses a line from the mastoid to the spinous process of the seventh cervical vertebra (C7), and the torso angle uses a line from C7 to the spinous process of the first sacral vertebra (S1). In all cases, a larger angle indicates greater tilt backwards.

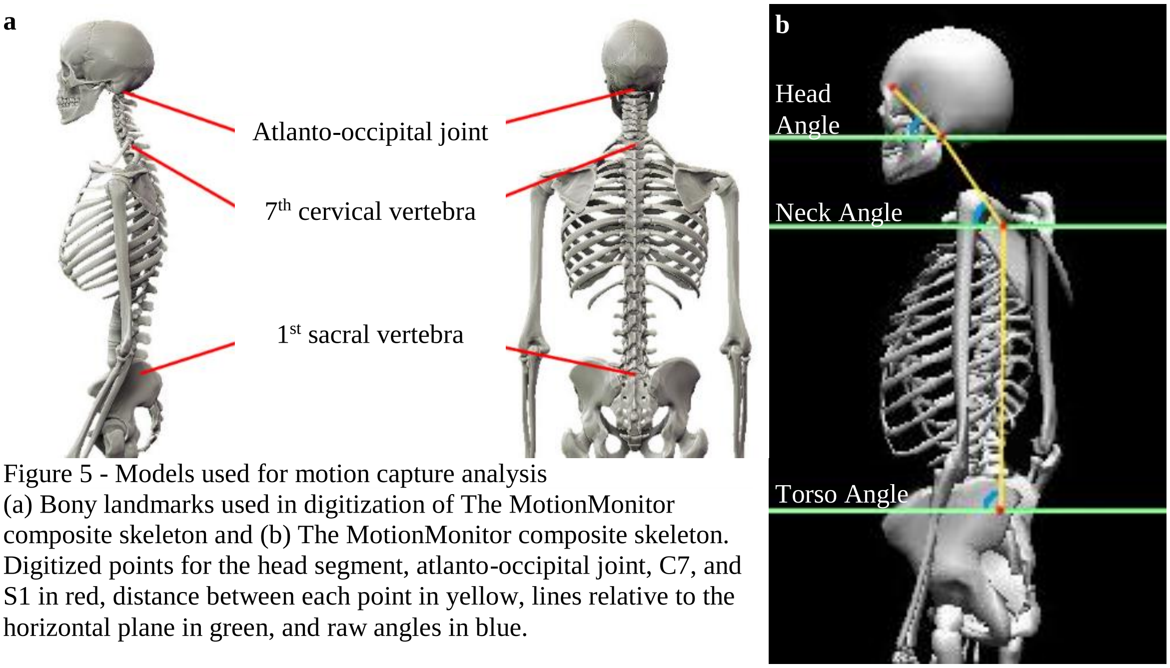

Figure 5 - Models used for motion capture analysis
(a) Bony landmarks used in digitization of The MotionMonitor composite skeleton and (b) The MotionMonitor composite skeleton. Digitized points for the head segment, atlanto-occipital joint, C7, and S1 in red, distance between each point in yellow, lines relative to the horizontal plane in green, and raw angles in blue.

Based on the angles relative to the horizontal plane, we measured FHP using the Neck-Torso angle (Figure 6). This subtracts the torso angle from the neck angle, giving a negative value that indicates a person’s degree of FHP; more negative values indicate a more forward head relative to the torso.

In addition to this, we included a measure of head tilt. Shifting the head a great distance forward or back leads to compression of neck. The Neck-Head angle subtracts the head angle from the neck angle, providing a measure of head on neck alignment (Figure 7). In this case, a more positive value indicates tipping the head forward relative to the neck, and a more negative angle indicates tilting the chin up. A slightly negative angle (less than five degrees) is expected, but due to anatomical differences, there is no absolute neutral.

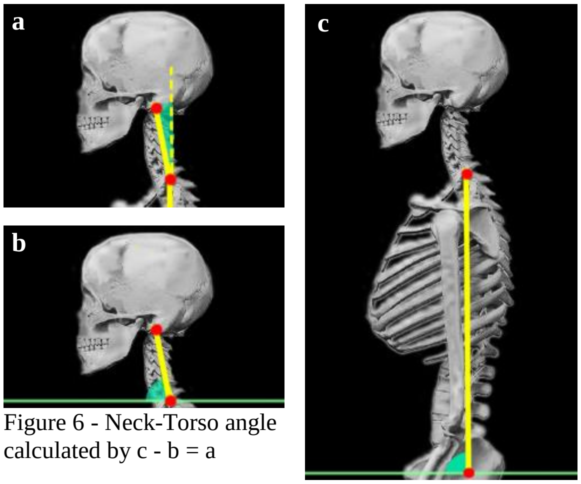

Figure 6 - Neck-Torso angle calculated by c - b = a

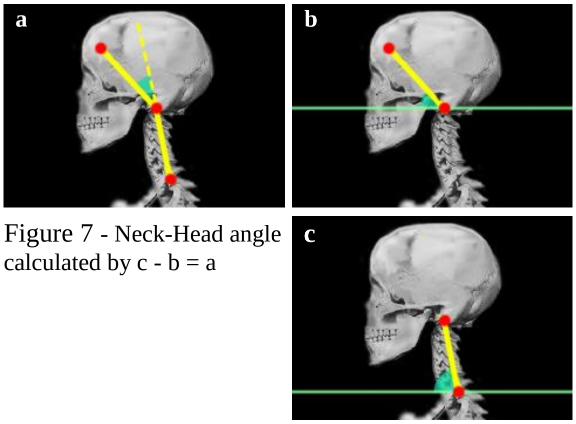

Figure 7 - Neck-Head angle calculated by c - b = a

Because compression is known to be particularly detrimental to the spine, we included a measure of neck length, defined as the total distance between the center of the C7 vertebra and the mastoid (Figure 8). A shorter distance between points indicates greater compression in the neck.

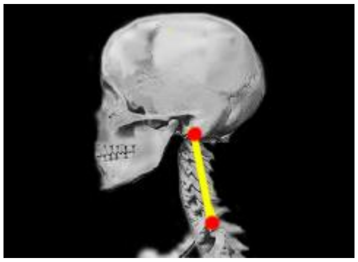

Figure 8 - Length of the neck

2.5 Statistical Analysis

We used Microsoft Office Excel 2013 for generating graphs and analyzing correlations, and SPSS Version 22 for conducting ANOVAs. In order to analyze the incomplete factorial design, we divided our data into multiple parts. Postural attention comparisons could be made using baseline, preparation and stepping, but speed effects could only be compared during preparation and stepping. The first ANOVA used a 2x3 to test the effects of attention and preparation; the two levels of attention were attended and habitual posture; the three levels of preparation were baseline standing and preparation for slow and fast stepping. We followed up on significant effects of preparation using a 2x2 ANOVA that compared attended to habitual posture (attention) at slow and fast speeds (speed) during movement preparation only.

CHAPTER 3: STUDY 1 RESULTS

3.1 ANOVA Results

a. Effects of attention and preparation for movement

To analyze the effects of attention and preparing for movement our first ANOVA compared posture during baseline (when participants do not immediately anticipate stepping) and when participants are preparing to step (one second prior to stepping) at a leisurely pace and a rushed pace, with and without attention to their posture. When attending to posture, participants had necks farther back relative to torsos, longer necks, and more upright torsos than when not attending to posture; figure 9 shows main effects of attention to posture in FHP (Figure 9a), $F(1, 31) = 60.1$, $p < 0.01$, neck length (Figure 9b), $F(1, 31) = 4.6$, $p = 0.04$, and torso angle (Figure 9d), $F(1, 31) = 19.0$, $p < 0.01$. When preparing to move, participants had necks farther forward relative to torsos and less upright torsos than during baseline standing; also shown in figure 9, there were main effects of movement preparation for FHP (Figure 9a), $F(1, 31) = 5.8$, $p < 0.01$, and torso angle (Figure 9d), $F(1, 31) = 13.6$, $p < 0.01$. Finally, when participants prepared to move, differences in alignment of the head with the neck produced by attention to posture diminished; figure 9c also shows an interaction of preparation and postural attention for head tilt, $F(1, 31) = 7.7$, $p < 0.01$, the effect of attention is significant for baseline $t(1,31)=-2.8$, $p < 0.01$; but not for preparing at a leisurely $t(1,31)=-1.0$, $p = 0.3$; or rushed pace, $t(1,31)=0.24$, $p = 0.8$.

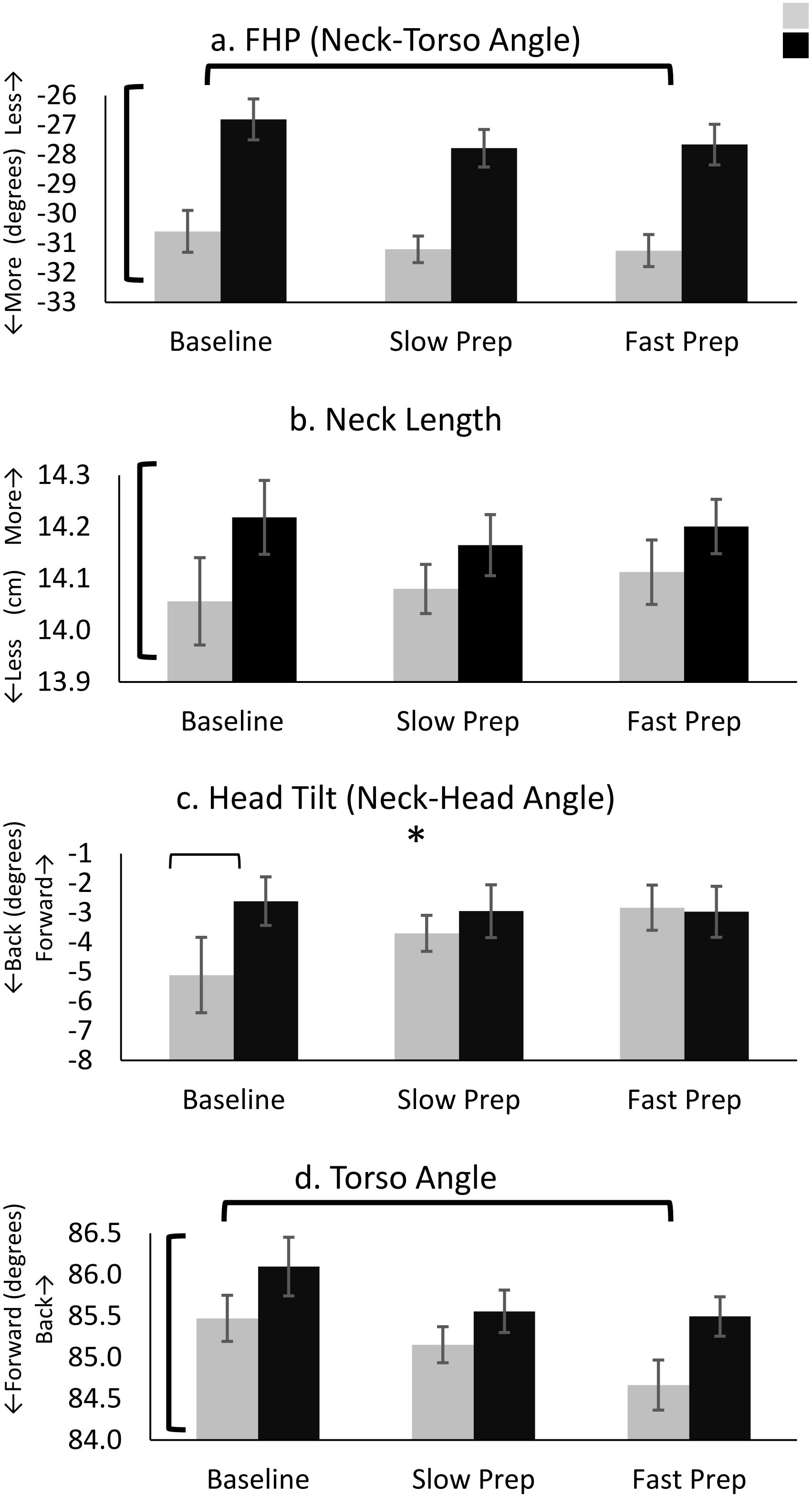

Figure 9 - Effects of speed and attention during movement preparation. Graphs of (a) FHP, (b) neck length, (c) head tilt, and (d) torso angle during baseline and preparation for a movement at a slow and leisurely pace, when not attending to posture (grey) and attending to posture (black). Solid brackets indicate **significant main effects**; vertical brackets for an effect of **attention to posture**, horizontal brackets for **effects of preparing to move**. Asterisks (*) indicate **interaction effects**. Thin brackets indicate **simple effects,** thin horizontal brackets for an effect of attention within the corresponding preparation condition. Condition means are located at each bar base. **Error bars** represent within-subjects standard error.

b. Effects of attention and speed during preparation for movement

To analyze the effects of speed and attention when preparing to move, our second ANOVA compared posture during preparation for movement at brisk and leisurely pace, with and without attention to posture. When preparing to move and attending to posture, participants had necks farther back relative to torsos and more upright torsos than when not attending to posture; figure 10 shows main effects of attention to posture in FHP, F(1, 31) =54.4, $p < 0.01$, and torso angle (Figure 10), F(1, 31) =17.2, $p < 0.01$. When preparing to move at a rushed pace, participants had less upright torsos than at a leisurely pace; figure 10 shows a main effect of speed for torso angle, F(1, 31) =4.8, p = 0.04. Finally, participants had less upright torsos when rushed, unless attending to posture; figure 10 shows an interaction of attention to posture and speed of movement for torso angle, F(1, 31) =5.0, p = 0.03. Head tilt and neck length had no significant effects or interactions.

