Bidirectional Effects of Neck Posture and Cognition: Studies of Attention and Inhibitory Control

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Abstract

The two studies presented within this dissertation investigate a bidirectional relationship between control of attention and a flexed neck posture. These studies have been submitted for publication as independent journal articles; they establish a cognitive foundation upon which neurological research on posture can be conducted. The first study, published in *Psychological Research* (Baer, Vasavada, & Cohen, 2022), demonstrates that while biofeedback improves postural alignment, this improvement comes at the price of cognitive task performance, and that higher levels of mindfulness reduce this tradeoff. The second study (submitted), demonstrates that inducing a flexed neck posture improves both reaction time and reactive inhibitory control but does not influence proactive inhibition. These studies together show that attention is an integral component in actively maintaining posture, and cognitive factors that moderate attention are also affected by induced changes in posture.

Acknowledgments

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Chapter 1: Introduction

Computer work is associated with poor posture and neck pain. Most office work occurs while seated at a computer workstation (OSHA, 2020); as a result, a large portion of work related musculoskeletal disorder (WRMSD) claims in offices are directly attributed to postural dysfunction during seated work, especially those relating to neck pain and back pain (OSHA, 2020). Extensive research links flexed and forward neck postures to computer work in a number of professions (Ariëns et al., 2001; Ariëns et al., 2000; Chiu et al., 2002; Kang et al., 2012; Silva et al., 2009). This forward movement of the head relative to the rest of the torso leads to increased compression of the intervertebral discs (Bogduk & Mercer, 2000; Kapandji, 1974; Vasavada et al., 2015; Yip et al., 2008) and increase the mechanical load on the spine (Bogduk & Mercer, 2000; Kellgren, 1977). This extended stress on the neck compresses nerves, leading to chronic pain and strain on surrounding muscle tissue (Ming, Närhi, & Siivola, 2004; Waldron, 1998).

Poor posture is widespread despite knowledge of the long-term consequences (Ariëns et al., 2001), which raises the question: why do we put our heads forward? We approached this question from two directions in this dissertation. In the first study, we address how correcting poor posture through biofeedback can increase cognitive load on concurrent tasks, interfering with performance. In the second study, we show that inducing a flexed neck posture can improve reaction time and stopping time during motor tasks, suggesting a short-term benefit which may lead to the formation of poor posture habits.

While the need for postural interventions is high (OSHA, 2020), the best practices for these interventions are not established, in part because of a lack of understanding of the processes underlying healthy posture, neck pain, and postural correction (Westgaard & Winkel, 1997). Attention may be important for maintaining upright posture (Baer, Vasavada, & Cohen, 2019), but current practices do not consider the following factors: (1) A trade-off between attention to a task and maintaining upright posture may negatively affect task performance. (2) Poor postural habits may develop over time because a flexed neck posture improves performance on immediate tasks. Little research has been conducted on what constitutes an effective postural intervention. By treating posture as a component in a dual task design for our first study, we provide insight into what factors of attention underlie effective maintenance of postural alignment. By manipulating posture in our second study, we provide insight into the effects of neck flexion on reaction time and inhibition.

Attention may be important for maintaining postural alignment. Posture may be thought of in two main ways: active correction of position of body segments to maintain stability in response to environmental changes (postural control), and maintenance of spinal alignment to reduce compression forces on the body (postural alignment). Numerous dual-task studies have demonstrated a link between management of attention and postural control (Hawkes et al, 2012; Mirelman et al., 2012; Yogev-Seligmann, Hausdorff, & Giladi, 2008). In our lab we recently discovered that this link extends to postural alignment during gait initiation; we demonstrated a trade-off between maintaining upright posture and the initiation of target directed movement (Baer et al., 2019). Forward head posture increased when anticipating movement and increased more when the anticipated movement was more difficult, suggesting that maintaining postural alignment could be considered a secondary task that becomes more difficult as the primary task becomes more demanding. Based on our previous research, we also theorize that postural alignment is linked to both mindfulness and inhibitory control. These concepts are related because they describe how attention is maintained and managed.

Mindful regulation of attention is the ability to maintain attention on the intended tasks in the present (Bishop et al., 2004). Mindfulness interventions have been shown to improve many facets of attention management (Jha, Krompinger, & Baime, 2007; Sanger & Dorjee, 2015) and reduce cognitive load in decision-making (Reber, 2014). In previous research, less mindful individuals had greater forward head posture when standing or anticipating movement than those who were more mindful (Baer et al., 2019), thus, we theorized that the role of mindfulness in attention also extends to active correction of postural alignment.

In contrast, the role of inhibition in regulating attention is more direct. To switch between tasks, one must stop the current task before beginning the next task. Attention needs to be directed to integrate sensory information and responses, specifically the inhibition of incorporating irrelevant information (Hampshire & Owen, 2006), and inhibition of an initiated response (Aron, 2012). We previously observed that young adults whose habitual posture includes more neck flexion perform worse on a Stroop task than young adults with less neck flexion (Baer et al., 2019). In addition, inducing a more forward neck position improved reaction times on saccade (Kunita & Fujiwara, 2009), and antisaccade (Kunita & Fujiwara, 2013) tasks. Together these studies suggest that inhibitory control may be involved in managing postural alignment, but the effects are not well understood, which leads to our second study regarding inhibitory control and fixed neck posture.

In the second study, we manipulated neck posture to study how a flexed neck posture improves performance on immediate tasks. In previous research, increased muscle tone from a flexed neck posture improved response time on reaction time tasks by reducing relevant sensory thresholds and increasing the likelihood of a response (Kunita & Fujiwara, 2009). These studies were performed primarily in a lab setting with a harness to fix neck posture in place and focused on the control of motor responses. However, inhibitory control tasks are not all alike (Aron, 2011). In order to resolve the apparent disconnect between increased neck flexion improving antisaccade performance (Kunita & Fujiwara, 2013), and being associated with worse performance on Stroop (Baer et al., 2019), we studied the distinction between proactive and inhibitory control tasks with our second experiment. By manipulating posture with simple tactile feedback, we were able to replicate the facilitation effect of a flexed neck in an applied setting and demonstrated that other inhibitory control tasks were not affected by a flexed neck posture.

This dissertation summarizes bidirectional influences on the formation of poor posture habits. The first study demonstrates how posture is hard to change, because some methods for correcting poor posture may impose additional cognitive load and interfere with other tasks. The second study suggests how the short-term benefit of a flexed neck on reaction time may lead to the formation of poor posture habits in the long term.

Chapter 2: Posture biofeedback increases cognitive load

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2.1. ABSTRACT

Attention may be important for actively maintaining posture during computer tasks, resulting in a dual-task tradeoff, where maintaining posture through extrinsic feedback imposes cognitive load. Mindfulness may make intrinsic postural feedback (which imposes less cognitive load) more available. Therefore, we hypothesized that the use of biofeedback would improve posture and negatively impact game performance; additionally, higher levels of mindfulness would be associated with lower game performance costs in the biofeedback condition. Healthy young adult participants played a challenging computer game for 10 minutes with and without neck-length biofeedback, in a counterbalanced repeated-measures design. For each condition we assessed posture using neck shrinkage (percentage of best), and task performance (computer game score). Neck length was better retained and game performance was worse with biofeedback than without, consistent with the hypothesis that posture biofeedback imposed a cognitive load. In addition, participants with the most neck shrinkage suffered the greatest performance decrements from using biofeedback, and neck length retention during the task *without* biofeedback was associated with lower self-reported daily neck pain and higher self-reported mindfulness. Thus, those with the greatest need for postural feedback suffer the greatest performance decrements from extrinsic feedback. The results are consistent with the idea that mindfulness enables people to use intrinsic feedback to maintain posture without imposing a dual-task cost.

2.2. INTRODUCTION

In cognitive psychology attention is considered a finite resource, and tasks that draw on this resource are said to incur cognitive load. Cognitive load is typically assessed in dual-task designs in which participants perform two tasks, singly and concurrently. If both tasks require attention, performing them concurrently results in a performance decrement relative to single-task performance. This decrement, referred to as a dual-task cost, increases with cognitive load resulting in an attentional tradeoff, where attention given to tasks is prioritized based on the perceived importance of each task.

Attention may be important for actively maintaining posture during computer tasks. Although balance is known to require attention (Woollacott & Shumway-Cook, 2002), maintaining postural alignment has not previously been considered a task which incurs a cognitive load. We recently demonstrated that neutral posture is not maintained before anticipated movement, especially when the anticipated movement is difficult (Baer et al., 2019). This finding suggests that the task of maintaining posture might be ignored in the presence of increased cognitive load. Therefore, investigations of interventions to improve posture need to address the possibility of concomitant performance decrements due to increased cognitive load.

Biofeedback devices are a relatively new intervention that may be used to reduce neck pain during computer work (Simpson, Maharaj, & Mobbs, 2019). Neck pain is a common musculoskeletal issue across multiple populations and age groups (Haldeman, Carroll, & Cassidy, 2010), often attributed to deviations from neutral posture during seated work (G A Ariëns et al., 2001; OSHA, 2020). Numerous proprietary biofeedback devices available on the market promise to improve posture by delivering a simple tactile or auditory cue when a person slouches or bends forward (Ailneni et al., 2019; Hwang, 2019). Though this idea is enticing, it relies on underlying concepts that have not yet been adequately investigated. For instance, there may be cognitive costs associated with biofeedback-based correction of posture that have not yet been considered.

Cognitive load in a dual task paradigm occurs when cognitive resources overlap between two tasks that are performed simultaneously. Both maintaining postural alignment and performing complex computer tasks may rely on visuomotor performance and prospective memory. Many computer tasks and games rely heavily on visuomotor performance for fast response times and coordination of fine motor movements (Li, Chen, & Chen, 2016)*;* and on prospective memory to manage sequential tasks and complex decision making (Martin & Schumann-Hengsteler, 2001).

To our knowledge, our previous study is the only one which has investigated the cognitive demands of postural alignment (Baer et al., 2019). Postural alignment is inherently a visuospatial (or at least spatial) task, so it might be expected to compete for that cognitive resource. In addition, attempting to change habitual postural alignment is likely to draw on prospective memory. When a person makes a plan to act against existing habits, interference is created by a conflict between well-learned responses and the intention to incorporate new prospective memory cues (Pink & Dodson, 2013). Postural alignment is probably a very well-learned habit, so intending to change postural alignment may incur cognitive load.

The opposite of doing things habitually is doing them mindfully. Mindfulness is defined as the ability to maintain attention on the present and on intended tasks through self-regulation (Bishop et al., 2004). Mindfulness interventions have been shown to improve many facets of attention management (Jha et al., 2007; Sanger & Dorjee, 2015) and reduce cognitive load in decision making (Reber, 2014). Thus, if attending to posture increases cognitive load, then mindfulness might ameliorate that load by increasing the total pool of attentional resources available or by lowering the amount of attention needed to notice small changes such as those associated with posture. We previously demonstrated that individuals who score higher on a self-report of mindfulness display less forward head posture when anticipating a movement than individuals who report lower mindfulness (Baer, Vasavada, & Cohen, 2019). This suggests that mindfulness may facilitate the awareness of deviations from neutral posture, leading to improved ability to maintain posture. In the context of maintaining posture, mindfulness may thus facilitate the use of intrinsic feedback (Patchan & Puranik, 2016).

Posture is most often assessed based on external measurement of body angles. However, due to substantial variation in neutral postural angles among individuals (Silva et al., 2009), there is no validated way to objectively define “optimal” neutral posture. Moreover, external angular measurements are not valid indicators of internal spinal alignment (Correia et al., 2021; Vasavada et al., 2015). Another way to assess posture may be to focus on *neck shrinkage*, which can be represented objectively by relative decreases in neck length from neutral. Spinal shrinkage is generally measured in terms of stature changes and is thought to represent compression of intervertebral discs due to increased spinal loading (Bonney & Corlett, 2002). Acute spinal shrinkage is associated with postural discomfort (Beynon & Reilly, 2001), and neck posture may be particularly important. As the head moves forward relative to the torso, the gravitational load on the spine increases (Vasavada et al., 2015). However, if the head is extended relative to the torso, this can also lead to neck shortening (Frantz, Cohen, & Vasavada, 2021). Thus, we chose to use neck shrinkage as a plausible monotonic measure of neck compression caused by failing to maintain a neutral cervical spine.

