Multimodal Multitasking: The Combined Effects of Postural and Cognitive Demands on Overall Workload

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ABSTRACT

Workers are challenged by the increasingly complex multitasking environments they experience. To interact effectively with these environments, they must avoid overload. When workers get overloaded (when their mental demands exceed the resource capacity) quality drops, performance degrades, and safety suffers.

What is largely unknown, however, is whether these results translate to postural tasks. Postural stability exhibits an entirely different set of challenges: injury, the danger of slips and falls, and risks associated with aging workers or those who have mental or physical challenges. An assembly line worker, for example, must assume different postures, interact with the product in some way, and react to visual and auditory alarms. Mistakes could be dangerous. It is clearly important, then, to understand the interactive effects of mental and postural workload.

The goal of this research was to quantify the effects of mental and postural demands on overall workload. To accomplish this, we implemented three studies that were designed to capture the synergistic effects of different task types on overall workload and compare different types of workload measures against each other to help further design research in the area. We designed a dual-task mental/postural protocol to test the differential effects of a series of cognitive demands found in dual-task postural studied.

The results of the first study depict a clear picture: the addition of an auditory task to unstable seating decreases postural sway. Based solely on this result, it might be concluded that workload did not increase. Using the same protocol while measuring mental workload however, we found that workload did in fact increase both subjectively and objectively, even when similar postural benefit was found. Even as performance seemed to improve, the participant moved nearer to possible overload and performance decrement (a condition we did not induce in this research). Based on the differences found between the different measures, we believe the importance of measuring overall workload as well as individual task performance in cognitive/postural dual-task research is very high.

PROPOSED PUBLICATIONS

Chapters 2-4 are drafted manuscripts in the process of being submitted for publication in peer-reviewed journals. As such, the preliminary information on each is presented below.

Cullen, R. H. and Agnew, M. J. (n.d.). *The Effects of an Audio-based Cognitive Task on Seated Postural Stability*. Manuscript in preparation.

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Cullen, R. H. and Agnew, M. J. (n.d.). *The Effects of Varying Mental Demands on Overall Workload in a Postural/Cognitive Dual Task Environment.* Manuscript in preparation.

STATEMENT OF ORIGINALITY

I hereby certify that all of the work described within this thesis is the original work of the author. Any published (or unpublished) ideas and/or techniques from the work of others are fully acknowledged in accordance with the standard referencing practices.

Ralph Cullen
June, 2014

DEDICATION

To Grandmother and Grandfather Cullen, without whom none of this would have happened.

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CHAPTER I: Introduction

Complex human machine interfaces, such as distracted driving, installing parts on an assembly line, and riveting structural beams into place on a construction site all share two important features. One, they all require the operator to multitask, interacting with two or more cognitive and/or physical tasks at once. Two, they are all potentially dangerous, oftentimes deadly. In 2011, distracted driving accounted for 10% of crash fatalities and over three hundred thousand injuries (NHTSA, 2013). In that same year, non-fatal injuries in manufacturing and construction reached over half a million and almost two hundred thousand, respectively (BLS, 2012).

Multitasking increases workload, a measure of the demands placed on the mental system (Altmann & Trafton, 2002; Kahneman, 1973; Wickens & McCarley, 2008). This increase takes up large amounts of a limited pool of mental resources (Navon & Gopher, 1979). When this workload reaches the limits of the mental system (i.e. when demand exceeds capacity), workers are overloaded and performance degrades (Kahneman, 1973). These degradations can result in slow and halting work as the operator struggles to keep abreast of the tasks, or when rework errors occur and have to be solved. This is a compounding issue; as poor work is passed on to other processes, and, ultimately, poor system functioning results because of the combined effects.

Overload is not just concerning in a productivity sense, it can have disastrous effects. Multitasking overload contributed to the deaths of 290 people aboard Iran Air Flight 655 when an AEGIS cruiser mistook them for a fighter jet and shot them down (Cooke & Durso, 2007); the coordinator responsible for making enemy designations was managing an incredible amount of information well above what one person should be able to process. These issues often go unnoticed or attributed to “operator error”, as overload may happen when expectations shift unexpectedly and the operators are unprepared (Cooke & Durso, 2007; Wickens & McCarley, 2008).