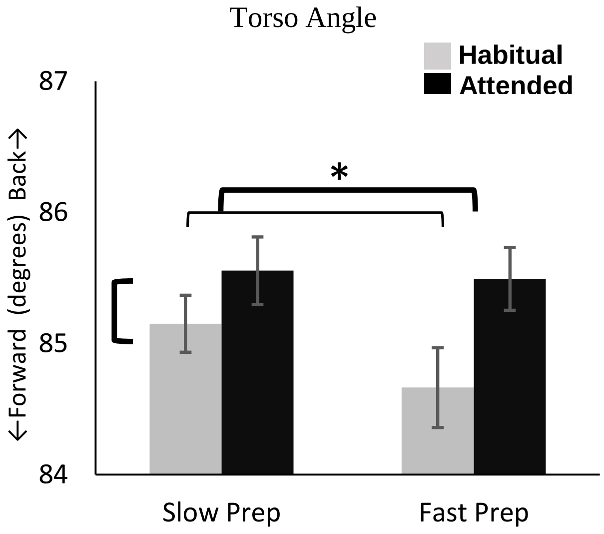

Figure 10 **-** Graphs of torso angle during preparation for movement at a slow (paired bars on the left of the graph) and leisurely (paired bars on the right) pace, when not attending to posture (grey) and attending to posture (black). Solid brackets indicate **significant main effects**; vertical brackets for an effect of **attention to posture**, horizontal brackets for **movement speed**. Asterisks (*) indicate **interaction effects**. Thin brackets indicate **simple effects,** thin horizontal brackets for an effect of speed within corresponding attention condition. Condition means are located at each bar base. **Error bars** represent within-subjects standard error.

3.2 Correlation Results

a. Correlations within condition

To determine whether inhibitory control was associated with postural alignment, we tested for correlations between Go/No-Go results and postural measures for each participant under each walking condition. For all conditions, we found significant negative correlations between number of Go/No-Go false alarms and head tilt (Figure 11a, 11b). Participants with worse inhibitory control exhibited more backward tilt of the head with respect to the neck compared to those with better inhibitory control. There were no significant correlations between other postural measures and Go/No-Go performance.

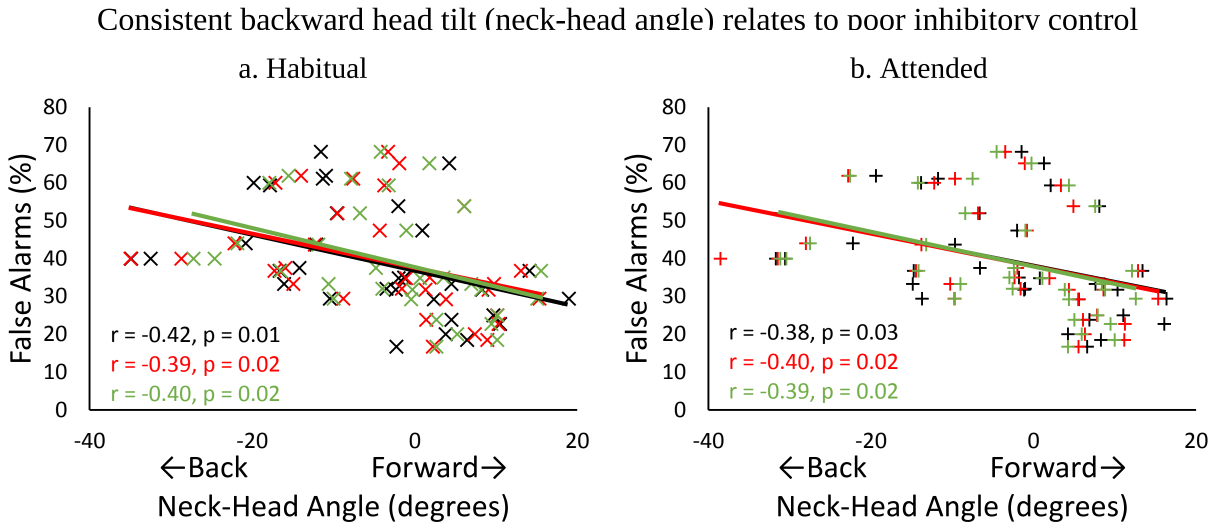

Figure 11 - Head tilt and Go/No-Go false alarm correlations within conditions
Graphs for habitual (a) and best (b) postures. Symbols indicating postural instruction and color in the legend (left).

	Habitual	Attended
Baseline	**r= -0.42, p=.017**	**r= -0.38, p=.032**
Slow Prep	**r= -0.39, p=.027**	**r= -0.40, p=.023**
Fast Prep	**r= -0.40, p=.023**	**r= -0.39, p=.027**

b. Across-condition correlation trends

To determine whether the effects on posture of attention to posture, preparation for movement, and time pressure were associated with inhibitory control, we calculated the difference between conditions for each manipulation and correlated that difference with Go/No-Go false alarm scores. To examine the effect of attention, we used the difference between habitual and attended conditions. To examine the effects of movement preparation, we used the difference between baseline and preparation. To examine the effect of time pressure, we used slow minus fast.

We did not find correlations between Go/No-Go performance and the effect of attention on any aspect of postural alignment that we measured. However, false alarms were associated with changes in neck length due to preparing for movement (Figure 6a). Reduced change in neck length when preparing to move at a rushed pace was associated with better performance on the Go/No-Go task. When rushed, participants with better inhibitory control (fewer false alarms) exhibited less reduction in neck length between standing and preparing to move than those with worse inhibitory control in both habitual, r(1, 31) =-0.40, p = 0.02 and attended conditions, r(1, 31) =-0.38, p = 0.03. This relationship was not present under leisurely conditions regardless of attention to posture. In addition, false alarms were associated with changes in neck length due to time pressure; while attending to posture a more shortened neck length when rushed was associated with worse performance on the Go/No-Go task, r(1, 31) = 0.39, p = 0.02. This relationship was not present when not attending to posture, r(1, 31) =-0.10, p = 0.58.

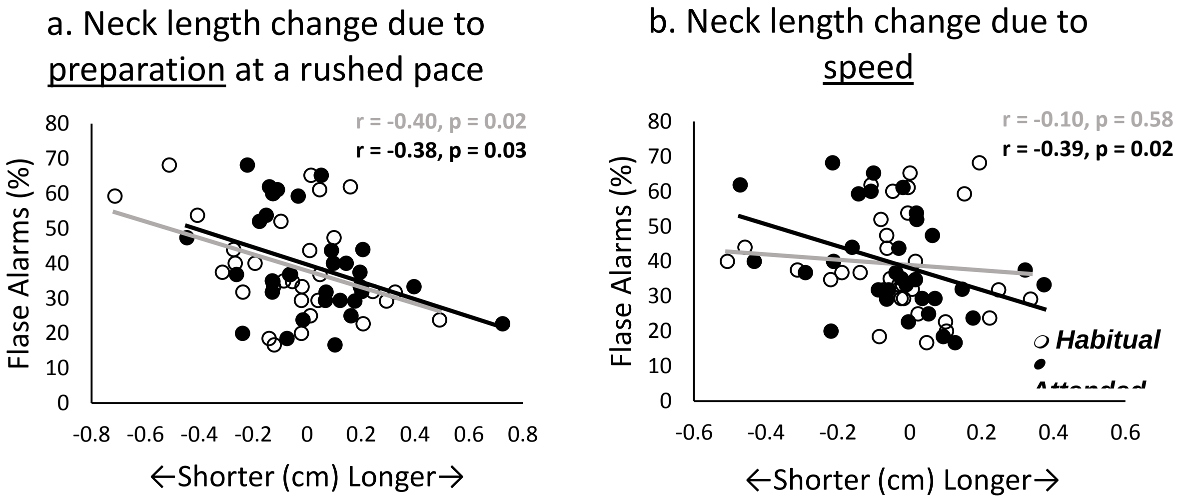

Figure 12 - Correlations between false alarms and neck length change between conditions
Graphs correlating Go/No-Go false alarm scores with change in neck length due to (a) preparing for movement at a rushed pace (baseline - fast preparation), and (b) time pressure (slow preparation - fast preparation). In habitual (unfilled circles, grey trendline) and attended postures (filled circles, black trendline).

CHAPTER 4: STUDY 1 DISCUSSION

4.1 Summary of Results

The goal of this study was to investigate a possible link between inhibitory control and postural alignment of the head and neck during the initiation of walking. Our central findings were that FHP increased when participants were preparing to move, FHP decreased with attention to posture, and weaker inhibitory control was associated with greater backward head/neck angle and increased neck shortening when preparing to move. With respect to our initial predictions, there were four main findings: (1) FHP was greater when preparing to move than when not preparing to move. Preparation also included a forward lean at the torso and a reduction in the differences in neck length and head/neck angle associated with attending to posture. (2) Relative to unattended posture, attending to posture led to reduced FHP and increased forward torso lean. Attending to posture also led to greater neck length and forward head tilt relative to the neck, but only in the baseline condition. Inhibitory control did not relate to changes in posture due to attention. (3) Time pressure increased forward lean of the torso but had no effect on neck posture. (4) Weaker inhibitory control (as assessed by false alarms on the Go/No-Go task) was associated with a backward head/neck angle. Shortening in neck length when preparing to move was also associated with weaker inhibitory control. The implications of these findings are explored in depth below.

4.2 Increased FHP During Movement Preparation

Our first hypothesis was that people would lead with the head when initiating movement, and this would present as increased FHP. This hypothesis was supported. A full second before taking the first step toward a target to be grasped, participants began to lean forward and also shifted their heads forward in relation to the torso, producing acute FHP. This novel finding supports the idea that people have a tendency to “lead with the head” when they expect to move. There is much research on adaptations in postural *control* that occur in advance of whole-body movement, such as the lateral shift necessary to unweight the stepping leg (Rajal G. Cohen, Nutt, & Horak, 2011; Massion & Viallet, 1990). To our knowledge, this is the first evidence for changes in postural *alignment* during preparation for movement, and it opens up a large potential area for future research. For instance, an important follow-up question is whether immediately before movement is a particularly potent time to bring awareness to posture, in order to bring about overall improvement in postural alignment.

4.3 Reduced FHP When Attending to Posture

Our second hypothesis, that attending to posture would reduce FHP, was also supported. When attending to posture, participants held their torsos more upright with necks father back relative to the torso, reducing FHP. This occurred whether participants were standing or preparing to move, at either a leisurely or rushed pace. This evidence is in line with previous research on postural attention (Levanon et al., 2012; Westgaard & Winkel, 1997); when people attend to their posture, they stand upright, aligning the head, neck and torso.