In summary, preliminary evidence suggests that maintaining posture is related to the ability to manage attention (Baer, Vasavada, & Cohen, 2019), and biofeedback devices do not take limitations of attention into account in their design. By treating maintenance of posture as a task in a dual-task experiment, we investigated the attentional cost of attending to posture, along with the effectiveness of biofeedback. We hypothesized that biofeedback would (1a) improve neck length retention, while (1b) worsening computer task performance, resulting in (1c) an attentional tradeoff between a participant's ability to maintain neck length and their overall game score. Further, (2) this attentional tradeoff would be reduced in people with higher levels of mindfulness. We also predicted (3) a correlation between neck disability and neck shrinkage during the task.

2.3. METHOD

2.3.1. Participants

We tested 42 participants (20 men and 22 women) aged 18 to 24 years (M = 19.7, SD 1.8), recruited from psychology courses at the University of Idaho. This study was approved by the Institutional Review Board of the University of Idaho; all participants provided written informed consent and received course credit for a two-hour data collection session. Prior to testing we screened participants for physiological and psychological issues that could interfere with their ability to perform the tasks. Participants were excluded from the study if they reported current musculoskeletal injuries (pain in any part of the body while standing or walking), neurological issues (diagnosed mental disorder), or any condition that could interfere with their ability to perform the task comfortably.

2.3.2. Equipment

Three-dimensional motion capture data were collected using eight Vicon Bonita motion capture cameras (Oxford, UK) and processed using The MotionMonitor software by Innovative Sports Training (Chicago, IL). Vicon precision for absolute position is 0.15 mm, with a variability of 0.025 mm within a single data collection session (Merriaux et al., 2017). Thirty reflective markers were placed on bony landmarks of the body (Figure 2.1), 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 8 body segments in Vicon: head, neck (atlanto-occipital, A/O to C7/T1 joint), upper torso (C7/T1 to T12/L1 joint), lower torso (T12/L1 to L5/S1 joint), left and right upper arm, and left and right thigh. Based on these Vicon segments The MotionMonitor produced a composite model of each participant's skeletal structure for analysis, with joint centers determined based on offset positions from surface landmarks recorded in anatomical position (Chaffin, Andersson, & Martin, 2006). The A/O (between the left and right mastoid process) and C7/T1 (7.18

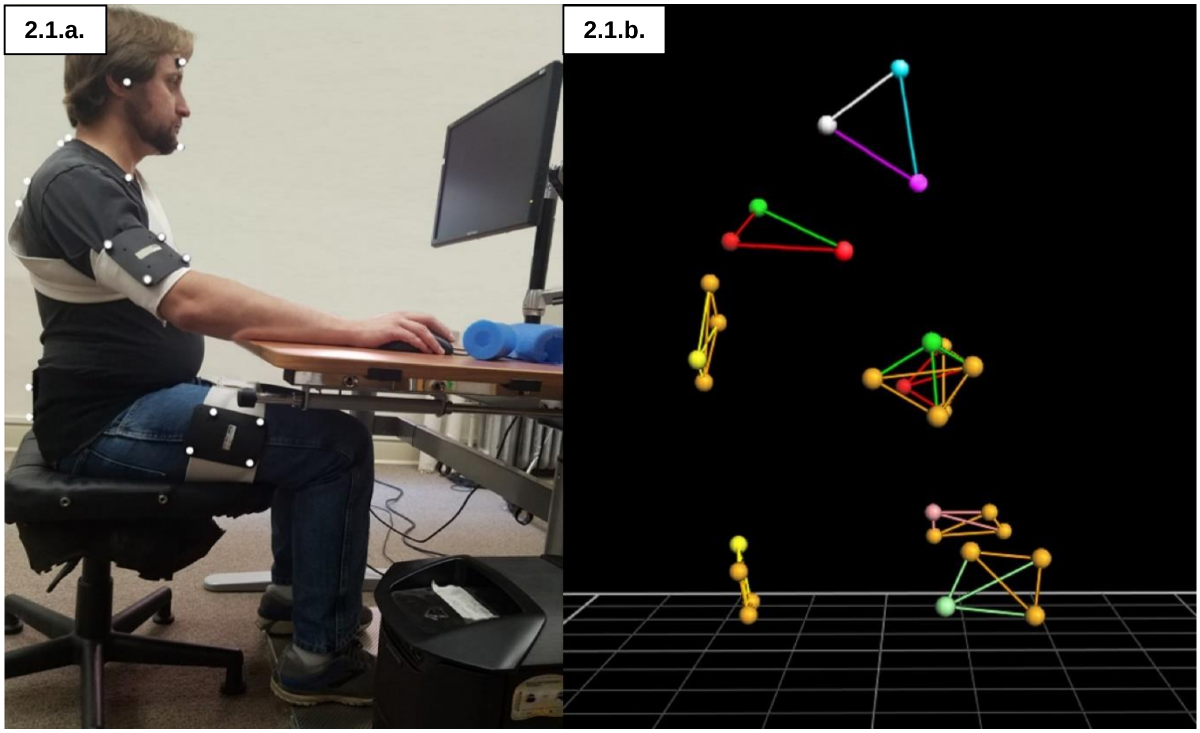


Figure 2.1. Reflective markers

a. Participant wearing reflective marker clusters for head; upper, middle, and lower torso; left and right upper arm; and left and right thigh.

b. Vicon segments produced by reflective markers shown in 1a.

cm forward, 3.35 cm down from the C7 spinous process) joint centers were used in analysis (Figure 2.2.a).

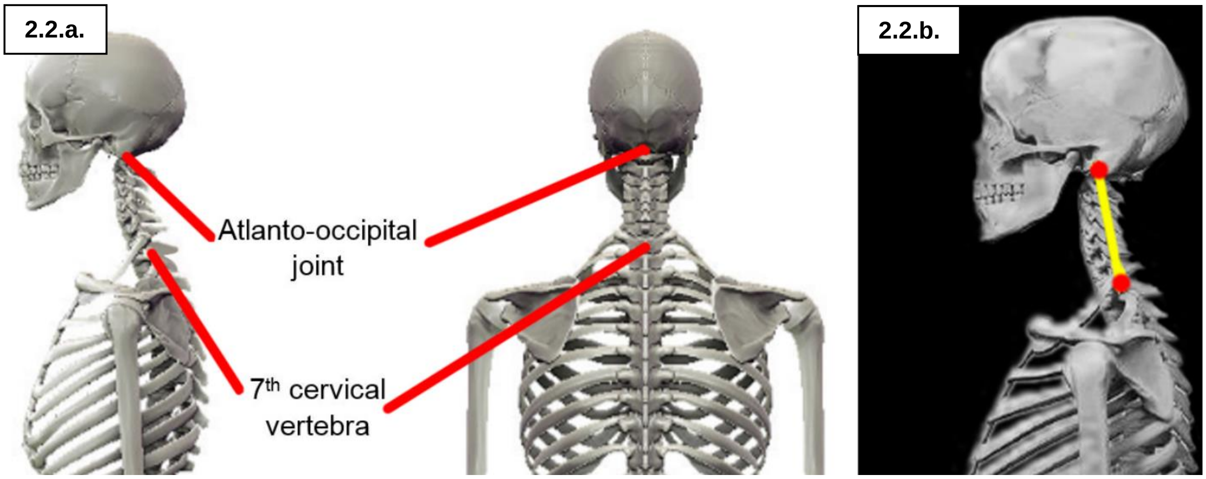


Figure 2.2. Anatomical landmarks
a. Bony landmarks used in digitization of composite skeleton.
b. The MotionMonitor composite skeleton. Digitized points for atlanto-occipital (A/O) joint and C7 are shown in red; dependent measure of relative neck length (neck shrinkage, distance between AO joint and C7 relative to best posture) are shown in yellow.

The participant workspace was equipped with an adjustable sit-stand desk, adjustable monitor display, and adjustable backless office chair (to accommodate the use of reflective markers). This allowed the workstation to be tailored specifically to each participant's anthropometry.

2.3.3. Protocol

First, the workstation was adjusted for each participant using standard ergonomic guidelines (Chaffin, Andersson, & Martin, 2006) such that ankles, knees, hips and elbows were at 90 degrees and the center of the screen was 10 degrees below eye-level. Participants were additionally instructed to allow their heads to float at the top of their spine to maintain an uncompressed neck. After workstation adjustments were made, reflective markers were attached (Figure 2.1). Participants were asked to maintain their posture as described above for 10 seconds for an initial baseline recording of neck length to base the biofeedback variable on.

Next, participants received a brief tutorial on the computer game (*Diner Dash 2* - Playfirst, 2006) and 5 minutes of unrecorded practice to mitigate possible practice effects. Participants then played two 10-minute sessions of the game, once with biofeedback and once without biofeedback, in counterbalanced order. Participants were urged to see how many points they could earn in the game. Before each trial, participants were given a brief reminder about maintaining the instructed posture.

After the first game session, participants were given 5 minutes of rest and allowed additional time if requested. After the second session, participants were asked to complete two surveys prior to being debriefed on the experiment.

Diner Dash 2 is an attention-demanding computer game in which the player takes the role of a waiter in a busy diner; performance is scored based on how players manage important hierarchical decisions in parallel over time. Because the game only requires mouse controls (no keyboard input), participants never have to look away from the screen (which would interfere with posture). The game uses second-order controls, which leads to delayed feedback and increased cognitive load (Sanders & McCormick, 1993); players click on a screen location with a task, and the waiter travels to that location at a set pace before any action can be completed. The game also challenges users with a graphically complex display, which further increases cognitive load (Bennett & Flach, 1992); the display is dynamic and uses abstract representations to indicate each goal (seating customers as they line up, taking orders as customers become impatient, serving orders as they pile up in the kitchen, bussing tables and serving bills to create reasonable turnover for customers).

Players are scored based on how many tables of customers are fully served, with bonus points awarded for customer satisfaction at the end of their meal. Each customer begins with three hearts, losing one each time an action takes too long to complete. The game ends if five customers leave unsatisfied. Customers arrive in groups of one to four, at an increasing rate as the game progresses. To achieve high scores (about twenty thousand), users must demonstrate cognitive competency by responding quickly to the changing environment (visuomotor performance), completing tasks in parallel (parallel information processing), and remembering unique customer types to prioritize for bonus points (prospective memory) to maximize point totals. Players who restart frequently due to failing objectives, and those who complete one continuous attempt without bonus objectives will both score poorly (below ten thousand points). This game has been modelled as a benchmark for measuring progress of policy learning algorithms, and should generalize effectively to measuring cognitive performance on visuomotor performance and prospective memory (Chen, Ma, & Hsu, 2020).

2.3.4. Measures

2.3.4.1. Neck shrinkage and biofeedback. As our primary measure of posture, and as a biofeedback variable, we used percentage of neck length relative to baseline (represents neck shrinkage when decreasing, and neck length retention when maintained), which helps account for anatomical differences between participants. Neck length was measured as the three-dimensional linear distance between the AO joint center and the C7/T1 joint center (Figure 2.2.b). We used a threshold of 97.5% of baseline to provide biofeedback to participants during tasks. We monitored posture in real time using a moving average of 10 seconds. If the average neck length shortened to less than 97.5% of baseline, a warning tone of 440 Hz would sound until the participant's posture was corrected (*i.e.*, returned within 97.5% of baseline). We selected this threshold based on pilot testing with 20 individuals; we asked participants to test various postures (slumped, forward head, military neck, downward gaze) and found that most participants were able to notice discomfort from approximately 1% neck shrinkage, and all participants noticed the difference at 2.5%. In addition to its use in biofeedback, neck length was recorded continuously for each 10-minute trial. We used the moving average across a 10 second period to account for head movement and occasional glances away from the screen.

2.3.4.2. Computer game. The Diner Dash game awards points based on speed and number of actions taken. After a loss total scores are reported, and the game can be restarted quickly. Total game score across all attempts for ten minutes was used as a measure of performance. Additionally, game scores were used to calculate a cognitive dual-task effect from the use of biofeedback (McIsaac, Lamberg, & Muratori, 2015). This measure quantifies the percent change in score between attempts on the task with and without biofeedback using the equation: (score with no feedback - score with biofeedback) / (score with no feedback * 100). This measure represents the attentional cost of biofeedback; a greater percent change indicates a greater decrement in performance on the task. All participants were given 5 minutes of practice to familiarize them with the game mechanics to control for possible practice effects. Participants were also asked about their previous experience playing computer games as well as specific experience with Diner Dash 2.