Even when not resulting in a catastrophe, overload must be avoided across many different jobs spanning many different hazards. As almost everyone multitasks, many are susceptible to overload. For example, maintaining posture is an important task for many professions. Errors in balance can lead to falls to the floor or from heights, contact with dangerous or hard surfaces, or loss of control of machinery or tasks performed. If the act of postural control were to contribute to workload, it could contribute to and be affected by overload, possibly causing a higher error rate and unsafe conditions, even when the individual tasks being performed are themselves assumed to be safe.

Concurrent Multimodal Tasks

Most published studies discussing multitasking cover solely cognitive tasks: ones where the primary workload is assumed to be cognitive (e.g. searching for visual stimuli, remembering previous instructions, or reacting to an auditory alarm). Tasks here are defined as individual entities that provide the operator with a goal; based on relevant information taken from the system, the operator must make a decision and interact with that system somehow to achieve or approach the task goal. Task demands can be of many types; collecting information, processing information, decision making, and response selection and execution can all carry with them demands (Parasuraman, Sheridan, & Wickens, 2000). Furthermore, tasks of many different modalities all consume mental resources (auditory versus haptic, balance versus visual, balance versus verbal, etc.) (Fitch, 2009; Fitch, Hankey, Kleiner, & Dingus, 2011; Siu & Woollacott, 2007; Slobounov, Hallett, Stanhope, & Shibasaki, 2005; Woollacott & Shumway-Cook, 2002).

Maintaining balance, then, does represent another type of task that could affect the limited mental resource bank and cause the aforementioned overload.

Since poor balance maintenance could create unsafe conditions for workers, the realm of postural and cognitive multitasking is especially important. Not only are there concerns regarding the degradation of cognitive performance, but it has been demonstrated that decreased postural performance leads to a higher risk of injury or falls (Condron, Hill, & Physio, 2002; Hausdorff, Rios, & Edelberg, 2001; Springer et al., 2006), especially among those of advanced age or with cognitive or physical disadvantages (Delbaere et al., 2010; Hauer et al., 2003; Hausdorff et al., 2006; Hausdorff et al., 2001; Liston, Bergmann, Keating, Green, & Pavlou, 2014; Montero-Odasso, Muir, & Speechley, 2012; Negahban, Ahmadi, Salehi, Mehravar, & Goharpey, 2013; Swanenburg, de Bruin, Uebelhart, & Mulder, 2010). This higher risk has created significant interest in the interactive effects of concurrent cognitive and postural tasks, but the results have been varied across the literature, and more research is needed (Fraizer & Mitra, 2008).

Cognitive and physical tasks affect each other in myriad ways, with many different aspects of the methodology and analysis identified as important factors worth consideration (Fitch, Kiefer, Hankey, & Kleiner, 2007; Woollacott & Shumway-Cook, 2002). For example, the difficulty of a given postural task affects balance (Moghadam et al., 2011; Riley, Baker, & Schmit, 2003), as does the type of cognitive demand (e.g. spatial, verbal, or memory) (Dault, Frank, & Allard, 2001; Kerr, Condon, & McDonald, 1985; Maylor, Allison, & Wing, 2001). Measurement type(s)/experimental methods also seem to cause differences; as results found in some types of postural measurements may not be replicated in others (Collins & De Luca, 1993; Moghadam et al., 2011; Riley, Balasubramaniam, & Turvey, 1999). For example, results seen in simple center-of-pressure path measures may not be replicated in more complex analyses such as stabilogram diffusion analysis (Miller, 2012).

The differences between studies are not just observed in response magnitude, they also present in opposite directions, or polarity. Concurrent cognitive tasks have been shown to both aid (Broglio, Tomporowski, & Ferrara, 2005; Riley et al., 2003; Salavati et al., 2009; Vuillerme & Vincent, 2006) and/or degrade balance (Pellecchia, 2003; Qu, 2010) based on the task types, measurement, and difficulty. These differences between analysis types and inconsistencies across methods and controls represent a concern; more needs to understood about why different methods and measures change the results found if the task demands should be purely additive (Fraizer & Mitra, 2008).