Changes in FHP due to attention did not directly relate to inhibitory control, but the effect of the interaction between attention to posture and preparing to move on head tilt and neck length shows that managing alignment during tasks requires attention. When simply standing, participants tilted their heads farther forward relative to their necks when attending to posture than when not attending to posture, but when preparing to move, differences produced by attending to posture diminished. Similarly, we found greater neck length when attending to posture while standing, but this effect also diminished when preparing to move. Both of these results indicate that participants were not able to maintain attention to posture when preparing to move. Drawing on the logic of dual-task studies (Shumway-Cook & Woollacott, 2012), we might consider moving to a target and maintaining upright posture to be separate tasks. Difficulty carrying them both out simultaneously suggests that maintaining posture requires active attention, and the act of moving toward a target draws on these resources, reducing upright posture. Our results here are consistent with those of Shahidi et al., 2013, who found that FHP was greater during an attention-demanding computer task than when simply sitting, and with those of Igarashi et al., 2015, who found reduced activity in lumbar multifidus and internal oblique (considered “postural muscles”) during arithmetic tasks relative to baseline. Taken together, results from these studies indicate that maintaining upright postural alignment requires attention. It follows that research into ways to improve postural alignment should consider the likely attentional costs of interventions, and should find ways to minimize those costs.

4.4 Effects of Compelling Conditions on Postural Alignment

Our third hypothesis was that FHP would be greater in conditions that are compelling (such as under time pressure) than in less compelling conditions, particularly in participants with poor inhibitory control. We did not find an effect of time pressure on any of our measures of neck alignment. This was the first study to ask whether time pressure would affect neck posture. However, a number of previous studies have examined the effect of time pressure, and other psychosocial manipulations, on trapezius muscle activity. The trapezius is responsible for extending the head and the neck, so contracting trapezius muscles would likely lead to pulling the head back with respect to the neck. There have been mixed reports about whether time pressure affects trapezius EMG. Szeto et al., 2002 found that trapezius activity was higher when typing quickly than when typing slowly, and Birch et al., 2000 found similar effects in a mouse task. However, other researchers have found that although psychosocial stress increases the activation of trapezius muscles during a computer task, time pressure alone is not a strong enough stimulus to cause a significant difference (Bloemsaat, Meulenbroek, & Van Galen, 2005; Chou, Chen, & Chiou, 2011; McLean & Urquhart, 2002).

4.5 Relationships Between Upright Posture and Inhibitory Control

Our final hypothesis was that chronic FHP is more pronounced in individuals with poor inhibitory control. This hypothesis was not supported. However, weak inhibitory control was associated with a backward-tilted head, and this relationship was present whether the participants were simply standing or preparing to move, and whether they attended to their posture or not. This suggests that inhibitory control does relate to the way people hold their heads. However, this correlational evidence does not allow us to determine whether and in what direction a causal relationship between head/neck angle and inhibition might exist.

Poor inhibition was also associated with shortening of the neck during preparation, especially for rushed movement, and especially when subjects were instructed to pay attention to their posture. This suggests that those with better inhibition are more able to maintain their intended posture when faced with compelling demands. It is likely that maintaining posture becomes more difficult as the task becomes more demanding, and with worse inhibitory control the result is an increase in co-contraction of neck muscles, leading to neck shortening and compression of the cervical spine. Again, strength of inhibitory control has been associated with postural control (Elliott, 2003; Hawkes et al., 2012; Mirelman et al., 2012; Muir-Hunter et al., 2014; Oliveri et al., 2012; Yogev-Seligmann et al., 2008). However, this is (to our knowledge) the first evidence that inhibitory control is connected to postural alignment. 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).

4.6 Strengths and Limitations of the Study

a. Strengths

This was the first study to investigate the possible role of inhibitory control in postural alignment, and the first study to show that postural alignment is altered in preparation for (or during early initiation of) stepping. Thus, it offers the possibility to considerably broaden the study of the relations among cognition, preparation, and motor behavior. In addition, our inclusion of several different measures of head, neck, and trunk alignment provides some initial insight into the complexity of the possible effects of cognitive factors on postural alignment. Some of our manipulations affected FHP but not head/neck angle, while others affected head/neck angle but not FHP. Particularly striking was the finding that shortening of the neck when preparing to move quickly related to inhibitory control, suggesting that this might be an important outcome measure to consider in future studies.

b. Limitations

First, the preparation time was defined as one second prior to the lifting of the foot.

Because the torso was already leaning forward at this time, this time point might more accurately be considered as an early phase of step initiation. Future studies should look even earlier, to see if changes in neck posture precede other aspects of preparation/initiation of movement. Second, because participants always performed trials with attention to their posture after they performed trials using their unattended posture, there could have been carryover effects in which attention was confounded with fatigue or greater familiarity with the instruction, resulting in carryover effects. Counterbalancing is not feasible for this variable, but it is possible that a different result would be obtained in a between-groups study. Third, the use of time pressure as a manipulation may not have been a compelling enough stimulus to elicit changes in posture. Future studies should examine the effects of more stressful or challenging conditions. Finally, we discovered many unexpected findings that suggest the interaction between posture and attention is more complex than we initially postulated, and additional physical and cognitive factors are likely to be involved. Finally, the landmarks used in for our postural measures consisted of the center of 4 markers on a headband worn above the ears, and points digitized on the surface of the skin, rather than those relevant to posture. In addition, because we are unsure of the exact position of the head segment point, it may have caused issues with the angle calculated. This discrepancy may explain why attention to posture caused a forward head tilt, which was not in line with our expectation.

4.7 Unexpected Findings

There were a number of unexpected findings: FHP did not relate to inhibitory control; participants in the study leaned forward at the torso when preparing to move, and this forward lean was influenced by speed of movement and attention to posture, and partially related to inhibitory control. There are several possible reasons our manipulations did not produce all of the expected effects; some of these are explored below.

Our most compelling evidence for a relationship between postural alignment and inhibitory control comes from our measure of neck compression, rather than FHP. When attending to posture, shorter necks during rushed preparation than during leisurely preparation or baseline standing was observed in those with worse inhibition. Though unexpected, it is possible that this relationship exists for the same reason as the one we expected to find with FHP. Exaggerated compression of the cervical vertebrae causes discomfort, which people would adjust their posture in order to prevent if they were aware of it. It is possible that individuals with poor inhibition do not prioritize attention to posture when attempting to rush toward a target, or that those with better inhibition are better able to maintain posture when faced with compelling demands. It is likely that maintaining posture becomes more difficult as the task becomes more demanding, and with worse inhibitory control the result is a shortened neck.

The consistent association between a more backward head tilt and less inhibitory control in all conditions suggests that inhibitory control relates to the way participants hold their heads. We expected decreased inhibitory control to result in FHP; these results suggest that inhibitory control relates to how the head balances or rests on the neck instead. Head balance could also affect spinal alignment, because a more exaggerated backward tilt compresses the intervertebral discs, and could produce the increased neck shortening we observed (Bogduk & Mercer, 2000).

When attending to posture and preparing to move at a leisurely pace, those with better inhibitory control remained more upright at the torso than those with worse inhibitory control. This suggests that inhibitory control plays a role in maintaining an upright posture when preparing to move. In this case, better inhibitory control represents an ability to maintain upright posture, despite temptation to lean forward when preparing to move. This is also supported by the observed effects of speed on torso lean, where rushing caused greater lean of the torso than a leisurely pace *unless* attending to posture. Furthermore, when preparing to move, rushing caused less torso lean in participants with worse inhibitory control than in those with better inhibitory control, regardless of attentional instruction. One must move one's center of mass forward in order to take a step (Farley & Ferris, 1998; Roger & Hagy, 1980), either by putting the head in front of the neck or by bending at the hip or ankle, and these results suggest that those with worse inhibition may do the former, and as a result lean forward at the torso less.

4.8 Conclusions

Maintaining neutral posture may require inhibition of an impulse to put the head forward of the body when anticipating movement. With repetition, this may become chronic. We found that acute FHP occurred when people prepared to move toward a goal, and attention to posture reduced FHP, but differences in head-tilt and neck length produced by attention to posture diminished when individuals prepared to step. Because of this, treating attention to posture as a discrete task requiring active attention may prove important in developing effective postural training. Attention is a limited resource, so it is important to understand how correcting posture may be influenced by additional tasks, or how it may interfere with other activities.

CHAPTER 5: STUDY 2 INTRODUCTION

To address the finding that rushing was not a sufficiently compelling manipulation to produce the effects on FHP that we expected, and to address the finding that inhibitory control (as measured by false alarms in the Go/NoGo task) did not relate to FHP, we performed a second study with a modified methodology. We adjusted how participants initiated movement, the way data were captured, and the walking and cognitive tasks participants performed. We also included additional measures of factors that might moderate the association between inhibitory control and postural alignment.

The results of the previous study suggested that speed was not a strong enough stimulus to stimulate FHP. Therefore, our second study included three tasks: walking up to a target and placing an empty tray at knee height, placing a tray with an object balanced on it at waist height, and placing an empty tray at waist height. Each of these walking tasks is intended to influence postural alignment. Placing the tray at knee height moves the location of the goal to a lower spatial location. If FHP is caused by the head “getting ahead of” the body, a low target might be a stronger stimulus to move the head forward and down. The balancing secondary task is intended to compel participants to split their focus. In previous research regarding executive functions, the requirement to perform multiple tasks has been shown to negatively influence performance (Hawkes et al., 2012). The empty tray at waist height is a simpler task, which we predict will have less impact on postural alignment than the other two tasks.

Measuring inhibitory control through false alarms during the Go/No-Go task may not have adequately addressed inhibition as a factor, so for our second study we added a Stroop task. We also chose to include an additional test of impulsivity; a type of behavioral inhibition (Richards et al., 1999). Impulsivity relates to long-term choices individuals make (Humphreys & Revelle, 1984; Mitchell, 1999; Richards et al, 1999) rather than motor inhibition. Impulsivity is considered a unique behavioral construct, because it is not directly related to other measures of inhibition (Clark et al., 2005), but instead provides insight into the motivations of individuals during decision making tasks (Humphreys & Revelle, 1984). The inclusion of this measure may provide a more complete explanation of a person's motivation to prioritize long term postural alignment or immediate task demands.

Other cognitive factors may interact with inhibitory control or influence alignment directly. One factor of particular interest is mindfulness, or level of awareness about one's own physiological state. Some evidence in the literature suggests that individuals with poor posture and neck pain are not aware of their poor alignment; thus, they may not be as mindful as others (Edmondston et al., 2007; Lee et al., 2014). Research relating mindfulness to posture is still underdeveloped, but mindfulness is important for maintaining awareness of one's physiological state (Sze et al., 2010) and mindfulness training has been shown to improve postural control in people with multiple sclerosis (Mills & Allen, 2000). Mindfulness training has also been effective for improving regulation of behavioral control in individuals with executive function deficits that produce impulsivity (Flook et al., 2010), and it has led to reductions in chronic pain (McCracken, Gauntlett-Gilbert, & Vowles, 2007).

While FHP is one measure of poor neck posture, the results from our first study in combination with previous research shows there are additional factors we must consider to measure healthy neck posture. We have determined that an increase in FHP, a shorter neck length, and extreme tilt of the head forward or backward are all measures of neck misalignment as a result of unhealthy neck posture.

Finally, research shows that neck pain and postural alignment are closely related (Ariëns et al., 2001; Ariëns et al., 2000; Chiu et al., 2002; Silva et al., 2009; Watson & Trott, 1993; Yip et al., 2008). Since part of our motivation for studying postural alignment is to understand neck pain, we included a self-report measure of neck pain.

5.1 Hypotheses

We hypothesized that people have a tendency to anticipate forward movement by leading with the head, causing unhealthy neck posture, and that this tendency is attenuated by inhibitory control. Based on our results from Study 1, we predicted that (1) neck misalignment would be greater when participants are anticipating movement than when they are not anticipating movement; (2) neck misalignment would be more pronounced in individuals with poor inhibitory control; (3) neck misalignment would be greater for conditions that place a greater burden on attention or create a stronger feeling of anticipation, and this would produce more neck shortening, especially in individuals with poor inhibitory control or high impulsivity; (4) attention to posture would reduce neck misalignment, except in those individuals with poor inhibitory control or low levels of mindfulness.