2.3.4.3. Questionnaires. The Neck Disability Index (NDI, Vernon & Mior, 1991) is a self-report measure of a person's perceived neck pain and its effect on their daily life. While we did not specifically recruit participants who were suffering from or being treated for neck pain, we include this measure because young adults are at high risk for neck pain (Haldeman et al., 2010), and the questionnaire is sensitive enough to detect minimal neck pain that may otherwise go unreported (Jorritsma et al., 2012). 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 that best matches their perceived neck disability within that category, on a scale from “not at all disabling” to “severely disabling.” Each item is scored from 0-5 and the total score is doubled to calculate a percentage which indicates to what degree their life is affected by neck pain, with a higher score indicating more pain and disability.

The Mindful Attention Awareness Scale (MAAS, Brown & Ryan, 2003) is a 15-item questionnaire designed to assess awareness of and attention to what is taking place in the present. Each item describes a symptom of unawareness (e.g. pain awareness, reading, or sleeping) participants indicate how frequently they experience that phenomenon (1 for almost always, 6 for almost never). The final score is tallied and used to describe a person’s self-reported level of mindfulness, where a higher score indicates more mindfulness.

2.3.5. Statistical analysis

Data from The MotionMonitor were processed using custom code written in MATLAB R2017a; ANOVAs and correlations were conducted using SPSS Version 22. Relevant population parameters for game score, baseline neck length, MAAS scores, and NDI scores are displayed in Table 2.1. NDI scores were not normally distributed; the distribution was skewed towards lower neck pain scores; this reflects that our sample population was not recruited for neck pain.

Table 2.1. Population parameters for each measure used in analysis

Variable	Mean	SD	Skewness
Baseline Neck Length	14.3 (cm)	1.9 (cm)	-0.39
Average Game Score	20,101	6,275	0.51
MAAS Score	61.2	9.2	-1.11
NDI Score	8.3	6.8	**1.46***

Neck length measured during baseline (cm), average game performance (score), Mindful Attention Awareness Scale (MAAS) score, and Neck Disability Index (NDI) score. Includes mean (column 1), standard deviation (column 2), and skewness (column 3). *NDI scores were not normally distributed; the distribution was skewed towards lower neck pain scores; this reflects that our sample population was not recruited for neck pain.

To test the hypothesis (1a) that biofeedback would facilitate neck length retention, we conducted a 2 x 2 x 5 mixed ANOVA with factors for testing order (biofeedback first or no biofeedback first; between-groups), condition (biofeedback or no biofeedback; repeated-measures), and time (two-minute intervals; repeated-measures). Post-hoc comparisons were performed to assess the simple effect of condition in each testing order (paired t-tests) and the simple effect of time in each condition and across each testing order (four separate 1 x 5 ANOVAs). To test the hypothesis (1b) that biofeedback impairs computer task performance, we conducted a 2 x 2 mixed ANOVA with factors for order and condition as above.

To assess whether the results demonstrated a tradeoff between posture and cognitive performance (hypothesis 1c), we correlated the cognitive dual-task cost for each participant to their average neck length retention during the task with biofeedback. To test the hypothesis (2) that the attentional tradeoff would be reduced in people with higher mindfulness, we correlated MAAS scores to dual-task cost, average neck length percentage during each condition (biofeedback and no feedback), and the change in neck length over time (slope, in units of percent/10 min). To test the prediction (hypothesis 3) that neck pain would be associated with deviations from neutral posture during computer tasks, we correlated participants' NDI scores to their average neck length percentage and neck length slope. To determine if the cognitive tradeoff was related to neck pain, we correlated the cognitive dual-task cost with NDI score.

2.4. RESULTS

Data from five participants were removed due to unreliable motion capture data (several minutes of missing data due to poor marker visibility). Data from two participants were removed because game scores were greater than 3 standard deviations above the average. We analyzed data from the remaining 35 participants.

2.4.1. Neck length measure

Neck length retention is shown in Figure 2.3.a. Time spent playing the game led to neck shrinkage of 2.0% overall, $F(4, 128) = 4.77$, $p = 0.001$; contrasts revealed that neck shrinkage occurred after six minutes of play ($p < 0.01$) and continued to increase after eight minutes of play ($p = 0.03$). Condition also had an effect; neck shrinkage was 1.8% greater without biofeedback than with biofeedback, $F(1, 32) = 37.24$, $p < 0.001$. There was an interaction between condition and testing order, $F(1,32) = 8.8$, $p = 0.01$. Post-hoc tests of simple effects showed no effect of testing order in the biofeedback condition, but there was a significant effect in the no feedback condition, $p = 0.03$, demonstrating that participants had less neck shrinkage without feedback if they performed the task with biofeedback first. There was also an interaction between condition and time, $F(4, 128) = 3.68$, $p < 0.001$, without biofeedback neck shrinkage occurred over time: $F(4,132) = 8.80$, $p < 0.001$, but with biofeedback it did not: $F(4,132)=0.41$, $p=0.8$. There were no three-way interactions.

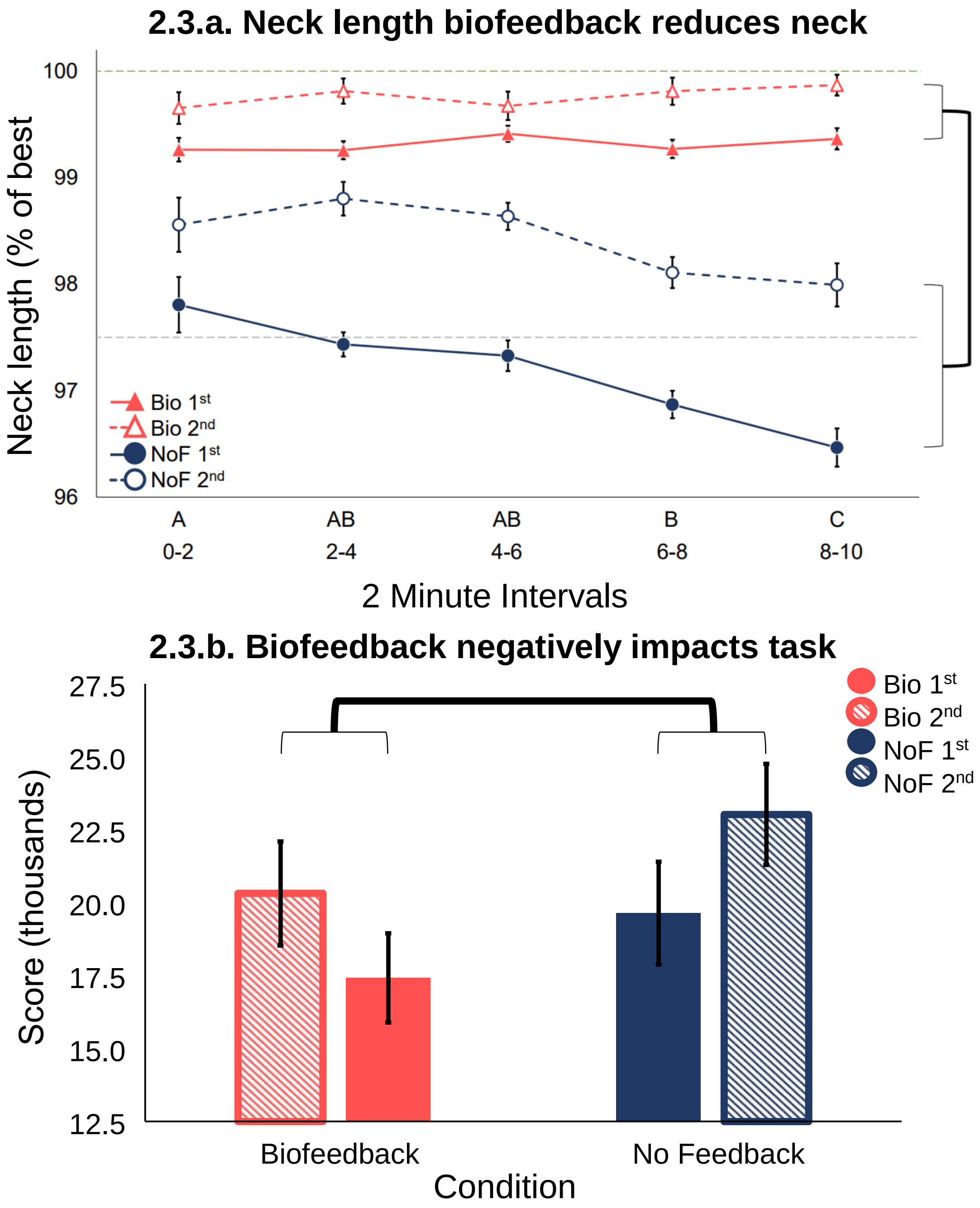


Figure 2.3. Effects of biofeedback

a. Neck length biofeedback reduces neck shrinkage. Neck length as percent of best posture (y axis) over two-minute intervals during the computer task (x axis); when using biofeedback (red triangles), and without biofeedback (blue circles), divided to show order effects (solid shape and line for first trial, empty shape and dashed lines for second trial). Lettering on the x axis represents contrast groups for time playing the game, indicating significant differences between 0-2 and 6-8 minutes and between all previous time periods and 8-10 minutes.

b. Biofeedback negatively impacts task performance. Game score between conditions (red at left: biofeedback, blue at right: no feedback); shaded bars indicate condition order (solid: first attempt; striped: second attempt).

2.4.2. Cognitive measure

2.4.2.1. Game performance is shown in Figure 2.3.b. Condition influenced game score, $F(1,31) = 5.0$, $p = 0.03$, such that score was worse when participants performed the task with biofeedback than when they performed without biofeedback. There was also a significant interaction with testing order, $t(16) = 4.2$, $p < 0.001$; such that participants who played the game with biofeedback first did worse during the biofeedback condition than the no feedback condition. When playing the game with no feedback first, there was no difference in score between conditions.

2.4.3. Correlation between cognitive and neck length data

2.4.3.1. Dual-task cost correlated with neck length percentage during biofeedback, as seen in Figure 2.4. Dual-task cost of biofeedback to game score was negatively correlated with average neck length percentage when playing the game with biofeedback, $r(33) = -0.44$, $p = 0.008$. When playing the game and maintaining posture with biofeedback, participants who had a smaller cognitive dual-task cost had better neck length retention than those with a larger dual-task cost. Dual-task cost did not correlate with NDI or MAAS scores. Table 2.2 shows a complete correlation matrix for all measures.

Table 2.2. Correlations between measures with and without biofeedback

	Dual-Task Cost	MAAS Score	NDI Score	Neck Length % (biofeedback)	Neck Length % (no feedback)	Neck Length % Slope (no feedback)
Average Game Score	-.20	.01	.29	.26	.31	.24
Dual-Task Cost		.1	.25	**.44***	NA[1]	NA[1]
MAAS Score			**-.39***	-.09	.13	**.52***
NDI Score				.03	-.12	**-.50***
Neck Length % (biofeedback)					**.53***	-.19
Neck Length % (no feedback)						.01

Each cell contains the Pearson's product-moment correlation coefficient (r-value) relating variables on each axis. Variables are average game score, dual-task cost to game score, Mindful Attention Awareness Scale (MAAS) score, Neck Disability Index (NDI) score, average neck length relative to baseline, and slope of neck length over ten minutes. Bold text and asterisks (*) denote statistical significance. [1]Not computed because without feedback there is no dual task and thus no dual task cost.