The Synergy of Multiple Tasks

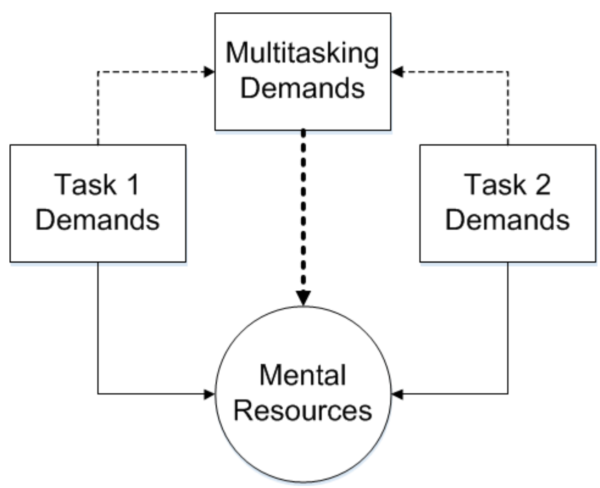

Figure 1. A simplified model of the demand sources on mental resources during dual-tasking.

Mental workload is defined by several authors as the interaction of outside demands on the cognition of the operator with the limited amount of mental resources he or she possesses (Moray, 1979; Wickens, 2008). Because workload describes demand and capacity, it organizes itself into two possible states; when demand is less than or equals capacity (in which case the operator is able to handle the demands) and when demand is greater than capacity (Wickens &

Hollands, 2000). The demands that affect workload can come from one or more tasks assigned to on the operator. These tasks do not have to be "cognitive" in nature to affect mental workload; both physical tasks and cognitive tasks have been shown to affect workload (Qu, 2013; Woollacott & Shumway-Cook, 2002).

A large part of the current research focuses on further understanding the effects of different types of tasks on mental workload, regardless of the primary nature of the tasks. "Cognitive tasks", therefore, are defined in this research as those where the demands are primarily cognitive in nature (e.g. perceptual speed, response time); the minimal physical aspects of the task are limited to the response required (e.g. clicking a mouse or responding verbally). The word "cognitive" was used here instead of "mental" (although the two words are often used interchangeably) to differentiate this task type from the measures of mental workload, as mental workload is used to describe an aspect of both tasks. "Physical" or "postural tasks", meanwhile, are defined as those where the primary aspects are physical in nature (e.g. gait or balance), the conscious cognition of which is largely limited to performance evaluation. Neither type can be called entirely "physical" nor "cognitive", but both affect mental workload as both demand mental resources.

If the demands of multitasking are purely additive, then the results of dual-task studies should be clear. Operators would be able to handle both tasks up until the point where they run out of mental resources, causing performance on one or both tasks to suffer (Kahneman, 1973). This result is not always reflected in dual-task and multitasking studies (Navon & Gopher, 1979). The cognitive demands of a dual-task environment extend past the demands of the individual tasks themselves (Altmann & Trafton, 2002). Figure 1 above depicts this effect. The demands of both task 1 and 2 affect the mental resources, but so does their interaction, the behavior of which varies.

When humans interact with two or more tasks at once, they are not truly “multitasking”, that is, not interacting with each task at the exact same time. Instead, people switch quickly between tasks, interacting with each in sequence, or in a serial fashion (Altmann & Trafton, 2002; Wickens & McCarley, 2008). This method necessitates cognitively activating and switching between tasks, activities that themselves require mental resources. Furthermore, as operators move between tasks, those aspects of the tasks that are similar can interfere, requiring still more mental resources to avoid interference (Fitch et al., 2011; Wickens, 1984).

Without some measure of the effects of the implicit demands of multitasking, it would be impossible to quantify the interaction of cognitive and postural tasks. Previous studies have assumed that these demands can be seen through their effects on the performance of one or both tasks (Woollacott & Shumway-Cook, 2002). The associated inference is that there are finite amount of undifferentiated resources, performance decrements happen when that limit is reached, and that the implicit demands of multitasking can be measured through the drop in performance of one or both tasks (Kahneman, 1973). This is not the case. There are indeed finite resources, but they are differentiated, allowing humans to process different types and timings of stimuli with different resource pools (Navon & Gopher, 1979; Wickens, 1984, 2008). The need, then, is for a measure of overall workload. Overall workload is defined as the workload resulting from the demands of all tasks combined with those implicit demands of the multitasking system itself.