CHAPTER 6: STUDY 2 METHODS

6.1 Participants

We tested 80 participants (29 men and 51 women), aged 18 to 29 years (M = 20.2, SD 5.1), recruited from psychology courses at the University of Idaho. Participants were offered course credit through SONA Systems for a two-hour data collection session. Due to technical complications, motion capture data were collected for 45 participants, Go/No-Go for 64, Delay Discounting (DD) for 70, Mindfulness Attention Awareness Scale (MAAS) for 79, Neck Disability Index (NDI) for 77, and Stroop for 77. Of the 70 collected, DD data for four participants were excluded because those participants always chose the immediate reward, regardless of the prompt, suggesting that they were making rule-based decisions rather than engaging with the task as intended.

6.2 Protocol

This study was structured similarly to the initial study, with changes intended to address the limitations of the initial study and diversify the cognitive tasks. Instructions regarding postural attention and time frames of data collection remained largely unchanged from the previous study. Participants performed three tasks, and four additional surveys were included.

As before, 3-dimensional body position data was collected from baseline trials, during preparation for movement, and at step onset. In addition, we measured anticipation for movement at the beginning of the count for each trial. Participants performed all tasks without any instruction about posture (habitual condition), and then were instructed to use their best posture (attended condition). During all trials, participants stood grasping a small tray (8 x 12 inches) lengthwise by the rim of the tray (1 inch lip which extends to all 4 sides). Baseline trials were collected for both attended and habitual conditions, while the participant stood for 10 seconds with no movement instruction.

During the three tasks, participants were instructed to stand and wait for the experimenter to count off three seconds before stepping; anticipation was sampled at the start of this count, step onset was defined as when one foot began to lift off the ground, and preparation was measured one second prior to the step. Each participant walked forward 2 meters and placed the tray on a shelf in front of them. Participants performed three different tasks for these trials: placing the empty tray at waist height (Simple), placing the tray at waist height while balancing a small (1 inch diameter, 4 inch length) cylindrical object on it (Rolling), or placing the tray at knee height (Down).

6.3 Measures

a. Motion capture data

Changes to the motion capture data consisted of the inclusion of a marker on the tragus of the right ear, a marker distal to the right eye, and one marker on the chin to track the position of the head. For the angles of the head and neck, offsets calculated by the MotionMonitor for the atlanto-occipital, and 7th cervical vertebra joint centers were used. These offsets use points on the surface of the skin for the mastoid and spinous process of the C7, translated in 3 dimensions based on 95th percentile anatomical estimates of the joint's location relative to the bony landmarks on the skin. The angle of the head used the positions of the eye and atlanto-ocipital joint of the head, the angle and length of the neck used the position of the atlanto-ocipital joint and joint center of the seventh cervical vertebra.

b. Cognitive tasks and surveys

In order to investigate a more diverse array of cognitive factors that may be associated with posture, the Stroop task, DD, and MAAS were included in the second study in addition to the Go/No-Go task from the previous study. A short survey on neck pain, the NDI, was also included.

The Stroop task (Stroop, 1935) is a test of inhibition that does not have a ceiling or floor and thus may provide a more sensitive measure of inhibition than the Go/No-Go task. The Stroop consists of three oral tasks, each with 50 items, always performed in the same order (Appendix 1). First, the participant names the color of 50 ink squares printed on paper. Then they read 50 words (color names that correspond to the ink colors used in the first task, written in black ink). The third task (the conflict condition) consists of a series of 50 color names, written in colored ink, and the participant is instructed to name the ink color. This acts as a test of inhibition because participants have to prevent the well-established habit of reading words in order to name the ink colors. Any time a participant makes an error, they must correct their mistake before continuing. Time to complete each task was measured, and the time for the conflict condition was used as a measure of inhibitory control.

The DD task is a measure of impulsivity: participants are asked a series of 138 computer-generated questions where they are asked to imagine a choice between being given an amount of money now ($0-10.50, in increments of $0.50) and a larger amount of money some number of days later ($10 in 0, 7, 30, 90, 180, or 365 days). From this, a coefficient for a response curve is calculated (k), the log value of which is used to infer a person’s relative impulsivity (from 1 to -8); a more negative logK value indicates greater propensity toward immediate rewards.

The MAAS (Appendix 2) is a 15-item scale designed to assess awareness of and attention to what is taking place in the present (Brown & Ryan, 2003; Chambers, Lo, &

Allen, 2008). Each item is a statement accompanied by a scale; participants indicate how frequently they experience the described statement (1 for not at all, 6 for high frequency). The final score is tallied and used to describe a person's self-reported level of mindfulness, where a higher score indicates greater mindfulness.

The NDI (Vernon & Mior, 1991) is a brief survey consisting of questions about a person's current and recent level of neck pain, which acts as a measure of a person's perceived neck pain and its effect on their life (Appendix 3). The NDI consists of 10 questions addressing pain intensity, personal care, lifting, reading, headaches, concentration, work, driving, sleeping, and recreation. For each of these categories, participants mark the statement in a list of six that best matches their perceived neck disability within that category, on a scale from "not at all disabling" to "severely disabling." This score is used to calculate a percentage which indicates to what degree their life is affected by neck pain.

CHAPTER 7: STUDY 2 RESULTS

There are several differences between Study 1 and Study 2 in the data reported. Due to differences in marker configurations (made to improve reliability of tracking), the overall values for FHP, neck length, and head tilt are not directly comparable between the two studies. In addition, while preparation (1 second before movement) was included in Study 1, Study 2 uses anticipation (3 seconds before movement) instead*. Finally, Study 2 included a measure of the tilt of the entire body. However, we found no significant differences between whole body angle and torso angle measures. Therefore, only torso angle is reported, as in Study 1.

7.1 ANOVA Results

To analyze the effects of task and attention on posture, we performed a 2 x 4 ANOVA which compares attended and unattended posture during Baseline (when participants do not immediately anticipate stepping) and when participants are anticipating one of three movements (at the beginning of the countdown for movement): placing the empty tray at waist height (Simple), placing the tray at waist height while balancing an object on the tray (Rolling), and placing the empty tray at knee height (Down). When attending to posture, participants had necks farther back relative to torsos, heads tilted farther back relative to necks, and more upright torsos than when not attending to posture; figure 13 shows main effects of attention to posture on FHP, $F(1,43) = 48.0$, $p < 0.01$; head tilt, $F(1,43) = 20.4$, $p < 0.01$; and torso angle, $F(1,43) = 10.7$, $p < 0.01$. Also shown in Figure 13, there were main effects of task for FHP, $F(3,129) = 15.1$, $p < 0.01$; head tilt, $F(3,129) = 13.5$, $p < 0.01$; and torso angle, $F(3,129) = 3.1$, $p = 0.03$. Figure 13 also shows an interaction of anticipation and postural attention for FHP, $F(3,129) = 4.4$, $p = 0.01$; and torso angle,

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*Anticipation differs significantly from preparation for all variables except neck length

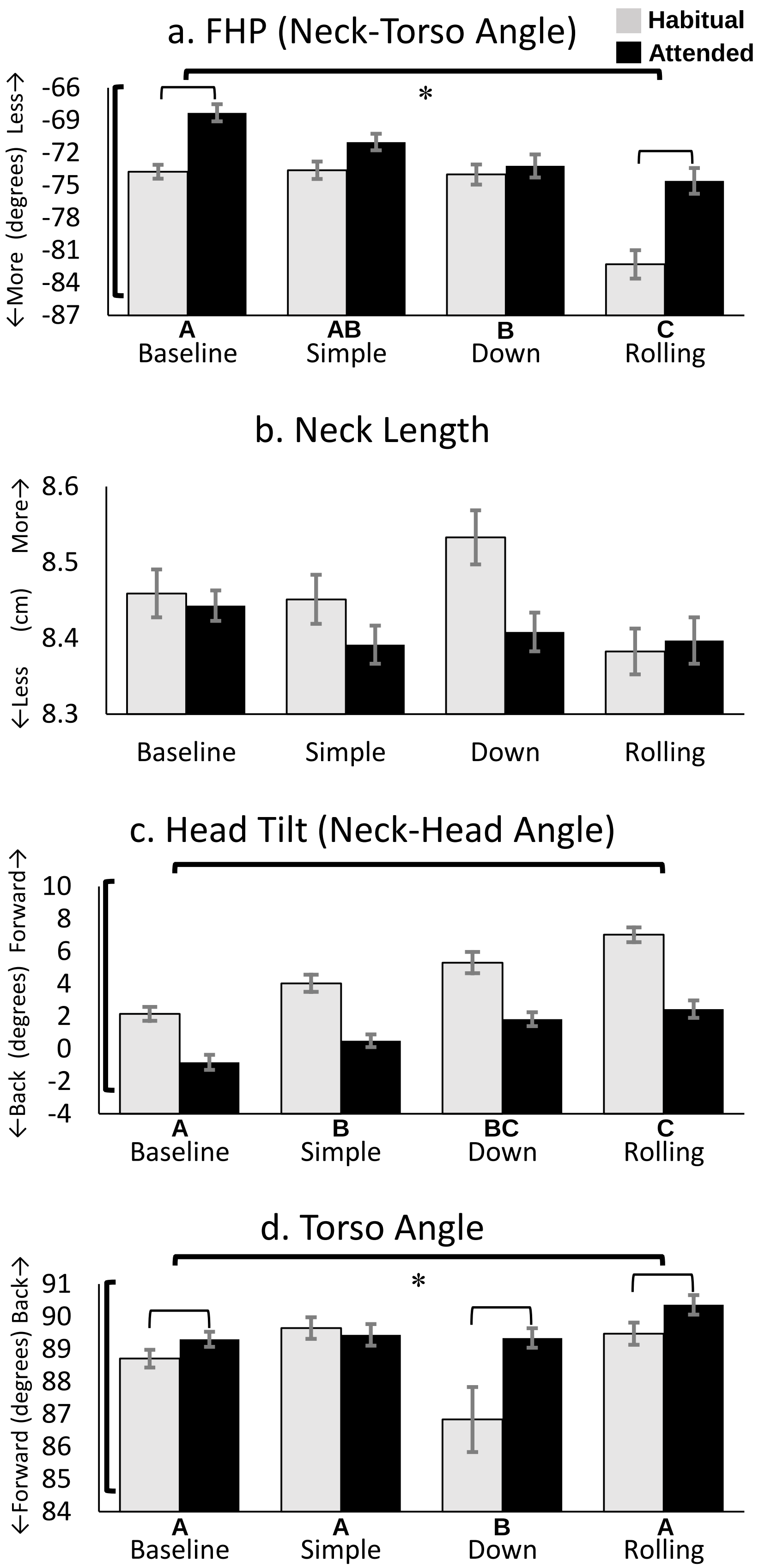

Figure 13 - Effects of task and attention to posture

Graphs of (a) FHP, (b) neck length, (c) head tilt, and (d) torso angle during Baseline and anticipation of Simple, Down, and Rolling; while not attending to posture (grey) and attending to posture (black). Solid brackets indicate **significant main effects**; vertical brackets indicate an effect of **attention to posture**, horizontal brackets indicate **effects of task**. Lettering indicates **contrast groups** for main effects of task. Asterisks (*) indicate **interaction effects**, and thin horizontal brackets indicate significant **simple effects** of attention within the corresponding task. Condition means are located at each bar base. **Error bars** represent within-subjects standard error.

F(3,129) = 7.2, $p < 0.01$. Significant main effects of task and interactions were followed up with contrasts and tests of simple effects respectively.

Contrasts revealed less FHP in Baseline than Down (p = 0.01) and Rolling ($p < 0.01$) tasks, and greater FHP in Rolling than during any other task (Baseline: $p < 0.01$, Simple: p = 0.02, Down: p = 0.03). Contrasts also revealed greater backward head tilt in Baseline than in any anticipation task (Simple: p = 0.01, Rolling: $p < 0.01$, Down: $p < 0.01$), and greater forward tilt in Rolling than Simple ($p < 0.01$). Lastly, contrasts revealed greater forward lean of the torso in Down than any other task (Baseline: $p < 0.01$, Simple: p = 0.02, Rolling: p = 0.03).