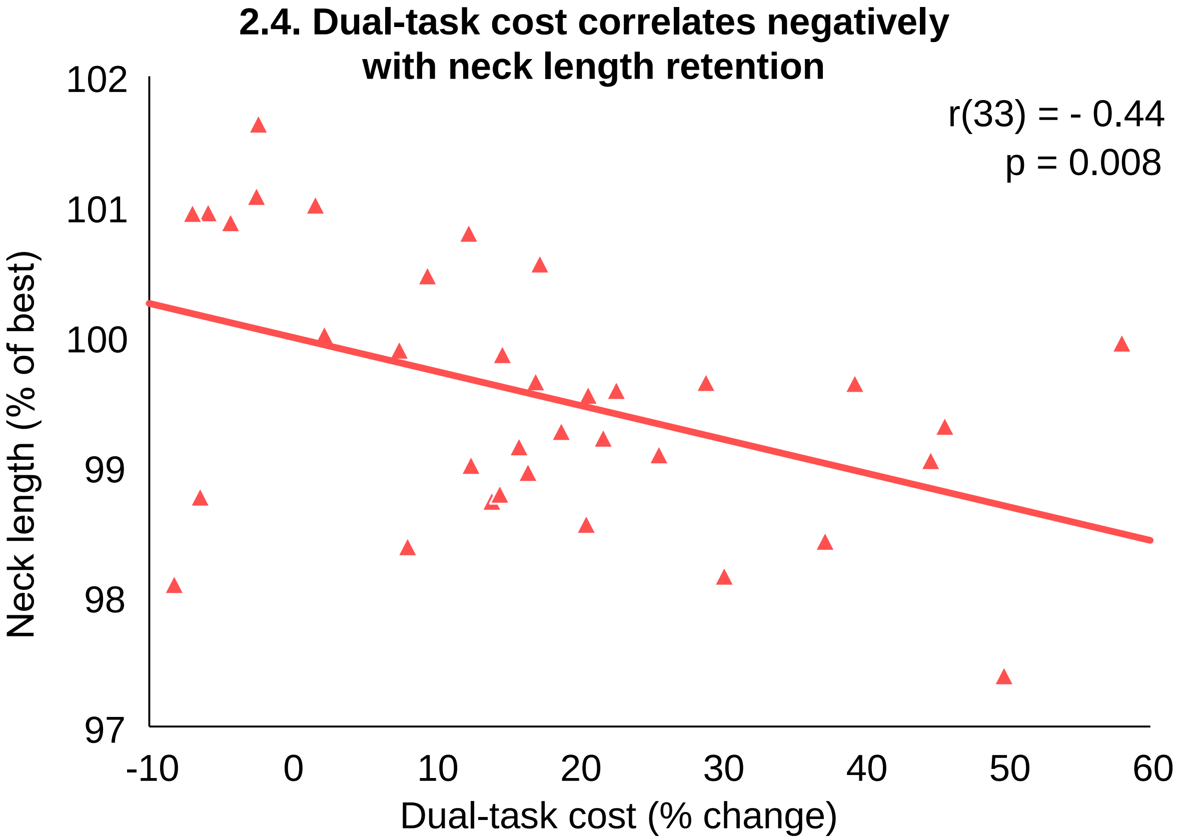


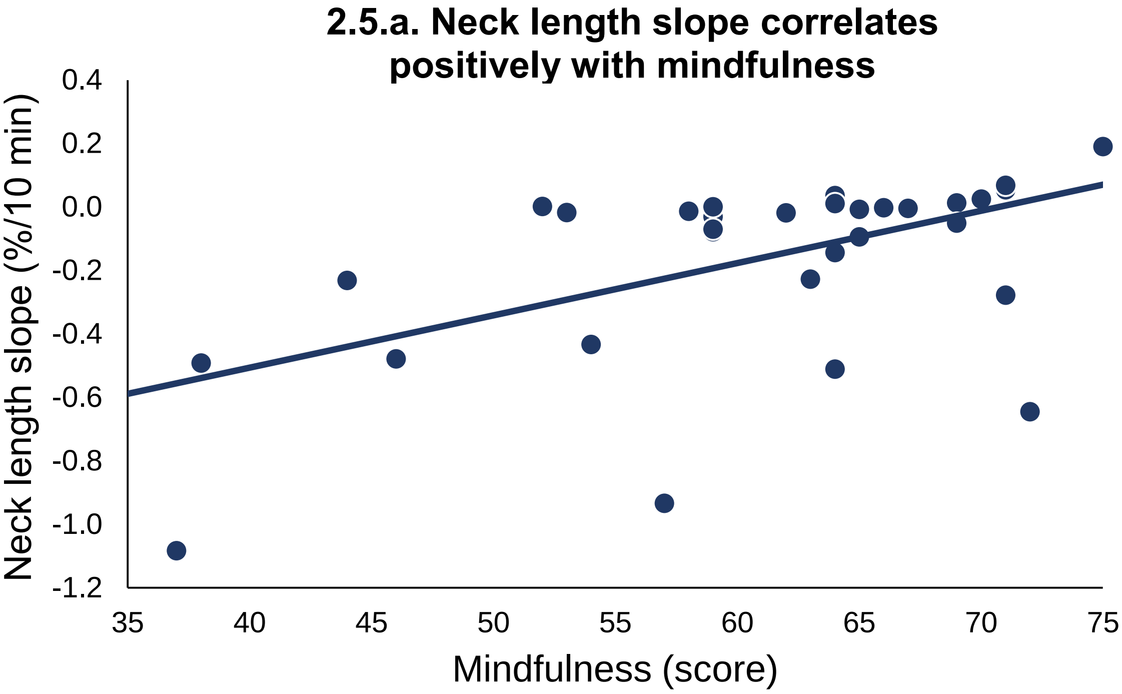
Figure 2.4. Dual-task cost correlates negatively with neck length retention
Graph of correlation between average neck length (as a percentage of best posture) with biofeedback (y axis), and dual task cost to game score as a result of biofeedback (x axis).

2.4.4. Correlations between survey measures and neck length data

2.4.4.1. Survey measures. Average score on the MAAS was 61.2 (SD = 9.2). Average score on the NDI was 8.34 (SD = 6.8). There was no difference in score on either measure between participants who played the game first with biofeedback or without.

2.4.4.2. Neck length slope during the task correlated with MAAS, as seen in Figure 2.5.a. MAAS scores positively correlated with neck length slope during the task without feedback, r(32) = 0.52, p < 0.001. Participants who reported higher mindfulness had better neck length retention (less negative slope) during the task without biofeedback than participants who reported lower mindfulness.

2.4.4.3. Neck length slope during the task correlated with NDI, as seen in Figure 2.5.b. Neck disability scores negatively correlated with neck length slope during the task without feedback, r(32)= -0.50, p = 0.001. Participants who reported greater neck pain disability in their daily life had more



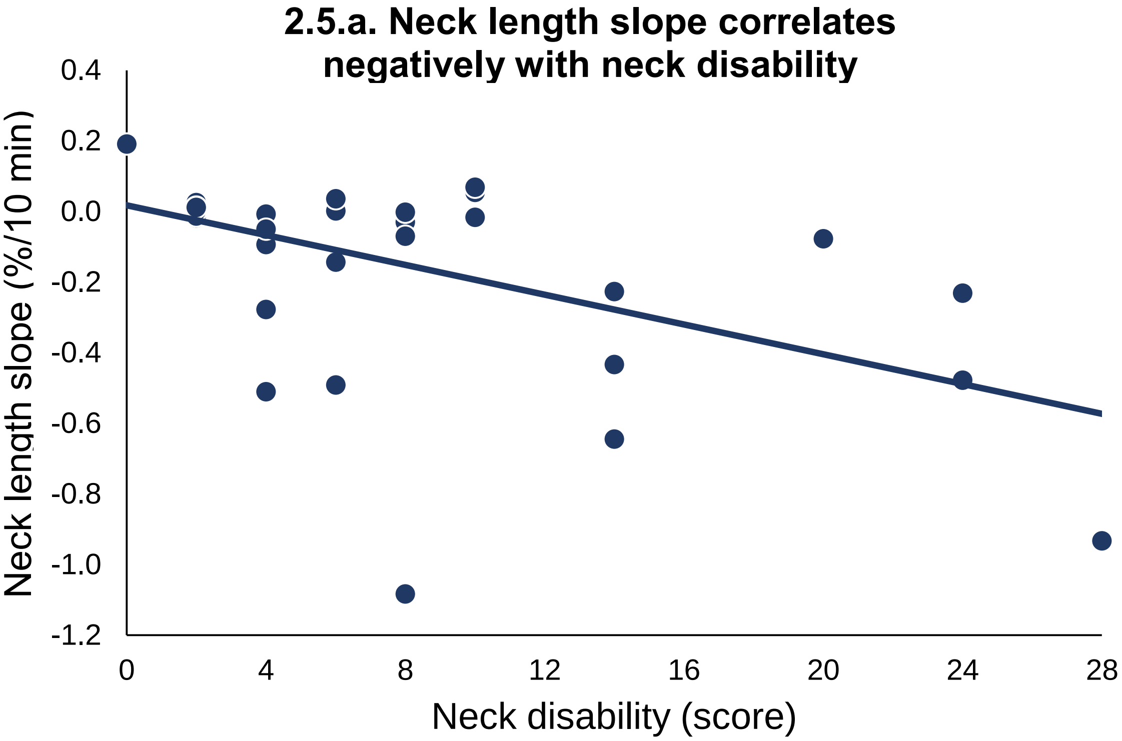


Figure 2.5. Change in neck length correlates with self-reported mindfulness and neck disability
a. Correlation between the slope of change in neck length over ten minutes of play without feedback (y axis, % change in neck length/10 min, negative numbers represent neck shortening over time) and score on the Mindful Attention Awareness Scale (x axis). Higher mindfulness was associated with greater retention of neck length.
b. Correlation between the slope of change in neck length over ten minutes of play without feedback (y axis, % change in neck length/10 min, negative numbers represent neck shortening over time) and score on the Neck Disability Index (x axis). Higher neck pain was associated with lower retention of neck length.

neck shrinkage during the task without feedback than participants who reported less neck pain disability in daily life.

2.5. DISCUSSION

2.5.1. Summary of findings

This study demonstrated that posture biofeedback creates a cognitive load that interferes with performance of a challenging cognitive task. While biofeedback did improve neck length retention during an attention-demanding computer game, participants' game scores were significantly worse during the biofeedback condition than without biofeedback, indicating a dual-task cost. Dual-task cost correlated with neck length percentage during the task while using biofeedback, suggesting a relationship between the two. In addition, higher self-reported mindfulness was correlated with neck length retention without the use of biofeedback. Finally, higher neck disability scores were correlated with greater neck shrinkage without the use of biofeedback.

2.5.2. Interpretation

2.5.2.1. Posture is hard to change. Poor working posture is widespread despite the numerous physiological drawbacks (DHHS, 1997; Griegel-Morris et al., 1992; Hlavenka, Christner, & Gregory, 2017; Murray et al., 2013). Why might this be so? The relationship seen here between the increased dual-task cost of biofeedback and the greater neck shrinkage during the biofeedback condition suggests that to change poor habitual posture, not only is attention to feedback required, but those with worse postural habits incur a greater attentional cost as a result. Thus, there is a built-in deterrent preventing those with poor postural habits from *actively* attending to their posture to correct it. This poses a practical problem; if performance on the primary task worsens with biofeedback users may become frustrated, leading to low compliance, and ultimately not reducing neck pain.

Cognitive-motor tradeoffs are frequently observed in studies of gait and balance (Hawkes et al., 2012; Huxhold et al., 2006; Mirelman et al., 2012; Yogev-Seligmann, Hausdorff, & Giladi, 2008) but have not previously been observed in studies of posture. We recently found evidence for a *motor*-mo tor tradeoff involving posture and anticipation of gait (Baer, Vasavada, & Cohen, 2019); the present study is the first to demonstrate a *cognitive*-motor tradeoff in a study of neck length. These results provide the first evidence that attention is important for managing neck posture.

2.5.2.2. Mindfulness may facilitate the use of intrinsic biofeedback. Mindfulness is important for maintaining awareness of one's physiological state (Sze et al., 2010). It has been proposed that individuals with forward neck posture and neck pain are not aware of their postural deviations (Edmondston et al., 2007; Lee, Lee, & Yong, 2014); thus, they may not be as mindful as others. Furthermore, more mindful individuals have been shown to have less flexed neck posture (Baer, Vasavada, & Cohen, 2019). While mindfulness did not relate to dual-task performance cost in the present study, it did relate to how well participants maintained their neck posture without feedback. This suggests that rather than contributing to active management of attention during dual-task performance, mindfulness may *automatically* bring attention to subtle changes in posture, facilitating the use of intrinsic feedback (Lutz et al., 2009).