Goals of the Current Research

To address the need for a better understanding of the common, complex, and potentially dangerous environment of multitasking, the goal of this research is to *quantify the effects of concurrent cognitive and postural demands on overall workload.* Previous studies have matched one or two cognitive demands with a postural demand and reported the results of how each affected the other. The current goal is to understand the dual-task environment as a system including not only the demands and performance of each task individually but their interactive effects and contribution to the overall workload level of the operator.

As the main focus of this research is to understand overall workload, our choice of measures of that workload was important. This research utilized two types of measures of overall workload, physiological and self-report. Electroencephalography (EEG) and heart rate variability (HRV), both physiological measures, have been used to measure workload (Berka et al., 2007; Hankins & Wilson, 1998; Kothe & Makeig, 2011; Krause, Heikki Lang, Laine, Kuusisto, & Pörn, 1996; Shaw, Satterfield, Ramirez, & Finomore, 2013; Zarjam, Epps, Chen, & Lovell, 2013).

EEG is a measure of brain activity (Schwarz-Ottersbach & Goldberg, 1986) and has previously also been used to understand postural control (Sipp, Gwin, Makeig, & Ferris, 2013; Slobounov et al., 2005), making it a clear choice to help understand overall workload in a multimodal setting. EEG is also a good candidate because the different task demands discussed occur throughout the brain; posture is managed in the cerebellum and vestibular system, vision uses the visual cortex in the occipital lobe, audition is managed in the auditory cortex, and executive functions take place in the frontal cortex. As we are looking at overall workload, we analyzed data from the parietal and frontal lobes, as is common with workload studies.

HRV is a another physiological measure of mental workload (DiDomenico & Nussbaum, 2011) and a viable candidate for dual-task measures. Previous studies have shown that as workload increases, variability decreases (DiDomenico & Nussbaum, 2011; Hankins & Wilson, 1998). It has also been shown to affected by physical exertion and balance-related tasks such as yoga (Sarang & Telles, 2006).

NASA-TLX, a self-report workload measure, was also employed. NASA-TLX assesses six different aspects of workload found to contribute to overall workload: mental (cognitive) demand, physical demand, temporal demand, performance, effort, and fatigue (Hart & Staveland, 1988). NASA-TLX is a subjective workload measure and provides a non-invasive way to quickly assess subjective ratings of workload during of immediately after tests for both cognitive and physical tasks (Mehta & Agnew, 2011). It also addresses both cognitive and physical stresses separately as well as measures that might be affected by either or both. Together, these two measures provide a breadth of knowledge regarding overall workload, how it affects both brain function *and* subjective experience of the operators.

To accomplish the goals of this study, three specific aims were developed and subsequent studies were designed to address each. These are discussed below.

Specific Aim #1: Develop a dual-task protocol comprising cognitive and postural demands. Study 1 was necessary to the overall goals of this research. Without a protocol free of common confounds, it would not have been possible to successfully test the effects of cognitive and postural demands on overall workload. Because of the variability induced in EEG signals due to eye movement, we developed a protocol utilizing an auditory task, a type of task not commonly discussed in the literature. This protocol provided both a common approach to compare to similar studies already completed and baseline of results to compare to the effects found in overall workload.

Specific Aim #2: Characterize the effects of cognitive and postural demands on overall workload, assessing how multitasking synergy affects multimodal multitasking. Study 2 directly addresses the goal of this research, quantifying the effects of the cognitive/postural dual task environment on overall workload. Based on the results of this study, we hoped to better understand how the two tasks interacted as well as whether, even if no performance decrements are found, there are differences in workload when a second task is added. Additionally, comparing the EEG and HRV data with that of the NASA-TLX provided an understanding of how the two measures correlate. As workload is dependent on attention (Wickens & McCarley, 2008), it was important to determine the effects the added collection has on participants.

Specific Aim #3: Quantify the detrimental effects of different types of cognitive demands on overall workload. Study 3 broadened the scope of the results, determining how different levels of difficulty and different types of cognitive demands affect the measures of overall workload. With this information, we learned more regarding which task attributes are likely to provide postural benefit, which could cause decrement, and which might be added concurrently with what effect. Without looking at these task aspects, the effects of cognitive tasks on postural demands would not have been well understood.