Tests of simple effects revealed that participants had less FHP when attending to posture than when not attending to posture during Baseline, t(1,43)= 5.2, $p < 0.01$; and Rolling, t(1,43)= 7.7, $p < 0.01$; but not during the Simple or Down tasks. Simple effects also showed that participants stood more upright at the torso when attending to posture than when not attending to posture during Baseline, t(1,43)= -2.19, p = 0.04; Down, t(1,43)= 2.6, p = 0.01; and Rolling tasks, t(1,43)= -3.0, $p < 0.01$; but not Simple.

7.2 Correlation Results

a. Correlations within cognitive measures

To determine whether sex, BMI, NDI, MAAS, DD, Go/No-Go, or Stroop scores were related, correlations were run across all available observations (t-tests were used for sex effects). Within our sample, men had a greater BMI than women, t(75) = 2.1, p = 0.04; and men reported higher levels of mindfulness than women t(75) = 2.0, p = 0.049. MAAS correlated positively with DD, r(66) = 0.28, p = 0.02; negatively with NDI, r(67) =-0.35, $p < 0.01$; and negatively with Stroop performance, r(74) =-0.23, p = 0.046 higher reported levels of mindfulness were associated with greater likelihood to delay immediate rewards, lower reported levels of neck disability, and better performance during inhibitory tasks.

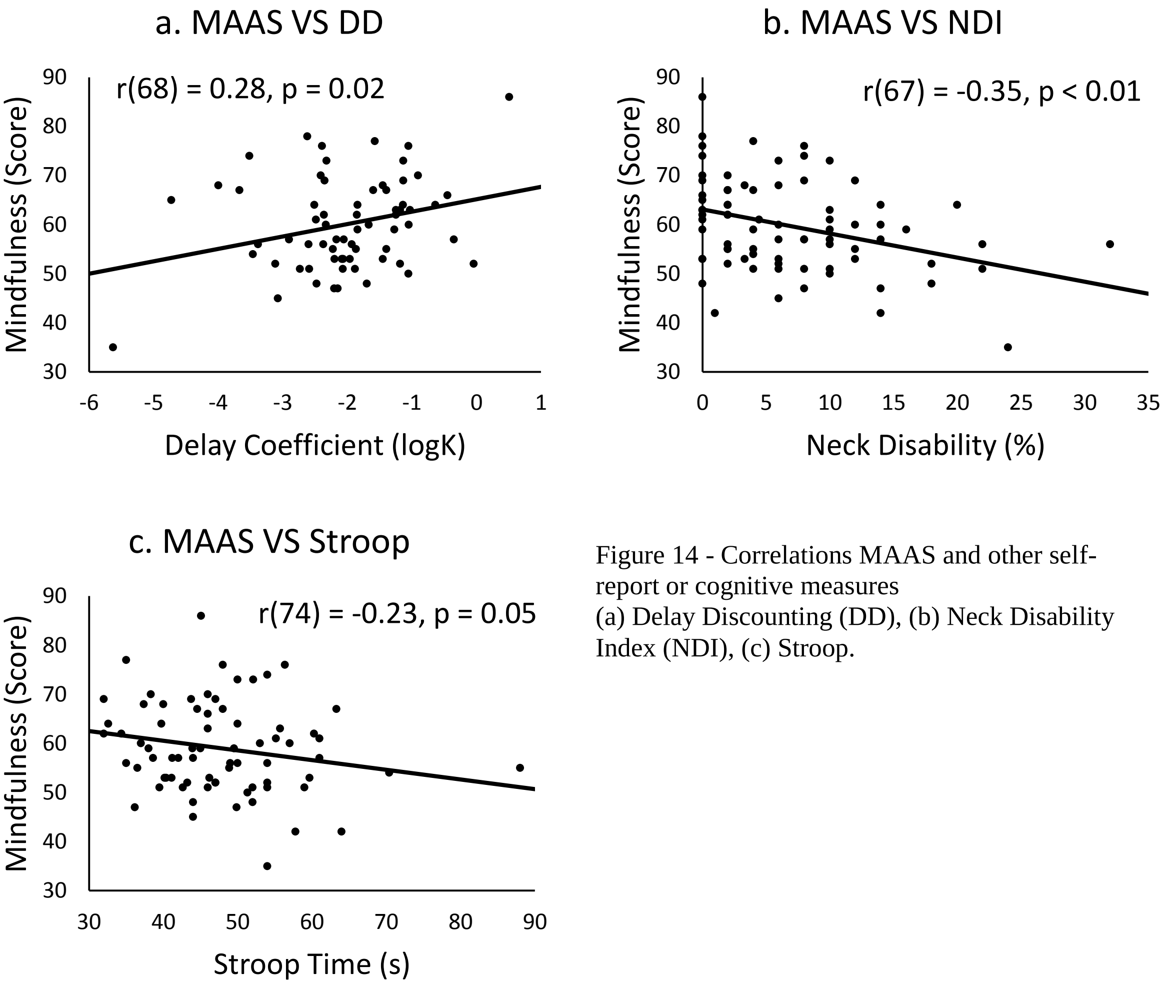

Figure 14 - Correlations MAAS and other self-report or cognitive measures
(a) Delay Discounting (DD), (b) Neck Disability Index (NDI), (c) Stroop.

b. Correlations within conditions

To determine whether sex, BMI, NDI, MAAS, DD, Go/NoGo, or Stroop scores were related with aspects of postural alignment, we tested for correlations between these measures and postural measures for each participant. Initially, anticipation measures were averaged across tasks; if the average anticipation correlated with any cognitive measure this was followed up with tests of correlations for each independent task. For all correlations, only baseline is reported unless it was not significant or unless separate task correlations differed significantly from one another.

We found significant correlations between MAAS scores and FHP when participants were not attending to their posture (Figure 15a); low self-reported mindfulness was associated with high FHP when participants stood without postural instruction during baseline r(42) = 0.47, p < 0.01; and when they were anticipating movement r(42) = 0.38, p = 0.01. Stroop performance was also related to FHP in the absence of postural instruction during baseline (Figure 15b), r(41) = -0.36, p = 0.02; and when participants were anticipating movement r(41) = -0.38, p = 0.01. Slower completion of the Stroop conflict condition was associated with more FHP.

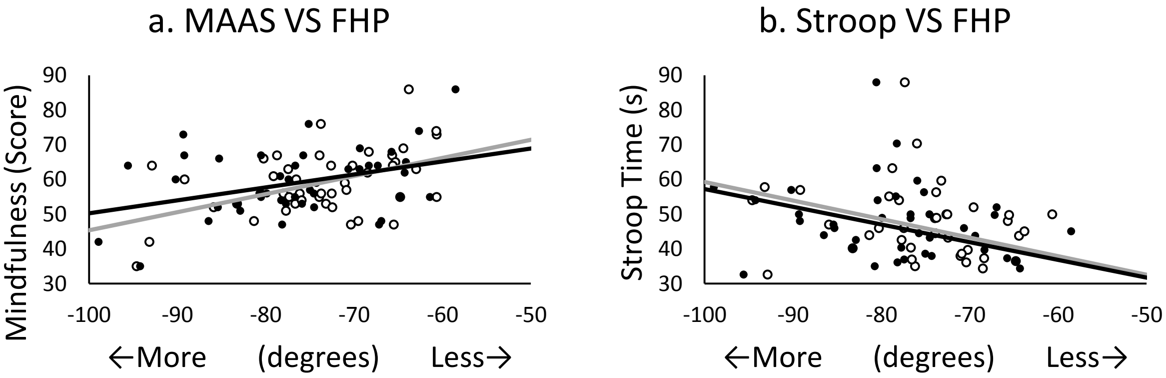

Figure 15 - Correlations between cognitive measures and FHP
During baseline (unfilled points, grey trendline) and anticipating movement (filled points, black trendline) in the absence of postural instructions. (a) MAAS scores and (b) Stroop scores.

For both conditions, we found significant negative correlations between neck length and neck disability index (Figure 16), and significant positive correlations between neck

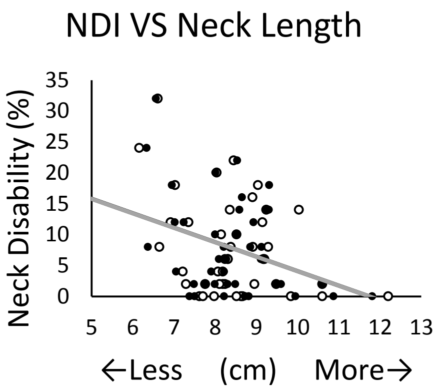

Figure 16 - Correlations between NDI scores and neck length during baseline in the absence of postural instructions (unfilled points, grey trendline) and when attending to posture (filled points, black trendline). Table (below) of r-values for correlations between NDI and neck length. Significant values shown in bold.

Condition	**Habitual**	**Attended**
Baseline	**r(37) =-0.45, p < 0.01**	**r(37) =-0.32, p =0.047**
Simple Anticipation	**r(37) =-0.35, p = 0.03**	**r(37) =-0.33, p = 0.04**
Down Anticipation	**r(37) =-0.41, p < 0.01**	**r(37) =-0.37, p = 0.02**
Rolling Anticipation	**r(37) =-0.42, p < 0.01**	**r(37) =-0.32, p =0.047**

length and delay discounting scores (Figure 17); shorter necks when standing or anticipating any task were associated with greater neck pain and a propensity to choose immediate rewards over delayed rewards.

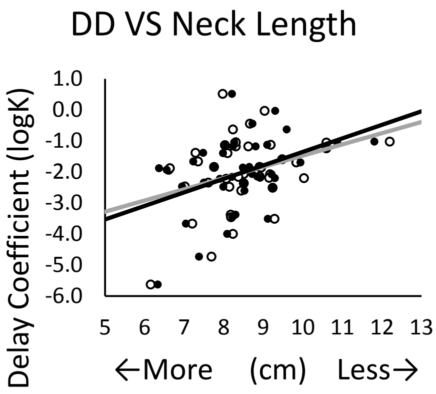

Figure 17 - Correlations between DD scores and neck length during baseline in the absence of postural instructions (unfilled points, grey trendline) and when attending to posture (filled points, black trendline). Table (below) of r-values for correlations between DD and neck length. Significant values shown in bold.

Condition	**Habitual**	**Attended**
Baseline	**r(42) = 0.35, p = 0.02**	**r(42) = 0.42, p < 0.01**
Simple Anticipation	**r(42) = 0.40, p = 0.01**	**r(42) = 0.39, p = 0.01**
Down Anticipation	**r(42) = 0.40, p = 0.01**	**r(42) = 0.37, p = 0.01**
Rolling Anticipation	**r(42) = 0.40, p = 0.01**	**r(42) = 0.41, p = 0.01**

For both conditions, we found significant negative correlations between number of Go/No-Go false alarms and head tilt (Figure 18). Participants with a greater backward head tilt had more false alarms than those with a more forward tilt of the head.

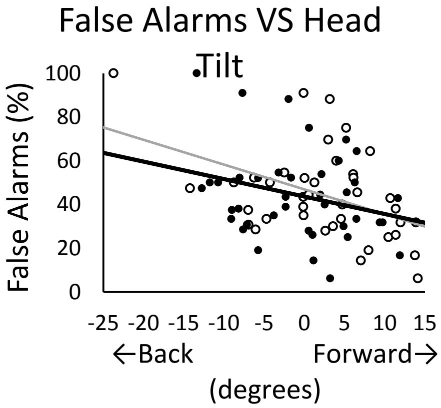

Figure 18 - Correlations between Go/No-Go false alarms and head tilt during baseline in the absence of postural instructions (unfilled points, grey trendline) and when attending to posture (filled points, black trendline). Table (below) of r-values for correlations between Go/No-Go false alarms and head tilt. Significant values shown in bold.

Condition	**Habitual**	**Attended**
Baseline	**r(42) = -0.45, p < 0.01**	**r(42) = -0.32, p = 0.04**
Simple Anticipation	**r(42) = -0.35, p = 0.02**	**r(42) = -0.33, p = 0.04**
Down Anticipation	**r(42) = -0.41, p < 0.01**	**r(42) = -0.37, p = 0.01**
Rolling Anticipation	**r(42) = -0.42, p < 0.01**	**r(42) = -0.32, p = 0.04**

c. Across-condition correlation trends

To determine whether the effects of attention to posture or anticipation of movement were associated with cognitive factors, we calculated the difference between conditions or tasks for each manipulation and correlated that difference with test and survey scores. To examine the effect of attention, we used the difference between habitual and attended conditions. To examine the effects of anticipation, we used the difference between baseline and anticipation for each task.