Intrinsic feedback comprises internally generated cues that provide information on the internal state of an individual (Patchan & Puranik, 2016). One source of intrinsic feedback may be proprioceptive information related to shortening of the neck. Our results suggest that unlike extrinsic biofeedback, intrinsic feedback based on neck proprioception does not come with an attentional cost. In other words, using external feedback seems to be attentionally expensive, while using internal feedback seems to be more economical. Previous research has demonstrated that extrinsic feedback distorts timing for distinct events; responding to the external sound of a keypress produces less accurate timing estimates than responding to the internal proprioceptive feedback of the keypress (Cao et al., 2020). This implies that intrinsic feedback is less affected by mental noise compared to extrinsic feedback. Thus, greater mindfulness may enable better discernment of intrinsic feedback by reducing mental noise.

Also of note, participants with greater neck shrinkage during the task without feedback reported more neck pain in their daily lives. It is possible that participants who are less sensitive to immediate discomfort from shortening of the neck are more predisposed to long term neck pain as a result of poor postural habits, because they are not using intrinsic feedback to automatically sense and correct their posture.

2.5.3. Practical implications

In the present study, everyday neck pain was associated with neck shrinkage during a computer task. This may be because neck shrinkage reflects compression of the neck, which is representative of soft tissue damage associated with poor posture. However, commercially available postural biofeedback devices rely solely on angle measurements. Future postural biofeedback device development should consider incorporating measures of shrinkage.

While using biofeedback to improve posture may be reasonable in office work, it is not feasible in every workplace. For instance, surgeons, dental technicians, and heavy machine operators often have similar postural complaints to those in office work, but they may be unable to implement biofeedback interventions because these situations require focused attention to avoid making potentially dangerous or even fatal mistakes. Therefore, the reduced computer task performance associated with posture biofeedback could be a serious problem.

Cultivating the use of intrinsic feedback may be an important approach to improve posture. Embodied disciplines such as Alexander technique (Becker et al., 2018; MacPherson et al., 2015) and Tai Chi (Lauche et al., 2016) incorporate elements of mindfulness training along with practice attending to body positions and muscle tensions during activity. Thus, embodied mindfulness practices may enhance responsiveness to intrinsic feedback, and practitioners may become more able to effectively identify suboptimal postures. Another possible benefit of embodied mindfulness approaches is that they focus on improving postural habits, rather than providing frequent feedback about alignment as typical biofeedback does. A change in habit could reduce dual-task costs and subsequent frustration from reduced performance.

2.5.4. Strengths and Limitations of the Study

*2.5.4.1. Strengths***:** While dual-task designs are frequently used to study the impact of combining cognitive tasks with gait and balance tasks, this is the first application of the dual-task paradigm to demonstrate a tradeoff between cognitive performance and maintenance of posture. In addition, the use of a computer game in this context allowed us to emulate a real-life situation where this tradeoff may occur. Furthermore, our use of relative neck length as a measure of posture allows us to define biofeedback outcomes in monotonic terms (shorter is worse) across participants. This stands in contrast to methods that rely on angles, which interact unpredictably with one another (*e.g.*, the neck may flex with respect to the trunk and the head angle may extend with respect to the neck, resulting in different spinal loads) and do not have universally - or objectively - defined ideal values. Finally, our inclusion of mindfulness as a variable sheds light on how individuals attenuate the attention demands of managing posture and opens a conversation about the possible role of intrinsic feedback in managing posture while performing concurrent tasks.

2.5.4.2. Limitations: Previous studies of posture in the workplace have relied on angular measures such as forward head posture. Because this is the first study using neck length percentage as a measure of posture, it is difficult to directly relate our results to previous studies.

In addition, the use of game score as an overall measure of dual-task cost did not allow us to attribute performance differences to underlying cognitive factors. It would be valuable to repeat this study using measures for specific cognitive factors like reaction time or inhibitory control, both of which and are known to be affected by dual task costs and have previously been associated with posture (Baer et al., 2019; Fujiwara et al., 2009).

Finally, use of biofeedback to maintain posture has been shown to be more effective with a longer training period. The short training period with the task and biofeedback may not have been enough to understand the dual-task impact when either task is well-rehearsed. It is possible that when concurrent cognitive tasks are less challenging or more well-learned, the elevated cognitive costs of biofeedback seen here in people who deviated more from neutral posture will be reduced (Verhaeghen & Cerella, 2002).

2.5.5. Conclusion

The use of postural biofeedback during a computer task increased cognitive load. Biofeedback improved neck length retention while hampering computer task performance, demonstrating a dual-task tradeoff. This effect was strongest in the subjects who received the most feedback (i.e. those with the worst postural habits), indicating that those with the greatest need for postural feedback also suffer the greatest computer task performance decrements from extrinsic postural feedback. In contrast, subjects with higher self-reported mindfulness maintained their posture better without feedback, indicating that mindfulness may promote the use of intrinsic feedback, reducing reliance on extrinsic biofeedback. Therefore, interventions that target mindfulness may benefit posture and in turn reduce neck pain, without compromising task performance.

Chapter 3: Neck flexion improves reaction and stopping times but does not influence other aspects of inhibitory control

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3.1. ABSTRACT

Background: Maintaining an upright sitting posture in the workplace may reduce or prevent neck pain. However, other research shows that a flexed neck posture may improve reaction time. Neither the mechanisms nor the limitations of how a flexed neck could improve performance are well understood.

Hypotheses: We hypothesized that using a flexed neck posture would lead to a bias toward action, thus improving response time and interfering with inhibitory control.

Approach: Participants' neck positions were fixed in neutral or forward positions with tape while they sat at a computer and performed simple reaction time, go-nogo, stop signal reaction time, and Stroop tasks.

Results: Simple reaction times were 20 ms faster and stop signal reaction times were 50 ms faster in the forward condition than in neutral. However, there was no effect of head position on performance in go-nogo or Stroop tasks.

Conclusion: Our hypothesis was partially supported. Flexed neck posture facilitated response time for task involving later information processing stages (e.g. launching a motor plan) for both reaction time and stopping time, but it did not affect tasks relying on inhibition at earlier processing stages (e.g. generating a motor plan).

SIGNIFICANCE STATEMENT

Preparing to act by increasing neck flexion improves reaction time, but a flexed neck also results in forward head posture, which is associated with chronic musculoskeletal issues. This research investigated the effects of a flexed neck posture on both proactive and reactive inhibitory control, revealing that a flexed neck posture affected the execution of a motor plan but not the decision to generate one. A deeper understanding of the influences a flexed neck has on cognition may help to explain why poor postural habits develop, thus informing development of methods to mitigate long term negative musculoskeletal effects of poor posture.

3.2. INTRODUCTION

Extensive research links a chronic flexed neck to chronic neck pain (Ariëns et al., 2001; Silva et al., 2009; Yip, Chiu, & Poon, 2008), especially during computer work (Szeto, Straker, & Raine, 2002; Vasavada et al., 2015). Efforts to improve sitting posture emphasize maintaining a neutral spine (Westgaard & Winkel, 1997), but little attention is paid to underlying reasons people might deviate from these recommendations. One possible explanation originates in sports research on ready postures, showing that increased neck flexion can improve reaction time on motor control tasks (Fujiwara, Kunita, & Toyama, 2000).

Fujiwara and colleagues have demonstrated that more forward neck positions can reduce the threshold for sensory processing and muscle activation (Fujiwara, Tomita, & Kunita, 2009), leading to improved reaction times on saccade (Kunita & Fujiwara, 2009), antisaccade (Kunita & Fujiwara, 2013), and bilateral button pressing (choice reaction time) tasks (Fujiwara et al., 2012). In the aforementioned series of experiments, subjects put their heads forward prior to completing a set of reaction time tasks. The authors suggest that increases in muscle tone similar to those which occur during readiness for racing events improve response time by reducing relevant sensory thresholds. The resulting effect of this priming may negatively affect some aspects of inhibition.

In contrast to the positive effect a flexed neck posture has on reaction time, there may be a negative effect of increased neck flexion on proactive inhibitory control. We previously observed that young adults whose habitual posture includes more neck flexion perform worse on a Stroop task than young adults with less neck flexion (Baer, Vasavada, & Cohen, 2019). This supports the idea of a possible trade-off in which neck flexion primes a motor response but interferes with effective inhibition of unwanted responses.

If a flexed neck posture increases the likelihood of a response, we would expect experimentally-induced neck flexion to lead to improvement in reaction time tasks and worse performance in inhibition tasks. However, inhibitory control tasks are not all alike (Aron, 2011). In the early stages of information processing, it is possible for inhibitory control to be proactive in nature, because a respondent is given information necessary to choose not to respond to stimuli without generating a motor plan (Aron, 2011), thus restraining the response to prevent an error (Schachar et al., 2007). For example, both false alarm responses on go-nogo and slowed conflict condition time (because errors must be corrected before participants continue) for a Stroop task would reflect failures to restrain a response as a result of poor proactive inhibition (Aron, 2011). Therefore, we predicted that faster responses due to a flexed neck posture would lead to more errors on both the Stroop and go-nogo tasks, despite a facilitated response time.

During later stages of information processing when a motor plan has been initiated, respondents need to react to generate a new motor plan to cancel the first (Diesburg & Wessel, 2021; Schachar et al., 2007). Reactive inhibition is independent from proactive inhibition, and follows a race model where a successful stop only occurs if the inhibiting response catches up to the initial response (Raud et al., 2020; Schachar et al., 2007). For example, both antisaccade reaction time and stopping response time in a stop-signal task measure how quickly a participant is able to interrupt an action already in motion (Aron, 2011); antisaccade reaction time reflects time to change a motor plan after a reflexive eye movement has already begun (Hutton & Ettinger, 2006; Munoz & Everling, 2004), and stop signal response time reflects time needed between a go and stop signal to change a motor plan after a hand movement has begun (Eagle & Robbins, 2003; Eagle et al., 2008). Fujiwara found that antisaccade performance was facilitated by neck flexion, so we predicted that stop signal task performance would also be facilitated because these tasks both reflect faster cancellation of an already-initiated response.

By manipulating neck flexion during several timed computerized tasks, we investigated the influence of posture on reaction time and three forms of inhibitory control. We hypothesized that a flexed neck posture would facilitate late stages of information processing, but impair earlier stages, resulting in (1) improved reaction time during a simple reaction time task, (2) improved stopping time during a stop signal task, and (3) faster responses to stimuli in go-nogo and Stroop tasks, leading to (a) more false alarms on the go-nogo task, and (b) more errors during the Stroop conflict task.

3.3. METHOD

3.3.1. Equipment

To collect three-dimensional motion capture data, we placed 8 reflective marker clusters on participants’ body segments: head, neck (atlanto-occipital to C7/T1 joint), upper torso (C7/T1 to T12/L1 joint), lower torso (T12/L1 to L5/S1 joint), left and right upper arm, and left and right thigh (Figure 3.1.a.). These segments were tracked with eight infrared Vicon Bonita motion capture cameras (Oxford, UK) at a rate of 100 frames per second. We used *The MotionMonitor* xGen software by Innovative Sports Training (Chicago, IL) to produce a composite model of each participant’s skeletal structure and joint centers based on offset positions from surface landmarks recorded in anatomical position (Chaffin et al., 2006). The atlanto-occipital (AO, between the left and right mastoid process), C7/T1 (7.18 cm forward, 3.35 cm down from the C7 spinous process), and L5/S1 (9.49 cm forward from the L5 spinous process) joint centers were used in analysis (Figure 3.1.b).