This dissertation is organized into five chapters. The first chapter (this one) is an overview of the entire project, including the layout of the three aims and the studies that I designed to address each one. Chapters 2 through 4 describe each of those three studies, formatted as manuscripts describing the impetus, method, analysis, and conclusions of the individual studies. Chapter 5 summarizes the results found throughout all three studies, as well as some overall conclusions of the research as a whole.

Multitasking environments that combine postural and cognitive tasks, such as assembly or construction work, could be better designed to account for the synergistic effects of different task types. Environments could be evaluated for possible overload concerns, and the limits of the workers would be addressed in the layout and expectations of a work site or job. Based on the results, this work also explains some of the differences found across previous postural studies. In the long term, the results of this work should be used to inform the creation of standards in regulations that address the workload limitations of workers in complex jobs, acknowledging the interactive aspects of postural and cognitive work.

CHAPTER II: The Effects of an Audio-based Cognitive Task on Seated Postural Stability

Abstract

Multiple task environments are ubiquitous in modern work; almost every job requires operators to do multiple tasks in the same timeframe. Recent research has focused on the effects of physical and postural stress on cognitive tasks and vice versa. Our goal was to understand how identification and discrimination tasks in the auditory domain would interact with postural instability, as previous studies had shown mixed results (Easton, Greene, DiZio, & Lackner, 1998; Raper & Soames, 1991). We devised a dual task method and measured both cognitive and postural performance wherein participants interacted with an auditory discrimination task while seated on an unstable chair at different levels of stability. The presence of the auditory task decreased postural sway, but only when seating was unstable. Auditory task performance (accuracy and response time) showed no effects. Future designers of auditory systems and postural aids should be aware that simple auditory discrimination tasks do not impair balance.

Introduction

Almost all jobs require multitasking. Some environments are more explicit about multiple tasks; the operators as asked to complete several tasks at once concurrently; all are important to the completion of the job and the operator is evaluated on every one. Some environments exhibit more implicit multitasking, providing one primary task while requiring the operator to respond to other, unevaluated ones: listening for alarm signals, maintaining balance and posture, and monitoring internal well-being, all of these take attentional resources (Altmann & Trafton, 2002; Mehta & Agnew, 2011).

Part of understanding how people respond to each task is understanding how other tasks they do affect their ability to interact with critical tasks they are given. A relatively recent field of research seeks to understand how cognitive and physical tasks interact with each other (see Fraizer and Mitra (2008) for a review); how attentional limitations might cause degradation of one or both tasks in the presence of a sufficiently taxing version the other. Performance decrements would have an effect on both the design of auditory systems and the physical and postural aspects of the job.

Auditory stimuli pervade almost all types of work; because of the omnidirectional, always-on attributes of human audition, it is often used as a way of alerting or providing information with the need to already have an operator's attention. It is also used in the design if warning signals, as detection of a hazard and the ability to discriminate that hazard are critical in being able to respond appropriately. Design, then, has to go farther than just making sure these signals are clearly audible; it must ensure that the operator or bystander is able to identify those signals, recall learned instructions on how to respond, and respond appropriately, all within a set amount of time.

The goal of this study was to understand the differential effects of an auditory-based cognitive task and postural instability in a seated position to support similar research on other types of tasks and inform design of posturally demanding jobs, auditory tasks and warning systems.

Attentional Demands of Dual-Task Environments

One of the driving forces behind the interest in determining the interactive effects of cognitive and physical tasks is the need to understand how the brain manages multiple tasks at once and whether and how physical tasks are treated differently than cognitive ones.

Between different cognitive tasks, the very nature of a multiple task environment creates special demands, cognitive costs of activating and switching between the different tasks being done concurrently (Altmann & Trafton, 2002). These demands add to the demands caused by the tasks themselves, creating the potential for faster overload. Furthermore Multiple Resource Theory (Wickens, 1984) states that any aspects of concurrent tasks that overlap (modality, processing stage, location, etc.) will cause interference between the two tasks, harming performance.