We found a negative relationship between MAAS scores and the change in FHP due to postural attention (Figure 19, Table 4). Mindfulness was associated with reduction in FHP due to attention to posture. This relationship was present in Baseline, r(42) =-0.39, p < 0.01; Simple, r(42) =-0.42, p < 0.01; and Rolling, r(42) =-0.49, p < 0.01; the effect was not significant for the Down task.

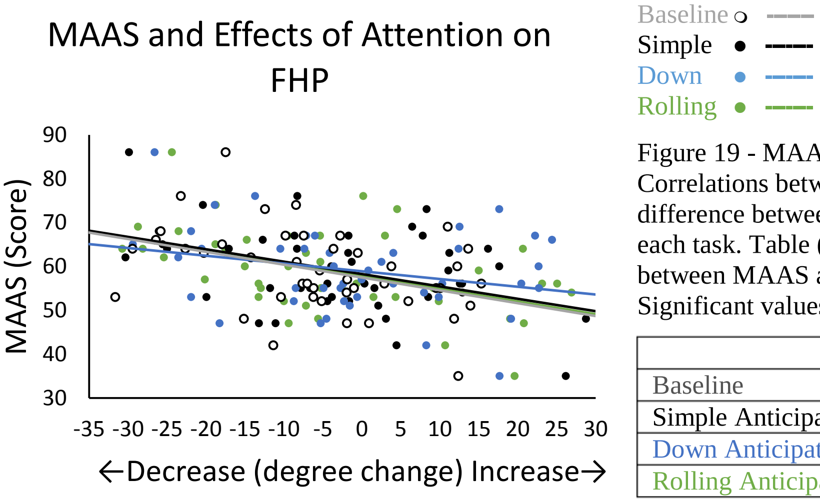

Figure 19 - MAAS and effects of attention on FHP. Correlations between MAAS scores and the difference between habitual and attended FHP during each task. Table (below) of r-values for correlations between MAAS and attended FHP for each task. Significant values shown in bold.

	Correlation
Baseline	**r(42) =-0.39, p < 0.01**
Simple Anticipation	**r(42) =-0.42, p < 0.01**
Down Anticipation	r(42) =-0.27, p = 0.07
Rolling Anticipation	**r(37) =-0.49, p < 0.01**

We found a positive relationship between Go/NoGo false alarms and the change in head tilt when standing due to attention, r(37) = 0.33, p = 0.04. We also found a positive relationship between Stroop performance and the change in head tilt when standing due to attention, r(37) = 0.31, p = 0.05. Worse inhibitory control was associated with greater backward head tilt when attending to posture than when not attending to posture (Figure 20).

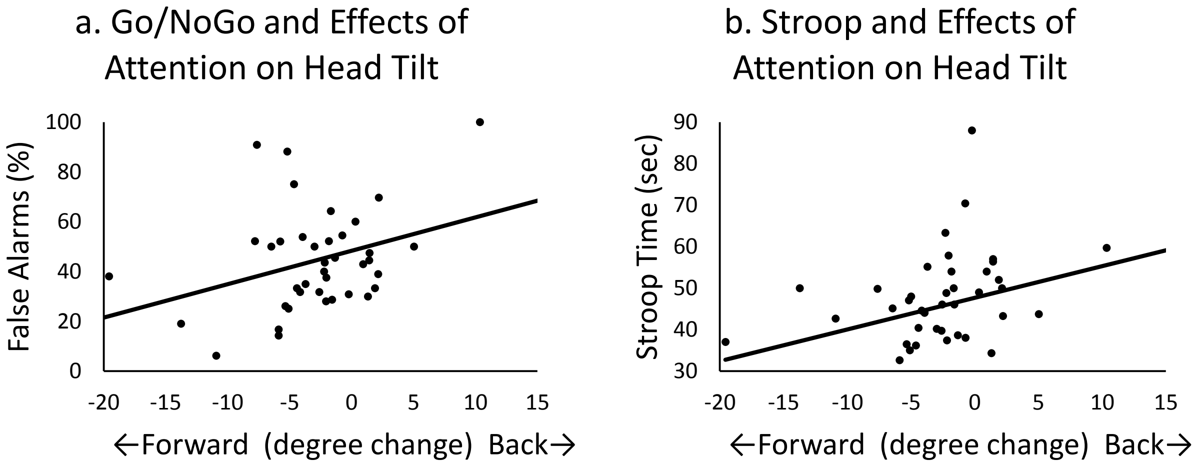

Figure 20 - Inhibition and effects of attention on head tilt
Correlations between head tilt change due to attention to posture during baseline standing and (a) Go/No-Go false alarm rates and (b) Stroop performance.

We found a negative relationship between Go/NoGo false alarms and the change in neck length when anticipating any movement, both when attending to posture, r(37) = -0.45, p < 0.01; and when not attending to posture, r(37) = -0.40, p = 0.01. Worse inhibitory control was associated with greater reduction in neck length when anticipating movement (Figure 21, Table 5).

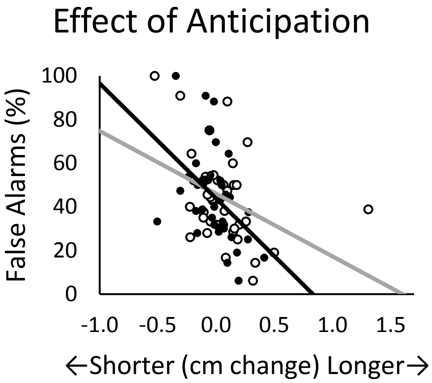

Figure 21 - Inhibition and effects of anticipation on neck length Correlations between Go/No-Go false alarm rates and the difference in neck length between standing and anticipating movement in the absence of postural instructions (unfilled points, grey trendline) and when attending to posture (filled points, black trendline).Table (below) of r-values for correlations between Go/No-Go false alarms and difference in neck length between standing and anticipating movement. Significant values shown in bold.

	Habitual	**Attended**
Simple	**r(37) =-0.33, p = 0.04**	**r(37) =-0.32, p = 0.05**
Down	**r(37) =-0.32, p = 0.05**	**r(37) =-0.34, p = 0.03**
Rolling	**r(37) =-0.33, p = 0.04**	**r(37) =-0.37, p = 0.02**

We also discovered a significant sex effect related to the change in head tilt due to anticipating movement for any task both when attending to posture, t(42)= -4.1, p < 0.01; and when not attending to posture t(42)= -2.2, p = 0.03. When anticipating movement, men tilted their heads forward less than women relative to standing.

CHAPTER 8: STUDY 2 DISCUSSION

8.1 Summary of Results

The goal of this study was to investigate a possible link between inhibitory control and postural alignment of the head and neck when anticipating movement. With respect to our predictions for the second study, there were five main findings: (1) FHP increased in anticipation of movement. (2) A shortened neck length was associated with self-reported neck disability and a greater propensity to delay immediate rewards. In addition, in anticipation of movement participants with worse inhibitory control exhibited greater shortening of the neck than those with better inhibitory control. (3) A greater increase in FHP occurred in anticipation of the Rolling and Down tasks, particularly in the absence of postural instruction, but did not result in shorter necks. (4) Attention to posture reduced FHP, particularly for participants with higher reported mindfulness, and FHP did not reduce in those with poor inhibitory control. In addition, weaker inhibitory control was associated with greater backward head/neck angle as in our previous study.

8.2 Neck Misalignment During Movement Anticipation

Our first hypothesis was that people would lead with the head in anticipation of movement, which would present as misalignment of the neck. This hypothesis was supported. At the beginning of the countdown for each task, participants shifted their heads forward in relation to their torsos, producing acute FHP. This finding is in line with our first study and provides additional support for the hypothesis that people tend to lead with the head when they expect to move. Further, the increase in FHP seen during the more difficult Rolling task (especially in the absence of postural instruction) suggests that when balancing the demands of multiple tasks, alignment of the head suffers in favor of attending to the balancing task.

8.3 Greater Shortening of the Neck With Poor Inhibitory Control

Our second hypothesis was that people with poor inhibitory control would exhibit greater neck shortening compared to those with better inhibitory control. This hypothesis was supported. Chronic shortness of the neck did not relate directly to any of our measures of inhibitory control (perhaps because of anatomical differences among participants), but acute shortening of the neck in anticipation of tasks was associated with inhibitory control. In addition, a consistently shorter neck was associated with neck disability and a propensity to prefer immediate rewards. These correlational results do not indicate whether impulsivity leads to a shorter neck or whether a shorter neck leads to neck pain, but they suggest that these are possible causal relations to explore. Previous research has shown that stress on the cervical vertebrae commonly results from compression of intervertebral discs resulting from shortening in the neck (Bogduk & Mercer, 2000), and these findings offer additional support that shortening of the neck and neck disability are closely related. The link between impulsivity and neck length is a novel finding, and more research will be required to understand this relationship.

Acute shortening of the neck in anticipation of any movement was related to an increased number of false alarms during the Go/NoGo task, and as with our previous study, this effect was stronger when participants were attending to their posture. This suggests that those with better inhibition are more able to maintain their intended posture when faced with compelling demands. We speculate that people with worse inhibitory control have increased co-contraction of neck muscles, leading to neck shortening and compression of the cervical spine. These results are in line with previous research showing that strength of inhibitory control is associated with postural control (Elliott, 2003; Hawkes et al., 2012; Mirelman et al., 2012; Muir-Hunter et al., 2014; Oliveri et al., 2012; Yogev-Seligmann et al., 2008); in combination with our previous research, this shows that the inhibition-posture link extends to postural alignment.

8.4 Increased FHP During More Difficult Tasks

Our third hypothesis, that more compelling tasks would result in greater neck misalignment, particularly in those with poor inhibitory control or high impulsivity, was also supported. FHP increased in anticipation for the Rolling and Down tasks; during the Rolling task, this difference was particularly noticeable when participants were not attending to posture. This increase in FHP provides additional support for our theory that in anticipation of movement, people have a tendency to lead with the head, and this is distinct from the biomechanical demands of stepping. For the Down task, the result was similar, but the effect was weaker. Differences in FHP produced by attention to posture diminished when anticipating the Down task, and in the absence of postural instruction this task also resulted in an increased forward lean of the torso. Both of these results indicate that participants were motivated to lead with the head in anticipation of tasks with compelling demands, and when not motivated to maintain an upright posture their attention shifted to the demands of the task.

Similar to the previous study, a shortened neck due to anticipating movement was related to increased false alarms during the Go/NoGo task. These results suggest that in response to pressure to move toward a target, those with poor inhibitory control cannot maintain alignment of the neck as well as those with better inhibitory control, resulting in a shorter neck length, and this is independent of locomotion or the specific nature of the task's demands.

Poorer inhibitory control, as assessed by the Stroop task, was associated with consistently greater FHP, unrelated to the difficulty of the task. This is in line with findings for older adults from other studies which shows that the severity of FHP increases with age, and decreases in postural control with aging are related to inhibition (Hawkes et al., 2012; Mirelman et al., 2012). The results from this study represent a novel finding which suggests that chronic FHP may be related to inhibitory control in young adults.

8.5 Reduced Neck Misalignment When Attending to Posture

Our fourth hypothesis, that attending to posture would reduce misalignment of the neck, except in participants with poor inhibitory control or low levels of mindfulness, was partially supported. When attending to posture, participants held their necks father back relative to the torso, reducing FHP. Attending to posture also caused participants to tilt their heads farther back, and neck length was not significantly different. This pattern was seen during quiet standing and when anticipating movement for any task. A recent study of postural instruction in patients with Parkinson's disease showed that when people "try hard" to pull themselves up to their greatest height, this leads to neck compression (Cohen et al., 2015). As-yet-unpublished data from our laboratory show that this holds true for healthy older adults as well (Kral, Baer, and Cohen, in preparation). Thus, while attention seems to reduce FHP, it may not in itself be enough to improve posture.

Lower reported levels of mindfulness correlated with consistently increased FHP during all tasks when not attending to posture. Previous research has shown that mindfulness can improve postural control for individuals with multiple sclerosis (Mills & Allen, 2000), but this is the first research to show that mindfulness is also important for maintaining postural alignment.