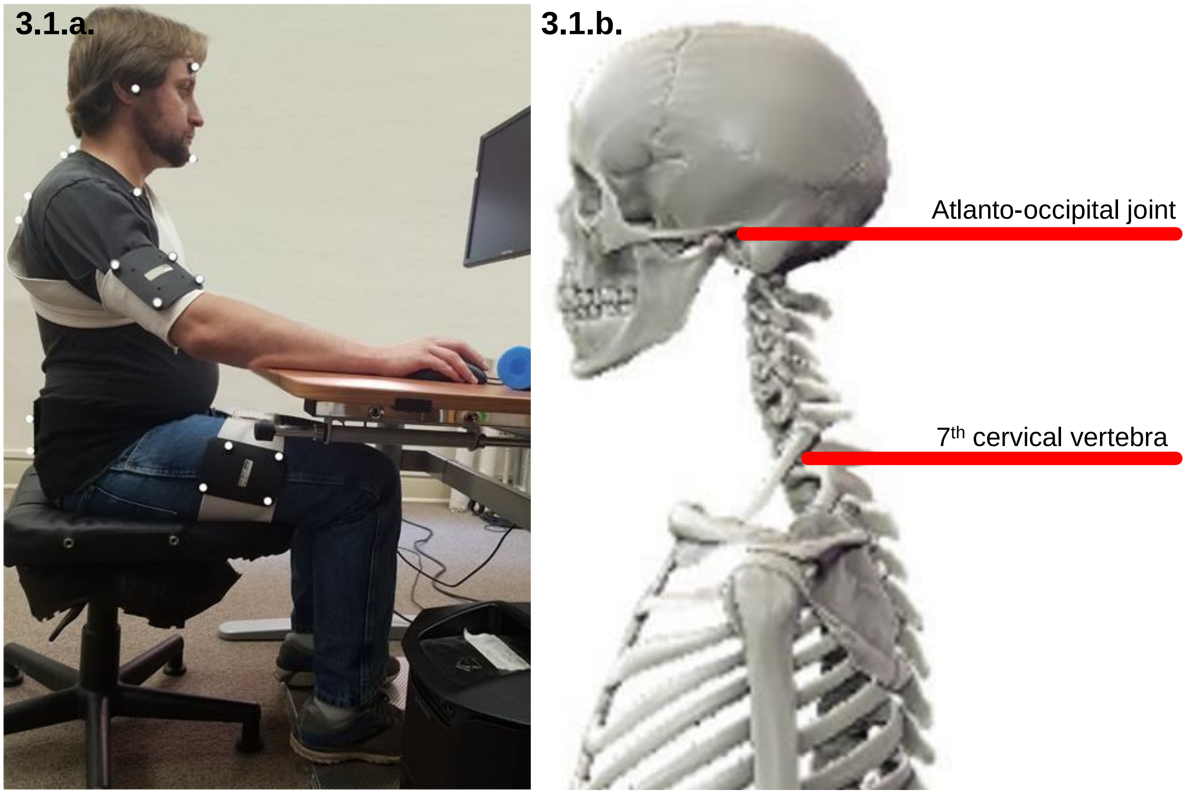

Figure 6.1. Setup

a. Participant sitting at adjustable workstation while wearing reflective marker clusters on the head, neck, upper torso, lower torso, left and right upper arm, and left and right thigh.

b. Composite model showing offset positions from surface landmarks for the atlanto-occipital joint, and C7/T1 vertebra.

The participant workspace was equipped with an adjustable sit-stand desk (Rebel Crank-Up 1000), adjustable monitor display, and adjustable backless office chair. This allowed us to tailor the workstation to each participant’s anthropometric measurements.

3.3.2. Participants

We tested 29 participants (13 men and 16 women) aged 18-24, recruited from psychology courses at the University of Idaho. This study was approved by the University of Idaho IRB, in accordance with the 1964 declaration of Helsinki; all participants provided written informed consent and received course credit for a two-hour data collection session. Prior to testing, we screened participants for physiological and psychological issues that could interfere with their ability to perform the tasks. Participants were excluded from the study if they reported current musculoskeletal injuries (pain in any part of the body while standing or walking), neurological issues (diagnosed mental disorder), or any condition that could interfere with their ability to perform the task comfortably. Participants were assigned alternately to experimental groups with flexed or neutral posture.

3.3.3. Protocol

After obtaining informed consent, experimenters adjusted the workspace for each participant using standard ergonomic guidelines (Chaffin, Andersson, & Martin, 2006) and attached reflective markers. Experimenters briefed participants on the importance of good sitting posture, indicating that ankles, knees, hips and elbows should rest at 90 degrees and the center of the screen should be less than 10 degrees below eye-level. Participants were instructed to maintain a neutral head position by allowing their heads to float at the top of their spines. We collected 10 seconds of baseline postural alignment data for the neutral condition according to these instructions. To collect baseline data for the forward condition, we asked participants to push their heads forward relative to their torsos by jutting the chins forward while looking at the computer screen.

To assure that participants maintained these postures while performing computer tasks, experimenters applied tape to the participants’ necks. The tape was placed across surface muscles which would contract, causing the tape to pull at the skin when the participant began to shift their head forward (in the neutral condition, Figure 3.2.a) or backward (in the forward condition, Figure 3.2.b). Each participant practiced all computer tasks once without postural instruction. They were then assigned to either the forward or neutral condition and completed all tasks (counterbalanced with a Latin square).

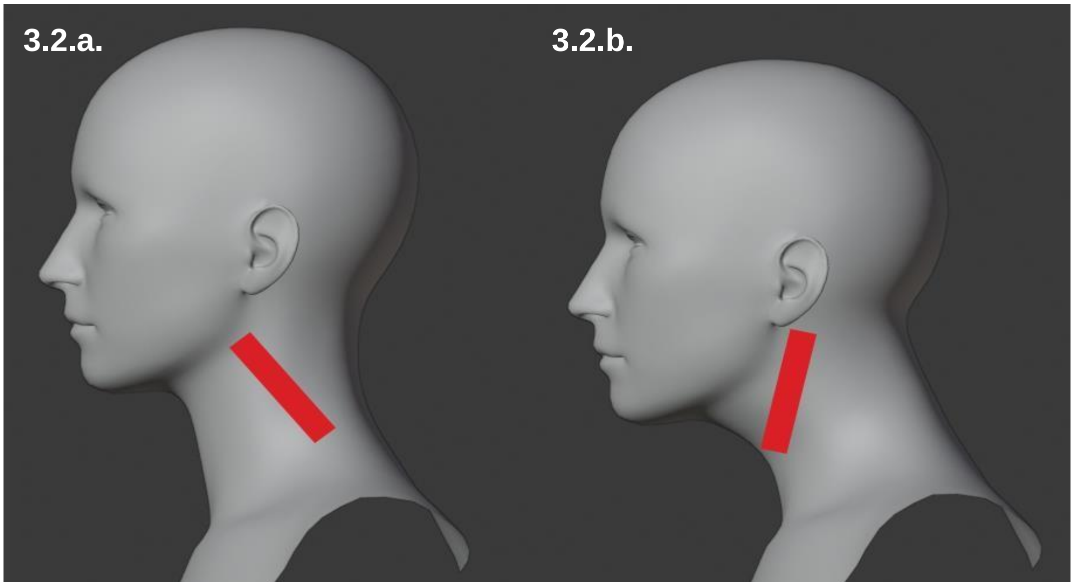

Figure 7.2. Tape position used to fix posture for (a) neutral and (b) forward conditions
a. The tape pulls at the skin to prevent participants leaning forward at the head.
b. The tape pulls at the skin to prevent participants from straightening or moving the head back.

3.3.4. Measures

3.3.4.5. Postural measures. We measured sagittal plane neck and torso angles in order to calculate flexion of the neck relative to the torso. See Figure 3.3. The neck angle used a line from the midpoint of the mastoid processes to the C7 joint and then forward. The torso angle used a line from C7 joint to the joint of L5 and the first sacral vertebra (S1) and then forward. In all cases, a larger angle indicates greater extension. We defined neck flexion by subtracting the neck angle from the torso angle (Figure 3.3.a), giving a value that indicates neck flexion relative to the torso, where a more positive angle indicates a more forward head position relative to the torso. Due to anatomical differences, there is no universal neutral angle for the neck.

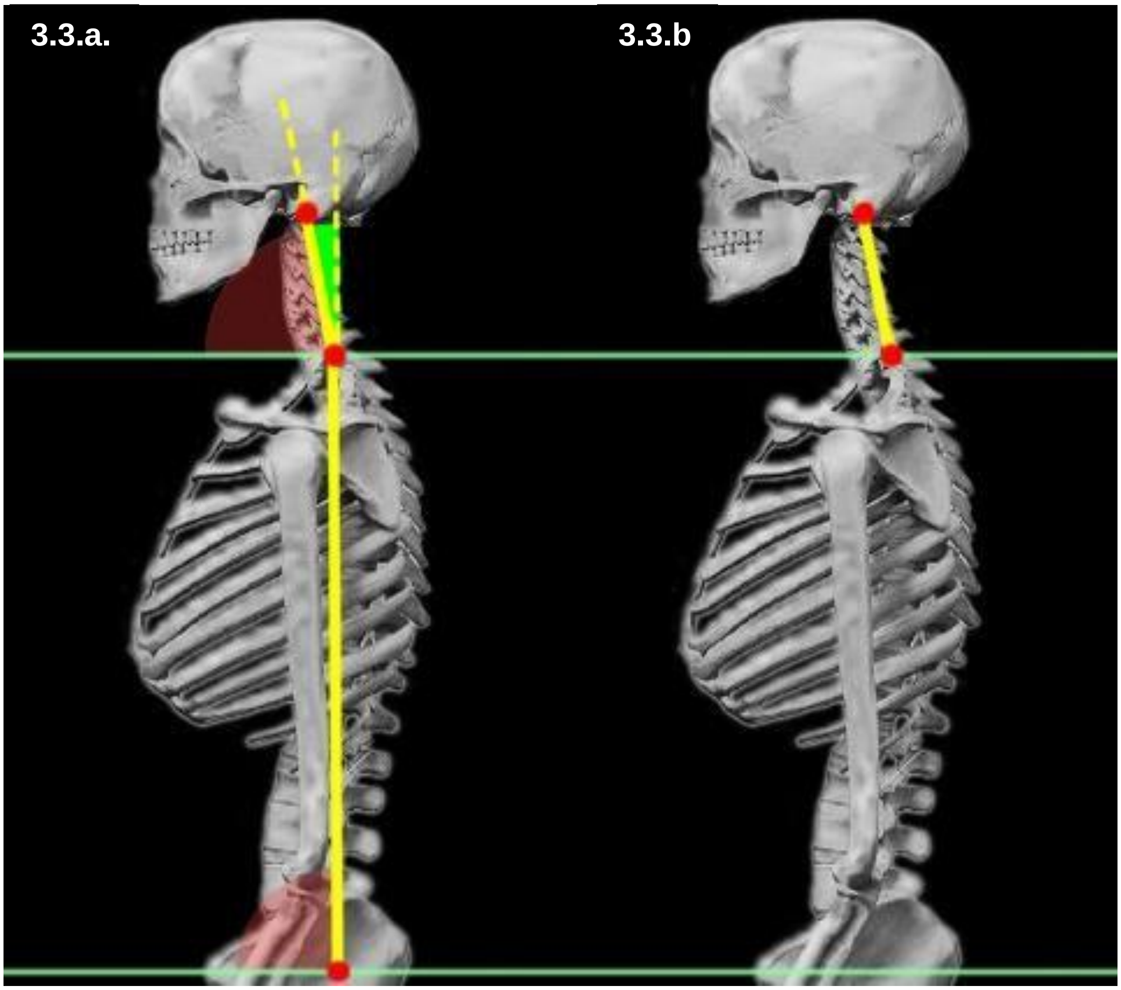

Figure 8.3. The Motion Monitor composite skeleton
a. Digitized points for atlanto-occipital (AO) joint, C7/T1 vertebral joint, and L5/S1 vertebral joint are shown in red. Dependent measure of neck flexion angle is shown in green
b. Neck length (distance between AO and C7/T1) is shown in yellow.

Additionally, we measured neck length to represent cervical spinal shrinkage, using the three-dimensional linear distance between the AO joint center and the C7/T1 joint center (Figure 3.3.b). Spinal shrinkage has been associated with pain and discomfort (Beynon & Reilly, 2001; Bonney & Corlett, 2002). In a previous study, greater neck disability correlated with increased neck shortening during a task (Baer et al., 2022).

3.3.4.1. Simple reaction time task. To measure reaction times, all participants completed the simple reaction time task (SRT). In this task, participants were presented with a random letter once every 1-2 seconds and responded by pressing the space bar with their dominant hand as fast as possible for 100 trials. Each letter remained visible for 250 ms; if participants failed to respond for

500 ms, the trial was counted as a miss. Reaction time was measured from the moment of stimulus presentation to the start of the button press, averaged across all successful trials.

3.3.4.2. Go-nogo task. As a measure of inhibitory control, we used a go-nogo paradigm, where participants were presented with stimuli similar to those they saw in the SRT. Participants responded by pressing the space bar as quickly as possible, unless the letter presented is “X,” (the nogo stimulus) in which case they were supposed to withhold their response. There were 100 trials; 20% of these were nogo stimuli. Responses later than 500 ms after stimulus presentation were considered misses; false alarms were counted if the participant failed to inhibit their response to nogo stimuli. This task could be used to measure inhibition in three ways: average reaction time for hits, change in reaction time compared to SRT, and percentage of false alarms.