These increases in demand for attentional resources become important because of the possibility of overload, where the need for resources overcomes the capacity of the system to respond. This overload has been suggested to take place in several different ways: either there is a general capacity for attention that can be exceeded (Kahneman, 1973) or there are specialized structures or bottlenecks that can be exceeded by the need to switch and deal with the incoming information in a serial fashion (Wickens, 1984). Either way, the effect is the same, when this capacity is reached, performance on one or both tasks suffers (Kahneman & Treisman, 1984).

Physical Dual Task Environments

Dual Task Interference. Similar results have been found with more physical tasks. The dual task approach has been thoroughly validated, with research that has pitted several physical tasks against each other, such as gripping and shoulder strength (MacDonell & Keir, 2005) or gripping and pushing (Keir & Brown, 2012), and research adding a cognitive aspect such as the Stroop task (DiDomenico & Nussbaum, 2011; MacDonell & Keir, 2005; Mehta & Agnew, 2011; Stroop, 1935). All of these studies have shown, in some way or another, an interference of the task on each other; that concurrent physical tasks impede the maximal forces provided otherwise (Keir & Brown, 2012) and that the addition of a cognitive task provided for a similar effect (MacDonell & Keir, 2005; Mehta & Agnew, 2011). All of these studies were focused on graded level of muscular exertion, however, not postural stability.

In the field of postural and motor control, a previous study illustrated that attentional resources are required to maintain posture in a standing position when concurrently under a mental workload (DiDomenico & Nussbaum, 2005). Furthermore, when those resources were exceeded, performance (either cognitive or balance) has been shown to degrade. It should be noted however, that in terms of methodology, this study focused on subjective assessments of performance, however; as workload and postural confidence were measured by self-report. In both cases, the interaction of the workloads was not well understood, workload measures in the postural study were subjective and the Stroop task was used as an experimental condition but not analyzed.

Dual Task Support. Other studies have found vastly different, results, however. Based on the layout of the postural conditions and the difficulty and type of tasks provided, studies have found a supportive effect of cognitive tasks on postural sway (Riley et al., 2003; Swan, Otani, & Loubert, 2007), that is, postural sway decreased in the presence of a memory-based cognitive task. This has also been found to occur in patients with low-back pain (Salavati et al., 2009; Van Daele et al., 2010).

The authors suggest that this may be due to some distracting nature of the added task; that no physical task is actually without a cognitive component. Fraizer and Mitra (2008) suggest that this may be because a “non-cognitive control” is not possible, the brain will be acting regardless of whether or not a task is provided and that the addition of a cognitive task provides a way to avoid over-focusing on the balancing task. It may also have to do with the arousal level at lower difficulties; that the participants are not performing as well because the tasks are too easy and they are not at an optimum level of arousal (Hüttermann & Memmert, 2014; Yerkes & Dodson, 1908).

Regardless of the reason, these two types of findings stand in stark contrast to each other but provide some insight into the complexity of the dual-task system. More research is needed to understand what aspects of the cognitive and physical tasks interact, something Fraizer and Mitra (2008) approached using standing postural stability.

Auditory Stimuli and the Physical Dual Task Environment

Previous studies into the effect of auditory stimuli on balance have been mostly focused on those stimuli as noise or background. In this context, sound is thought of as a stimulus, not as a task, much like the finding that keeping the eyes open aids balance (Silfies, Cholewicki, & Radebold, 2003). The results in the field of auditory stimuli are just as varied as those in the cognitive task literature, with some studies showing reduced sway during presentation of auditory stimuli (Easton et al., 1998; Lin, 2010) and others showing increased sway (Raper & Soames, 1991). This effect may be dependent on frequency, with some frequencies aiding balance whereas others do not (Sakellari & Soames, 1996).

Overview of This Study

Based on the literature, the way forward in the realm of the interaction of physical and cognitive tasks is to better understand what aspects of each cause the effects seen in the literature. With that in mind, the goal of the current study is to expand the current understanding by pairing a seated postural stability task with an auditory discrimination task, two analogs to tasks often encountered in modern jobs, postural control and discrimination of important auditory signals.