When asked to attend to their posture, participants with lower reported levels of mindfulness displayed less reduction in FHP than those who were more mindful, and participants who performed poorly on Stroop and Go/NoGo tasks displayed reduced effects of postural attention on head tilt. This is in line with research on attention to posture that shows that not everyone responds to instruction to maintain their best posture (Edmondston et al., 2007), and shows that attention is likely to play a role in modulating this tendency. The relationship with mindfulness was not present for every task however; the trend is most apparent during the Rolling task, suggesting that in a more difficult task, the more mindful individuals are able to better manage the tasks as the demand increases. During the Down task, there was a similar trend, but it was not significant, possibly because this task caused participants to bend more at the torso, and as a result did not produce more FHP.

These effects of attention may also relate to an unintended order effect. Because participants attended to posture second, they may be more able to manage the demand of anticipating tasks because they have prior knowledge of the task. While we did not expect this to influence our results, it is possible that this added awareness changed how participants prioritized posture and the demands of movement, and this is also what related to mindfulness and inhibitory control respectively.

8.6 Relating Mindfulness to Other Factors

A higher reported mindfulness related to lower reported neck disability, less impulsivity, and better inhibitory control, but interestingly, these other factors did not relate to one another, just to mindfulness. More research would be required to understand the directionality and nuances of this relationship, but it does suggest that these factors are interrelated, in line with much of the research on mindfulness showing that mindfulness training reduces impulsive tendencies (Chambers et al., 2008) and can reduce the impact of chronic pain (McCracken et al., 2007). In addition, the relationships between neck length, impulsivity and neck disability, in conjunction with the relationship between mindfulness, impulsivity, neck disability, and inhibitory control show that the construct of attention is highly influenced by multiple factors, and further research on the combination of these factors with respect to alignment may provide a valuable measure for predicting neck misalignment.

8.7 Strengths and Limitations

a. Strengths

This is, to our knowledge, the first study to assess postural alignment using dual task methodology (dividing attention between posture and tray-carrying) to manipulate the cognitive demands of different tasks. This method allowed us to show that people lead with their heads in anticipation of movement, and this is not solely due to the biomechanical demands inherent to stepping.

Our second experiment is also the first study to look at changes in the alignment of the head and neck several seconds before stepping. This allowed us to show that changes in posture reflecting the specific nature of the forthcoming task occur very early in the motor planning process. The inclusion of anticipation as a time to measure posture provides valuable insight on how individuals may fail to inhibit an automatic response to move toward a target.

Another strength of our approach in this study was our inclusion of multiple measures of inhibitory control and impulsivity. The fact that different cognitive measures correlated with different aspects of posture is testament to the complexity of both neck alignment and executive control; our findings highlight the importance of including multiple measures to assess both postural alignment and inhibitory control.

b. Limitations

The biomechanics of the neck are complex, and although we found a number of relationships between changes in neck posture and cognition, the inclusion of multiple postural measures complicates the interpretation of these results. Some of our measures related to FHP but not head/neck angle, while others related to head/neck angle but not FHP. Particularly, neck length is a promising outcome measure because it relates directly to compression of the neck, but our second study did not find a significant effect of attention to posture for neck length.

Our expectation was that the different measures of inhibitory control would be relatively similar, and that the Stroop task would be a more sensitive measure of inhibitory control than the use of false alarms. However, our measures of inhibitory control were not significantly correlated with one another, and many of the relationships between postural alignment and Go/NoGo false alarms did not extend to the Stroop task. While the ability to make discovery is a strength of our study, we also include it as a limitation because we do not currently have a good explanation for the pattern of results. Some studies have shown that there are fundamental differences in brain activation during these inhibitory control tasks, suggesting they are performed differently (Rubia et al., 2001), which may point us toward a way to explain our results.

The way in which we instructed participants to attend to their posture contributed to two limitations. First, because participants always performed trials with attention to their posture after they performed trials using their unattended posture, there could have been carryover effects in which attention was confounded with fatigue or greater familiarity with the instruction. (Counterbalancing was not practical, as carryover effects would have been guaranteed when the attended condition was first.) Second, research has shown that instructing participants to use their “best posture” will not produce ideal outcomes (Cohen et al., 2015). The importance of specific postural instruction is highlighted by the reduced neck length produced by attention to posture in this study. Future studies should explore different ways of instructing participants regarding their posture.

CHAPTER 9: GENERAL DISCUSSION

This study confirms many of the first study's findings regarding the role of inhibitory control in postural alignment and extends the research on postural alignment changes in preparation for stepping (one second before step onset) to changes during anticipating movement (about three seconds before movement), thus showing that expecting to move is a sufficient stimulus to impact postural alignment. Study 2 also extends the research on inhibitory control to other aspects of cognition.

9.1 Cognition and Postural Alignment

Particularly striking are the findings relating to mindfulness, showing that lower reported levels of mindfulness correlated with consistently increased FHP during all tasks when participants were not attending to posture. Furthermore, when asked to attend to their posture, participants with lower reported levels of mindfulness displayed less reduction in FHP than those who were more mindful. While these results are correlational, and as such it is impossible to determine causal relationships, these novel findings show that chronic FHP is associated with a person's level of awareness of the present, and this awareness is also associated with changes in FHP when attending to posture. These findings open up a large potential area of research on how awareness may relate to postural alignment, as well as how this awareness relates to adjustments made with active attention to posture. Mindfulness is a rapidly emerging area of research, numerous applications are being explored to improve behavioral issues (Chambers et al., 2008; Flook et al., 2010), reduce chronic pain (McCracken et al., 2007), and improve postural control (Mills & Allen, 2000); these findings are particularly exciting because they build on this foundation, relating mindfulness to the management of postural alignment.

Another novel finding was the relationship between a high level of impulsivity and a consistently shorter neck, regardless of task or postural instruction. To our knowledge, this is the first report of behavioral inhibition relating to neck misalignment. It is possible that impulsivity interferes with ability to maintain alignment of the neck. This assertion is in line with research relating impulsivity to the motivation that leads to addictive behaviors (Bickel & Marsch, 2001), suggesting that impulsive individuals prioritize immediate rewards over consequences. It is also intriguingly possible that neck alignment influences impulsivity; focusing on the immediate task rather than long term consequences of alignment might require less cognitive involvement, and produce a chronic tendency to overvalue immediate rewards.

Evidence from both studies shows that alignment and inhibitory control are closely related. First, the consistent association between a more backward head tilt and less inhibitory control in both studies strengthens the assertion that inhibitory control may relate to the way participants hold their heads and thus may be an important avenue for future research. Although FHP was not associated with false alarms on the Go/NoGo task, it was associated with poor Stroop task performance. The difference might be because the Stroop task has no ceiling effect, so it will detect even small differences in young adults. However, Go/NoGo consistently correlated with backward head tilt, while Stroop was not, suggesting that these measures may relate to different aspects of inhibitory control. Go/NoGo is inhibition of an automatic response to a quickly presented stimulus (Rubia et al., 2001), and Stroop is the inhibition of a well-learned contextual cue (Stroop, 1935). Taken together, these results provide the first evidence that postural alignment is associated with inhibitory control, and future research would benefit from exploring the nuances of this association.

9.2 Attention to Posture Between Studies

Attention to posture had different effects in the two studies. During our first study, effects of attention to posture did not relate to inhibition, and attention to posture produced a forward head tilt and longer neck. When one attends to posture, it is expected that they lift themselves up, and this would result in a backward head tilt. During the second study, postural changes due to attention to posture were associated with mindfulness and inhibitory control, and attention to posture produced a more backward head tilt, and no effect on neck length. While it is uncertain what produced these differences between our studies, it is likely that this is due to the changes in motion capture tracking which we made for the second study. We moved the head segment from an arbitrary point above the brow to the eye in front of the body, the atlas to the joint between the head and the neck (inward, backward, and down), and the C7 to the joint center (inward and upward). This shift may have changed the trajectory of the neck-head angle (head forward when attending for the first study, and head backward when attending for the second study), and the length of the neck between the studies (shorter necks on average during the second study). We are more confident in our measurement for the second study, because the landmarks used are relevant to postural alignment of the head, neck and torso.

9.3 Anticipation of Movement and Cognition

The goal of our study was to determine whether anticipation of movement would produce an impulse to move toward a goal which would cause acute leading with the head, seen as FHP. We also believed that changes in postural alignment produced by this tendency is attenuated by inhibitory control. Expanding on the logic of dual-task studies, if we consider balancing an object on the tray and maintaining postural alignment to be separate tasks, anticipating movement represents a goal with immediate demands which supersede the maintenance of postural alignment in favor of moving the head towards a target. In addition, the increase in FHP during the Rolling task represents a decrease in performance on the postural alignment task when presented with the demands of a more complex secondary task. This effect is not present when participants attended to their posture, likely because participants prioritized postural alignment when they were instructed to pay attention to their alignment. These findings are in line with the research on postural control in the context of a dual-task study, showing that during more difficult tasks postural control performance is reduced (Hawkes et al., 2012). In addition, these results are in line with studies on computer use, which showed increased FHP during a computer task when compared to normal sitting (Shahidi et al., 2013), and increased lumbar muscle activity during simultaneous arithmetic and mouse tasks, compared to just the mouse task (Igarashi et al., 2015). To our knowledge, this is the first study to show that anticipating a more difficult task is a compelling stimulus which results in acute FHP, and perhaps even more surprising, this effect can be ameliorated by simply asking participants to pay attention to their posture.

In addition, both studies showed that shortening of neck length when anticipating movement was associated with poor inhibitory control. In our first study, this relationship was only present when participants were rushed, but interestingly, the task had no influence on the relationship found during the second study. This evidence provides further support that the beginning of movement may be a particularly potent time to correct a person's alignment. Although a large body of research points to changes in postural *control* in preparation for stepping (Cohen et al., 2011; Yogev-Seligmann et al., 2008), this is, to our knowledge, the first evidence for changes in postural *alignment* during preparation for movement, and it opens up a large potential area for future research.

9.4 Conclusion

Maintaining neutral posture may require inhibition of an impulse to put the head forward of the body when anticipating movement. With repetition, this impulse may become a chronic issue. Taken together, these two studies constitute evidence that when provided with a target for movement, people have a tendency to lead with the head, producing FHP. The resulting FHP is likely to be independent of leaning of the rest of the body in preparation for movement, because it occurs so far in advance of the actual task. Additionally, the use of a dual-task methodology in the context of postural alignment shows that this FHP is even greater during more difficult tasks. This provides evidence that postural instruction may be important in the face of compelling demands in order to reduce the impact of this acute misalignment. In particular, treating attention to posture as a discrete task requiring active attention may prove important in developing effective postural training.

This research also demonstrates that shortening of the neck in anticipation and preparation for movement are related to inhibitory control. This evidence constitutes a link between inhibitory control and postural alignment, extending the relationship between postural control and inhibition found in previous studies, and showing the importance of studying cognition in the context of postural alignment.

We also found that attention to posture does not necessarily improve alignment; simply instructing individuals to use their best posture may be ineffective, particularly in individuals with low mindfulness. In our first study, the effects of attention on differences in alignment of the head with the neck, and on neck length, diminished when preparing to move. In our second study, attention to posture reduced FHP but had no influence on neck length; lower levels of mindfulness were related to reduced effects of attention to posture on FHP and head tilt. In conjunction with the findings of dual-task studies, this research suggests that to improve postural alignment, studies should address mindfulness as well as the influence of attention.

FHP alone may not be an adequate measure of neck misalignment, and other factors should be included when assessing neck posture. In particular, shorter neck length was associated with neck disability, supporting the assertion that shortening of the neck is closely related to neck pain.