3.3.4.3. Stop signal task. The stop signal task was used as a measure of inhibitory control that provided an estimate of how quickly participants could stop a response which was already in motion. For each trial, participants were presented with a square, and prompted respond to as fast as possible by pressing a space bar. For half of the trials, a sound occurred after a short delay. When participants heard the sound, they were expected to stop their response. The delay at which the sound was presented varied based on each participant’s prior success; the delay was lengthened after every successful stop and shortened after every failure to stop. After 100 trials, consecutive trials were presented with varying delays until each participant’s overall success rate totaled approximately 48-52%; or until 120 trials were completed. The difference between a participant’s average delay and their reaction time on hits was used to calculate the participant’s stop signal reaction time (SSRT), which represented how quickly after a stimulus is presented each participant would be able to stop an action which is in progress (Aron, 2011; Dawn M. Eagle et al., 2008). The lower a participant’s SSRT, the faster they are able to stop.

3.3.4.4. The Stroop task used in the present study consists of the classic three part task, displayed on a computer screen so participants could maintain a fixed posture for each condition. Participants said aloud the color of 50 squares presented on screen (10 each of black, purple, blue, red, or green), then read aloud 50 color words (10 each of black, purple, blue, red, or green), and finally said the color of 50 words (10 of each color and word, all incongruent). The last part, called the conflict condition, required participants to inhibit the well-learned response of reading in order to correctly say the ink color. For each trial, experimenters explained the instructions with an example slide, then confirmed that the participant was ready to begin. To start the trial, the experimenter advanced the slide, and participants were timed as they read through the entire list, stopping to correct any mistakes they made along the way. Participants' total time to complete each condition was recorded in seconds and used to calculate average response times for each item in milliseconds. Average response times for the color, word, and conflict conditions were computed for each participant, and errors during the conflict condition were assessed. We additionally used interference as a measure of inhibition per Golden, Freshwater, & Zarabeth (2003), computed as the difference between time to complete the conflict condition and the sum of the times to complete the color and word conditions.

3.3.5. Statistical analysis

Data were processed using custom code written in MATLAB R2017a (Natick, MA); ANOVAs and correlations were conducted using SPSS Version 22. To demonstrate that the forward condition produced greater neck flexion than the neutral condition, we conducted a between-group t-test comparing neutral and forward baseline postures. Levene's test showed that homogeneity of variance was present for all dependent measures. Shapiro-Wilk tests showed that residuals were normally distributed for all dependent measures. Therefore, t-tests were justified.

To confirm that the postural difference was present during the tasks, we conducted a 2x5 ANOVA with dependent variable of neck flexion angle and factors of condition (neutral and forward) and task (baseline, SRT, go-nogo, stop signal, Stroop). We also repeated the ANOVA with neck length as the dependent variable. Post-hoc comparisons were performed to assess pairwise differences between each task if significant main effects were found.

To test the hypotheses that increased neck flexion improves reaction time, improves SSRT, and impairs performance of go-nogo and Stroop tasks, we conducted one-tailed independent-sample t-tests comparing the results for the neutral and forward condition of each task: SRT; SSRT; go-nogo (reaction time, reaction time change, and false alarms); and Stroop (response times for color, word, and conflict conditions; errors in conflict time; and interference). To test for the presence of the previously observed relation between inhibitory control and neck flexion, we tested for correlations between each measure of inhibitory control and flexed neck posture using Pearson's r.

3.4. RESULTS

Nine participants were excluded from analysis: four were excluded due to experimenter error during collection of kinematic data (missing data), and five were excluded because they did not understand experiment instructions (two participants with more than 70% false alarms on go-nogo and 100% false alarms on SSRT; three participants with less than 3 degrees difference between the neutral and flexed neck positions).

3.4.1. Kinematics

The results of our experimental conditions on neck flexion are shown in Figure 3.4. The use of tape to maintain posture led to a 5 degree increase in flexion during baseline for the forward condition compared to neutral; t(9) = 7.45, p < 0.001. During the computer tasks, this difference between conditions was maintained; F(4,19) = 14.01, p < 0.001. There was also a main effect of task

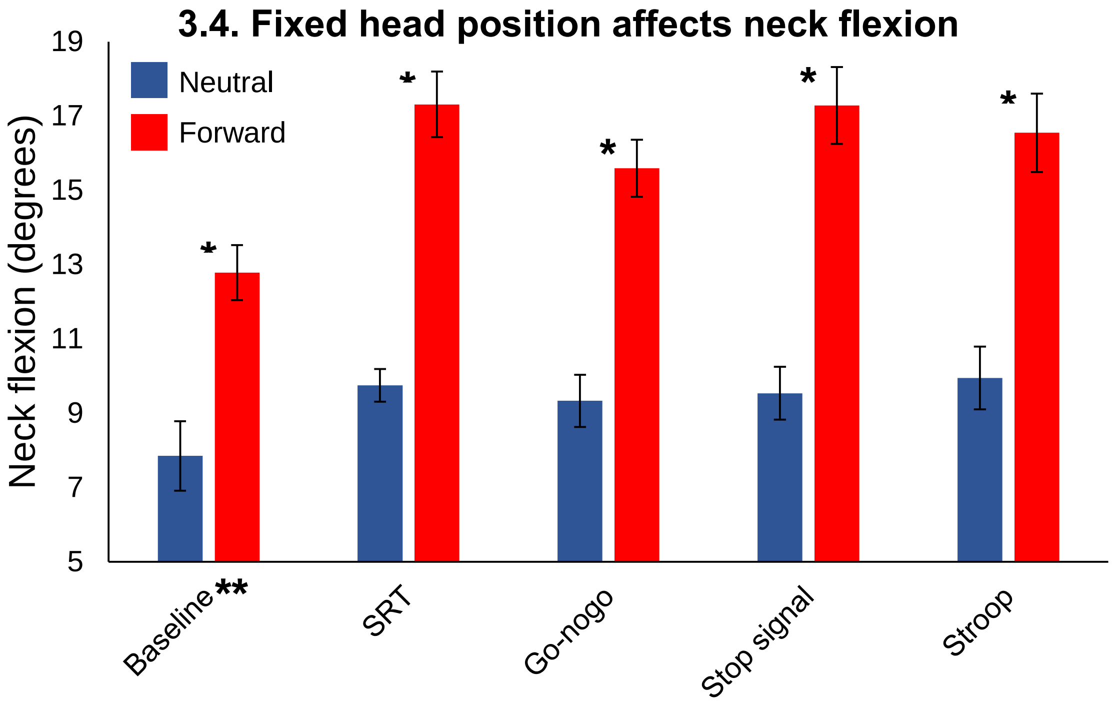

Figure 9.4. Fixed head position affects neck flexion

2x5 ANOVA comparing the effects of head position on neck flexion angle (degrees), with factors for condition (red = forward; blue = neutral) and task (baseline, simple reaction time (SRT), go-nogo, stop signal, and Stroop tasks). Error bars represent standard error. Asterisks represent significant effects (p < .05).

* Main effect of condition showing that neck flexion was greater in the forward condition.

** Post-hoc comparison of baseline to other tasks showing that neck flexion was greater during tasks than during baseline.

on flexion; F(4,19) = 4.66, p = 0.01. Post-hoc tests of simple effects showed that during tasks, participants neck flexion was 3 degrees greater than baseline on average; SRT, p = 0.01; go-nogo, p = 0.02; stop signal, p = 0.01; and Stroop, p = 0.02. There were no significant interactions.

The results of our experimental conditions on neck length are shown in Figure 3.5. Overall, the use of tape to maintain posture led to a 2 mm decrease in neck length during the forward condition compared to neutral; F(4,19) = 17.38, p < 0.001. There was also a main effect of task on neck length; F(4,19) = 7.75, p < 0.001. Post-hoc tests of simple effects showed that during tasks, participants neck length was one-quarter centimeter shorter than baseline on average; SRT, p = 0.007; go-nogo, p = 0.002; stop signal, p = 0.001; and Stroop, p = 0.009. There were no significant interactions.

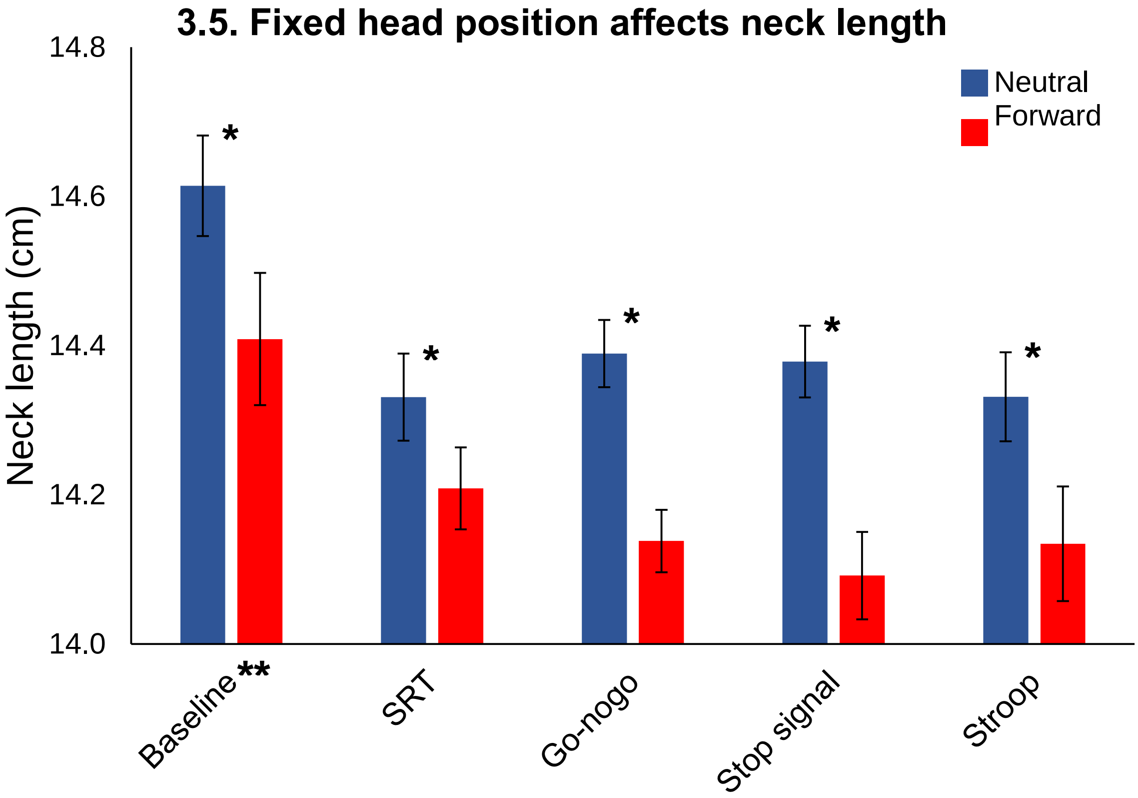

Figure 10.5. Fixed head position affects neck length
2x5 ANOVA comparing the effects of head position on neck length (cm), with factors for condition (red = forward; blue = neutral) and task (baseline, simple reaction time (SRT), go-nogo, stop signal, and Stroop tasks). Error bars represent standard error. Asterisks represent significant effects (p < .05).
* Main effect of condition showing that participants' neck length is shorter in the forward condition.
** Post-hoc comparison of baseline to other tasks showing that participants' neck length was greater during baseline than other tasks.

3.4.2. Reaction time and inhibitory control tasks

All task performance scores are shown in Table 3.1. Reaction times were 20 ms faster in the forward condition than neutral; t(18) = 2.08, p = 0.03, and stop signal reaction times were 50 ms faster in the forward condition than neutral; t(18) = 2.24, p = 0.02. Go-nogo false alarms, go-nogo RT, reaction time change between SRT and go-nogo, Stroop response times (color, word, and conflict), conflict errors, and interference were not significantly affected by condition.