To inform this question, we designed a study in which participants would complete different levels of a seated postural task with and without interacting with the auditory discrimination task. The auditory discrimination task was designed to be free-field and binaural to simulate a common working environment for such discrimination. The postural control task was induced using a wobble chair, a mechanism designed to create and control different levels of seated postural stability. The wobble chair is a well-modeled and commonly used method of measuring postural stability (Lee & Granata, 2008; Lee, Granata, & Madigan, 2008; M. L. Tanaka, Ross, & Nussbaum, 2010) and has been used before in studies measuring effects of cognitive tasks on lower back pain participants (Radebold, Cholewicki, Polzhofer, & Greene, 2001; van Dieën, Cholewicki, & Radebold, 2003). The different levels of physical difficulty were achieved using the wobble chair's ability to raise and lower the stability of the seated participant, explained later.

Based on previous studies, we were unsure as to whether the cognitive task would provide a benefit or detriment to postural sway, as both have been found in cognitive task and auditory studies. We took steps to ensure that our task did not fall under the categories previously shown to affect balance, so no difference was directly expected. The cognitive task, however, would either not be affected (if the combined difficulty was within the attentional resources of the participants) or would be negatively affected (if the participants were overloaded).

Method

Participants

We recruited 30 young adult participants, 15 males and 15 females (aged 18-31). All conditions were given to every participant; the study was within-subject. The participants were recruited from the Virginia Tech community and were compensated for their time in the experiment. All participants were screened to have far visual acuity of 20/40 or better using a modified Snellen eye chart (Snellen, 1866), and no significant low back pain for the last three years, supported by completion of the Roland-Morris low-back questionnaire (Roland & Morris, 1983). The participants were also screened to determine whether or not they had hearing loss that might have affected the experiment by being presented with all tones beforehand. Demographic and basic anthropometric data for the participants is shown in Table 1.

Table 1. Demographic and anthropometric data for the sample.

	Mean	Std. Dev.
Age	25.03	3.42
Height (in.)	67.27	3.12
Weight (lbs.)	149.30	24.24

Design

The experiment was within-subjects, with all subjects completing each type of trial. The two independent variables were the cognitive task (either absent or present) and the level of stability of the wobble chair (50% and 75% of gravitation gradient as well as fully stable). These conditions were fully crossed, providing six different trial types. Presentation order of the different trials was counterbalanced across both stability and cognitive task using a latin square to control for order effects across independent variables. The data collected comprised two broad categories, cognitive response (response time and accuracy) and postural sway (force data). Neither gender nor order was significant for any dependent variable.

Materials

The experiment was divided into two major parts, the cognitive (auditory discrimination) task and the physical (seated postural control) task. Each was controlled separately by different apparatuses and collected data independently to avoid overtaxing the computer systems. See Figure 2 for a picture of the experimental layout.

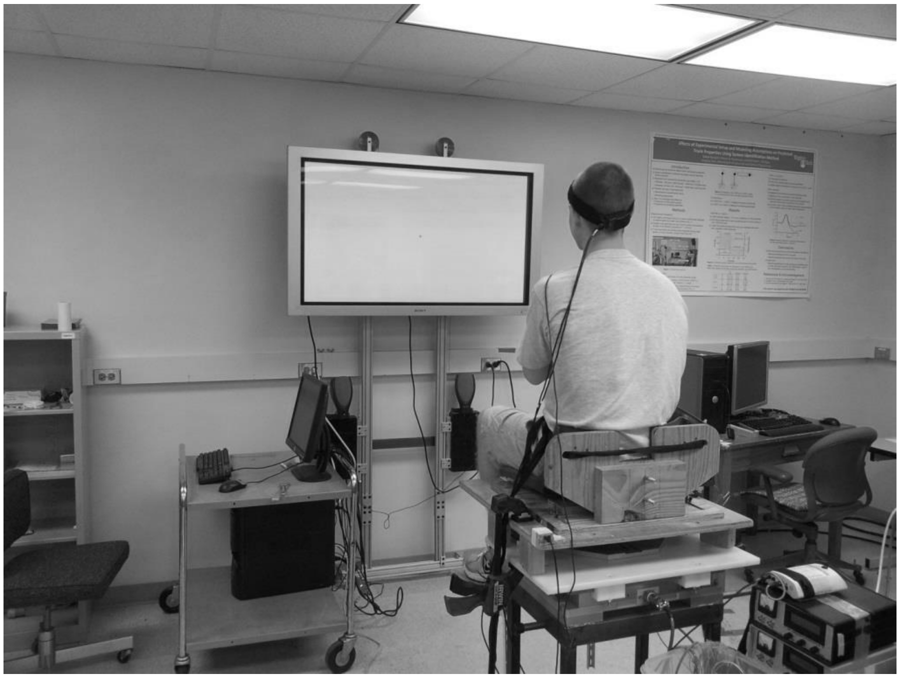

Figure 2. The participant interacting with the cognitive task while on the wobble chair. Participants were asked to keep erect posture during the experiment. A fixation cross was provided to participants to standardize visual input.