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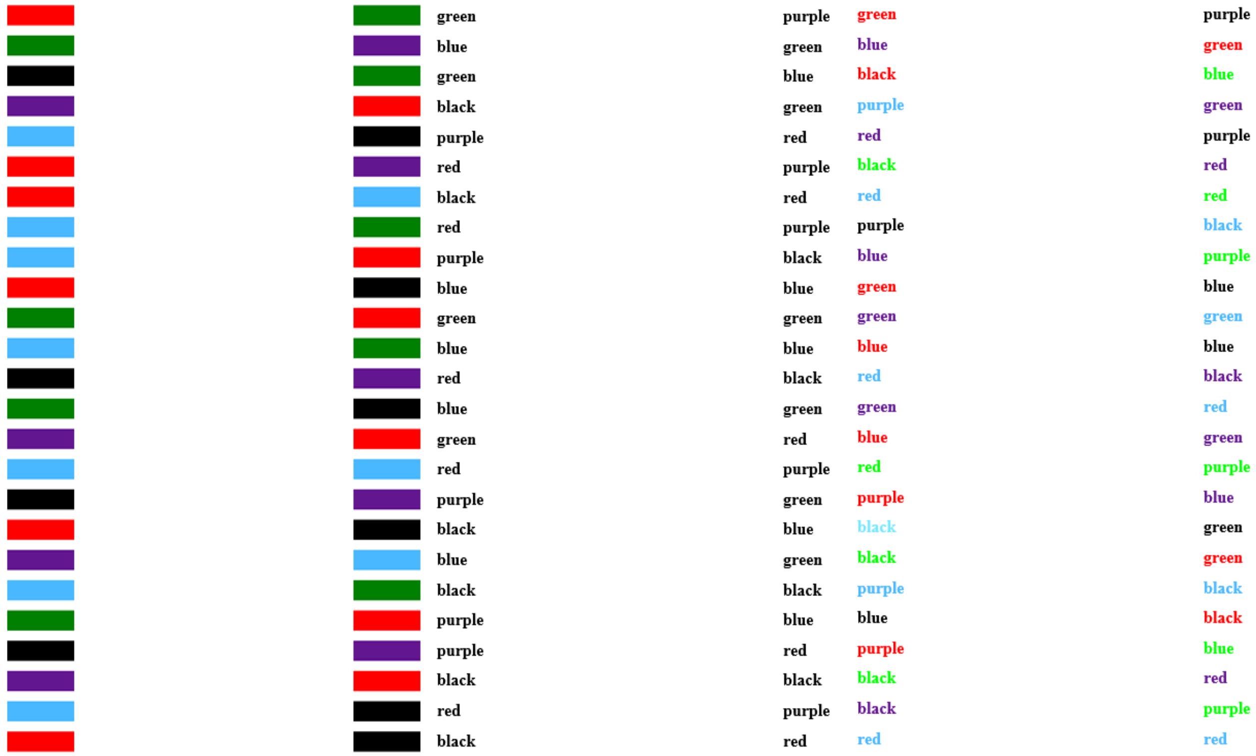
APPENDIX A: QUESTIONNAIRES

1. Stroop Task



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Instructions: Say the Word

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Instructions: Say the Ink Color

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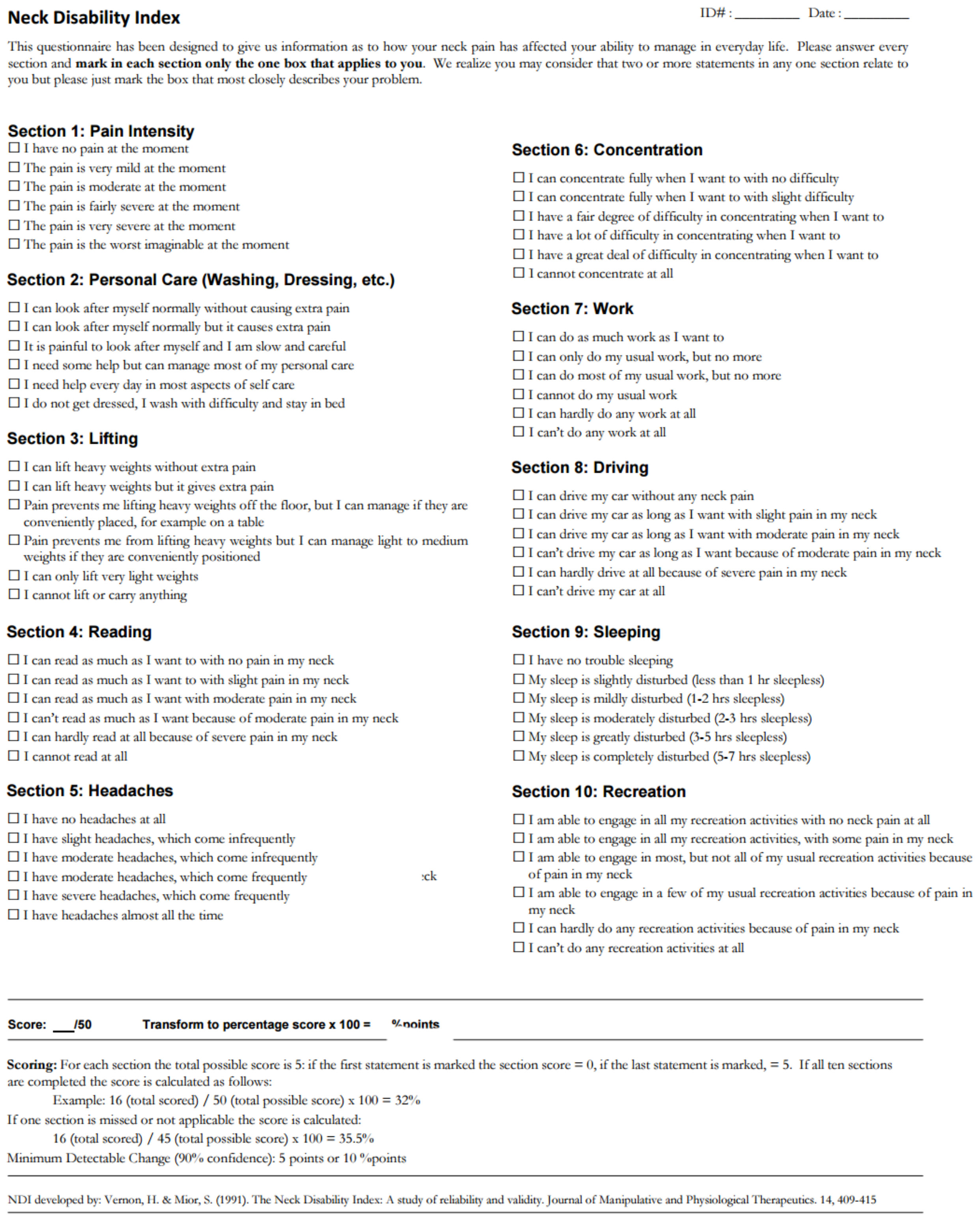
2. MAAS

	always					*never*
1. I could be experiencing some emotion and not be conscious of it until some time later.	1	2	3	4	5	6
2. I break or spill things because of carelessness, not paying attention, or thinking of something else.	1	2	3	4	5	6
3. I find it difficult to stay focused on what's happening in the present.	1	2	3	4	5	6
4. I tend to walk quickly to get to where I'm going without paying attention to what I experience on the way.	1	2	3	4	5	6
5. I tend not to notice my feelings of physical tension or discomfort until they really grab my attention.	1	2	3	4	5	6
6. I forget a person's name almost as soon as I've been told it for the first time.	1	2	3	4	5	6
7. It seems I am "running on automatic" without much awareness of what I'm doing.	1	2	3	4	5	6
8. I rush through activities without being really attentive to them.	1	2	3	4	5	6
9. I get so focused on the goal I Want to achieve that I lose touch with what I am doing right now to get there.	1	2	3	4	5	6
10. I do jobs or tasks automatically, without being aware of what I'm doing.	1	2	3	4	5	6
11. I find myself listening to someone with one ear and doing something else at the same time.	1	2	3	4	5	6
12. I drive places on "automatic pilot" and then wonder why I went there.	1	2	3	4	5	6
13. I find myself preoccupied with the future or the past.	1	2	3	4	5	6
14. I find myself doing things without paying attention.	1	2	3	4	5	6
15. I snack without being aware that I'm eating.	1	2	3	4	5	6

3. NDI



Neck Disability Index

ID# : ________ Date : ________

This questionnaire has been designed to give us information as to how your neck pain has affected your ability to manage in everyday life. Please answer every section and **mark in each section only the one box that applies to you**. We realize you may consider that two or more statements in any one section relate to you but please just mark the box that most closely describes your problem.

Section 1: Pain Intensity

☐ I have no pain at the moment
☐ The pain is very mild at the moment
☐ The pain is moderate at the moment
☐ The pain is fairly severe at the moment
☐ The pain is very severe at the moment
☐ The pain is the worst imaginable at the moment

Section 2: Personal Care (Washing, Dressing, etc.)

☐ I can look after myself normally without causing extra pain
☐ I can look after myself normally but it causes extra pain
☐ It is painful to look after myself and I am slow and careful
☐ I need some help but can manage most of my personal care
☐ I need help every day in most aspects of self care
☐ I do not get dressed, I wash with difficulty and stay in bed

Section 3: Lifting

☐ I can lift heavy weights without extra pain
☐ I can lift heavy weights but it gives extra pain
☐ Pain prevents me lifting heavy weights off the floor, but I can manage if they are conveniently placed, for example on a table
☐ Pain prevents me from lifting heavy weights but I can manage light to medium weights if they are conveniently positioned
☐ I can only lift very light weights
☐ I cannot lift or carry anything

Section 4: Reading

☐ I can read as much as I want to with no pain in my neck
☐ I can read as much as I want to with slight pain in my neck
☐ I can read as much as I want with moderate pain in my neck
☐ I can't read as much as I want because of moderate pain in my neck
☐ I can hardly read at all because of severe pain in my neck
☐ I cannot read at all

Section 5: Headaches

☐ I have no headaches at all
☐ I have slight headaches, which come infrequently
☐ I have moderate headaches, which come infrequently
☐ I have moderate headaches, which come frequently :ck
☐ I have severe headaches, which come frequently
☐ I have headaches almost all the time

Section 6: Concentration

☐ I can concentrate fully when I want to with no difficulty
☐ I can concentrate fully when I want to with slight difficulty
☐ I have a fair degree of difficulty in concentrating when I want to
☐ I have a lot of difficulty in concentrating when I want to
☐ I have a great deal of difficulty in concentrating when I want to
☐ I cannot concentrate at all

Section 7: Work

☐ I can do as much work as I want to
☐ I can only do my usual work, but no more
☐ I can do most of my usual work, but no more
☐ I cannot do my usual work
☐ I can hardly do any work at all
☐ I can't do any work at all

Section 8: Driving

☐ I can drive my car without any neck pain
☐ I can drive my car as long as I want with slight pain in my neck
☐ I can drive my car as long as I want with moderate pain in my neck
☐ I can't drive my car as long as I want because of moderate pain in my neck
☐ I can hardly drive at all because of severe pain in my neck
☐ I can't drive my car at all

Section 9: Sleeping

☐ I have no trouble sleeping
☐ My sleep is slightly disturbed (less than 1 hr sleepless)
☐ My sleep is mildly disturbed (1-2 hrs sleepless)
☐ My sleep is moderately disturbed (2-3 hrs sleepless)
☐ My sleep is greatly disturbed (3-5 hrs sleepless)
☐ My sleep is completely disturbed (5-7 hrs sleepless)

Section 10: Recreation

☐ I am able to engage in all my recreation activities with no neck pain at all
☐ I am able to engage in all my recreation activities, with some pain in my neck
☐ I am able to engage in most, but not all of my usual recreation activities because of pain in my neck
☐ I am able to engage in a few of my usual recreation activities because of pain in my neck
☐ I can hardly do any recreation activities because of pain in my neck
☐ I can't do any recreation activities at all

Score: ___/50 **Transform to percentage score x 100 =** **%points**

Scoring: For each section the total possible score is 5: if the first statement is marked the section score = 0, if the last statement is marked, = 5. If all ten sections are completed the score is calculated as follows:
Example: 16 (total scored) / 50 (total possible score) x 100 = 32%
If one section is missed or not applicable the score is calculated:
16 (total scored) / 45 (total possible score) x 100 = 35.5%
Minimum Detectable Change (90% confidence): 5 points or 10 %points

NDI developed by: Vernon, H. & Mior, S. (1991). The Neck Disability Index: A study of reliability and validity. Journal of Manipulative and Physiological Therapeutics. 14, 409-415