Table 3.1. Effect of head position on reaction times and errors

	SRT (ms)	SSRT (ms)	GnG FA (%)	GnG RT (ms)	RT Δ (ms)	Color (ms)	Word (ms)	Conflict (ms)	Conflict Errors	Interference (ms)
Neutral	301.7 ± 7.7	292.2 ± 19.3	30.0 ± 4.2%	360.5 ± 11.7	61.0 ± 10.5	591.1 ± 42.5	449.8 ± 24.4	887.4 ± 50.8	0.4 ± 0.2	153.6 ± 56.5
Forward	281.0 ± 7.1	239.1 ± 12.6	33.9 ± 4.6%	359.0 ± 9.2	79.1 ± 13.0	574.3 ± 24.3	435.3 ± 16.2	917.8 ± 29.2	1.2 ± 0.4	91.70 ± 30.4
t (df)	**2.08** **(18)**	**2.24** **(18)**	0.63 (18)	0.09 (18)	1.06 (18)	0.35 (18)	0.48 (18)	0.56 (18)	1.69 (18)	0.99 (18)
p-value	**0.03***	**0.02***	0.27	0.46	0.15	0.37	0.31	0.30	**0.05**	0.17

Effects of condition (rows) on responses to reaction time and inhibitory control measures (columns): mean ± standard deviation. Asterisks denote significant effects of condition. Measures: Simple reaction time (SRT), stop-signal reaction time (SSRT), go-nogo false alarm responses (GnG FA), go-nogo reaction times (GnG RT), reaction time change between simple reaction time and go-nogo tasks (RT Δ), response times for Stroop (color, word, and conflict), conflict errors, and Stroop interference.

3.4.3 Relation between inhibitory control and posture

Neither baseline neck flexion nor neck flexion during task execution correlated with performance in any of the tasks, in either the neutral or forward conditions.

3.5. DISCUSSION

3.5.1. Summary of findings

The goal of this study was to compare the effects of flexed neck posture and neutral posture on reaction time and inhibitory control. Previous research has shown that a flexed neck posture improves reaction time and stopping time during motor execution (Fujiwara, Tomita, & Kunita, 2009; Kunita & Fujiwara, 2009; Fujiwara et al., 2012); however, a flexed neck is associated with poor inhibitory control performance on Stroop and go-nogo tasks (Baer, Vasavada, & Cohen, 2019). This apparent disconnect led us to hypothesize that a flexed neck posture primes a go response which improves the speed of responses, at the expense of inhibitory control performance. With respect to our initial predictions, we showed that a flexed neck (1) improved reaction time and (2) improved stopping time, but (3) did not affect performance on other inhibitory control tasks.

3.5.2. Interpretation

The faster reaction time and stopping time in the flexed neck condition is consistent with previous results, which showed that a flexed neck posture improves reaction time and performance on antisaccade tasks. Preparatory muscle contractions occur in advance of movement; this muscle contraction may prime the execution of a motor plan (Fujiwara et al., 2000). Although the stop signal task and antisaccade tasks are typically used to assess inhibitory control, they share important similarities with a reaction time task. Stop signal and antisaccade tasks measures rapid action control, where stopping is an action. In both of these research paradigms, the initiation of a motor act occurs reflexively with the presentation of a stimulus, and the participant is required to interrupt this reflexive response on some trials (Aron, 2011). For stop signal and antisaccade tasks, the motor plan is generated in advance of the inhibition cue, and the reactive response occurs in parallel with the execution of a motor plan.

Results in the Stroop task were mixed. Response times were not significantly affected by a flexed neck posture. However, we did observe a near-significant (p=.05) increase in errors in the neck flexion condition compared to the neutral condition. Furthermore, it is possible that the null results seen in response times could reflect a combination of underlying influences. In the Stroop task, participants had to correct errors before continuing, which slowed completion time in the conflict condition. If neck flexion increased response speed even when the prepared response was incorrect (increasing the tendency to make errors), the increased speed and need to slow down to correct errors could somewhat cancel each other out in the conflict condition, while only facilitation would be observed in the color naming and word reading conditions (where there were almost no errors). Although the effect was not significant, the difference of 60 ms in Stroop interference score between the groups suggests that a higher-powered study might be able to detect this effect. Alternatively, it is possible that the facilitation effect of neck flexion seen in simple eye movement and reaching tasks does not carry over to the more complex motor behavior of speaking aloud.

Results in the go-nogo task did not support our hypotheses. We expected that neck flexion would lead to a faster reaction time and an increase in false alarms in this task. We did not see either of these effects. One possible explanation is that the facilitation effect did not carry over to a task with uncertainty about whether a motor plan should be executed. While all the other tasks in this study required at least an initial response in every trial, the go-nogo task included trials in which participants were instructed not to respond at all. Perhaps this period of indecision eliminated the facilitation effect.

Alternatively, our results may reflect how inhibition acts on different parts of the information processing stream. Go-nogo and Stroop tasks are differentiated from antisaccade and stop-signal tasks by requiring a proactive decision not to move rather than stopping an action in progress (Aron, 2011). Thus, the go-nogo and Stroop tasks capture the selection and execution of a motor plan in the response time. It's possible that a flexed neck only affects the execution of motor plans that are already primed (as in stop signal and antisaccade tasks), whereas motor plan selection (as in go-nogo and Stroop tasks) is not affected.

3.5.3. Practical implications

This study explored a previously reported performance benefit of acute flexed neck posture. Extensive research links chronic flexed neck posture (often termed forward head posture) in computer work with chronic neck pain (Kang et al., 2012; Levanon et al., 2012; Ming, Närhi, & Siivola, 2004; Szeto et al., 2002). Sitting with a flexed neck posture leads to increased compression of the vertebrae and increases the mechanical load on the spine. This extended stress on the neck compresses nerves, leading to pain and strain on surrounding muscle tissue. All this leads to the question: why do people sit this way, if it is so bad for them? One possible answer is that the short-term benefits of faster response times may be more salient than the long-term costs to health.

Understanding potential benefits of a flexed neck posture despite its association with long term neck pain may improve our understanding of why poor posture develops, thus providing crucial foundational knowledge for those seeking to develop effective postural correction to remedy neck pain. In particular, effective posture correction may depend on the client's willingness to let go of performing as fast as possible, and this may need to be made explicit. Although the absolute difference in reaction time between the two conditions in this study was small (around 50 ms), the percent difference was substantial (about 20%) and would probably be perceptible to an office worker under pressure to complete work quickly. Of course, most real world tasks are not as simple as a pure reaction time task and would not be expected to have such a strong effect. For instance, the decline in performance that we previously saw in a biofeedback study using a complicated computer task was closer to 10% (Baer, Vasavada, & Cohen, 2022). Further evidence that people are willing to sacrifice a neutral head posture in the interest of completing a task can be seen in our previous work showing that neck flexion increases in anticipation of target-directed stepping (Baer, Vasavada, & Cohen, 2019).

The previously observed correlation between performance on the Stroop conflict task and forward neck flexion did not replicate. We speculate that this may be related to the different habits that people bring to sitting and standing postures. Previous research indicates that most people flex their necks more when sitting than when standing, and there may be greater variability of neck angle across people in standing posture than in sitting posture (Shaghayegh fard et al., 2016).

The present study investigated the influence of head posture on inhibitory task performance; previous studies have investigated the influence of head posture on perception of task difficulty. In one such study, participants with high "test anxiety, math difficulty and blanking out scores" (TAMDBOS) perceived a math task as more difficult when completing the task with a slumped (forward and down) head posture than an erect head posture (Peper et al., 2018). In another such study, participants perceived recalling negative memories as easier when in a slumped head posture, and recalling positive memories as easier while in a more erect posture (Peper et al., 2017). While neither of these studies tested the same posture we used, nor did they assess cognitive task performance, they do provide additional evidence that cognition is affected by posture.

3.5.4. Strengths of the study

Testing the effects of fixed neck flexion on inhibitory control offers novel insights into the nature of the relationship between posture and cognition. Our use of multiple tests of inhibitory control allowed us to elucidate the specific nature of the relationship, providing insight into possible reasons people may adopt a flexed neck posture when under pressure at work.

Our experimental design was based on the methodology laid out by Fujiwara and colleagues (Fujiwara, Tomita, & Kunita, 2009; Kunita & Fujiwara, 2009; Fujiwara et al., 2012), modified to provide greater ecological validity. Although the use of tape to affect neck posture does not allow the same degree of control as the harness used in other studies, it provides inexpensive biofeedback which could be used in any office. In our study, fixing posture led to a 5 degree difference between neutral and forward postures, representing a 60% change in neck angle between conditions. While a difference of 5 degrees seems small, previous research demonstrated an improvement in reaction time with comparable increases in neck flexion accompanied by muscle activation of the trapezius (the participant must tense their neck to maintain flexion) (Fujiwara et al., 2000). Therefore, our results suggest that the facilitation effect of neck flexion on reaction time could be achieved in an office setting. It would be beneficial to determine if the facilitation effect seen on the simple reaction time and stopping time used here would generalize to tasks common to office work, producing the perceived short term benefits that might encourage poor posture in the long term.

3.5.5 Limitations and future directions

The presence of tape on the neck may have introduced a distraction which could have affected results. However, the tape was present in both conditions, and it is likely that any form of fixed posture would produce similar attentional demands.

Further, it is possible that some of the null results surrounding inhibitory control were due to lack of power. All four of the non-significant tendencies seen in Table 3.1 suggest that inhibition might be impaired by a flexed neck posture. We conducted a post-hoc power analysis for the differences in go-nogo false alarms, reaction time change from SRT to go-nogo, Stroop conflict errors, and Stroop interference. Sample sizes of 350 (go-nogo false alarms), 106 (go-nogo RT Δ), 24 (Stroop conflict errors), and 76 (Stroop interference) participants per group would be needed for a future study to have 80% chance of detecting an effect in each of these measures.

The go-nogo task did not reveal a neck flexion facilitation effect on reaction time or an increase on false alarms. It is possible that the 20% rate of nogo stimuli may have resulted in participants hesitating before deciding to respond, introducing proactive inhibition, which was not affected by the neck flexion (Aron, 2011). In previous research, increased nogo stimulus probability positively correlated with brain activity related to decision making processes (Bruin & Wijers, 2002). Therefore we might expect that a flexed neck posture would have a greater effect on go-nogo performance with a lower rate of nogo stimuli than it did in the present study. A future study could vary the nogo stimulus rate to explore whether manipulating the demand for proactive inhibition affects the facilitation of response times by a flexed neck posture.

3.5.6. Conclusion

This study assessed the influence of neck posture on reaction time and inhibitory control, comparing a neutral posture with a flexed neck posture. Compared to neutral posture, a flexed neck posture facilitated later elements of a response (e.g. launching a motor plan) but did not influence inhibitory control which included earlier elements of a response (e.g. generating a motor plan). This may be because it only affects the execution of a motor plan, and not the decision to generate one. In conclusion, while a flexed neck posture can facilitate faster response times during simple tasks, tasks that require more complex cognitive involvement are unlikely to benefit.

Chapter 4: Conclusion

Neurological research on postural alignment is an emerging field of study, requiring a deep understanding of cognitive concepts such as attention and inhibitory control as well as an understanding of the mechanics of posture. The two studies presented within this dissertation investigated a bidirectional relationship between control of attention and a flexed neck posture to build this foundation, providing important information on the effects of attending to posture in a dual-task situation and the effects of a flexed neck posture on reaction time and inhibitory control.

The first study demonstrated that while biofeedback improved postural alignment, this improvement came at the price of task performance. From dual-task studies we know that attention is a limited resource, so the concern is that this attention decrement may discourage effective posture correction in addition to degrading task performance. The cost to attention was greater in those with worse postural habits. Further, subjects with higher self-reported mindfulness maintained their posture better without feedback. We conclude that mindfulness may promote the use of intrinsic feedback to reduce reliance on extrinsic feedback, which carries a greater cognitive load. This suggests that people with posture-related pain may be better off investing in mindfulness training (or embodied mindfulness) rather than biofeedback devices. Future research could explore this possibility.

The second study demonstrated that inducing a flexed neck posture improved reaction time and reactive inhibitory control but did not significantly affect proactive inhibition. This observed effect distinguishes facilitation of motor activity from cognitive influences on the decision to move. During tasks, individuals may balance the dynamic demands of attention on tasks with attention to posture in this way, i.e. adopting poor posture in the short term because they see an immediate benefit to reaction time. However, our results suggest that this strategy is not beneficial (and therefore not worth the risk of future neck pain) for tasks that require more complex cognitive involvement.

These studies together demonstrate that insight into the bi-directional relationship between postural alignment and cognition can be gained by thoughtfully combining tools from cognitive psychology with tools from biomechanics. This work lays a foundation for future studies of brain activity during different postural conditions.

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