The Cognitive Task. The cognitive task consisted of two one-second auditory tones presented in series one second apart. The four tones used were pure tones at octave intervals, 500, 1000, 2000, and 4000 Hz, tuned to be at equal loudness (70 phons) at the participant's ear. The tones were presented binaurally in a free-field to avoid the effects of dynamic presentation (T. Tanaka, Kojima, Takeda, Ino, & Ifukube, 2001). These frequencies were chosen because they did not fall into the frequency ranges shown to significantly affect postural sway (Sakellari & Soames, 1996). During piloting, it was determined that the 500 and 4000 Hz tones should not be used first as the response could be determined after only one tone.

Participants were presented with all tones before the beginning of trials to ensure that the tones were easily differentiable and given practice to minimize the effects of task learning. The participants were instructed to respond using a mouse, pressing the left button if the second tone was higher in pitch than the first and the right if lower. The mouse was placed in the right hand of the user with the cord draped over the left shoulder to avoid entanglement or effect on postural sway. They were also instructed to be as fast *and* as accurate as possible to avoid the effects of focusing on one of the other. A fixation cross (a plus sign) was provided, upon which participants were asked to focus to standardize the visual input across all trials. After each response, the participants were provided feedback as to their correctness and speed. Data, including the accuracy and response time for each trial, were collected by E-Prime 2 (PST, 2010) and stored on a Windows-based PC.

The Physical Task. The physical task undertaken by the participants was to sit in the wobble chair, a platform designed to produce different levels of seated stability though the use of four springs, one in each of the cardinal directions. In Figure 2, the participant is sitting on the wobble chair. The springs can be seen below the chair pan.

To determine stability, the wobble chair had to be calibrated to the participant, ensuring that the center of mass of the participant was over top of the ball bearing marking the center of the chair and that the springs were set at the correct positions to induce the desired amount of instability. This was done by calculating the gravitation gradient. The conditions in this experiment were set to 50% and 75% of gravitation gradient and a totally stable condition (where blocks holding the chair in place for entrance and egress were not removed), a condition close to the limit of postural stability of healthy adults (50%) (Mistry, 2011), and a mid-range (75%). These conditions were set by sliding the springs in or out to compensate for the weight distribution of each individual participant.

During the trials, participants were asked to keep as stable as possible while keeping the chair as close to the center of balance as possible. To avoid postural sway confounds, the participants were asked not to talk, close their eyes, or move their head during each trial. They were also asked to wear a headband outfitted with an accelerometer to track head movements. Finally, they were asked cross their arms in front of their chest and focus on the fixation cross provided on the screen.

Data from the physical task were collected using an AMTI force plate placed beneath the chair (at 1000 Hz). The data from this plate were recorded using National Instruments' LabVIEW (Elliott, Vijayakumar, Zink, & Hansen, 2007) on a Windows-based PC and stored for later analysis.

Procedure

The experiment took place over 90 minutes on one day. Participants were first briefed on the experiment and asked to complete a consent form prior to their participation. They were then asked to complete several demographics forms, the Roland-Morris questionnaire (Roland & Morris, 1983), the Snellen eye test (Snellen, 1866), and weighed and measured. Next, to assess perceptual speed and memory span, the Digit Symbol Substitution and Reverse Digit Span tests were administered (Wechsler, 1981).

The next step was to calibrate the chair to the participant. This involved setting the height of the foot pan, adjusting the chair pan to be over the participant's center of mass, and calibrating the springs to the correct gravitational gradient for each participant. Each calibration procedure utilized several 5-second collection periods on the chair.

Participants were then placed in the chair and given the instructions to the cognitive task. They were allowed to ask questions and then completed a 2-minute practice trial of the cognitive task to familiarize themselves. If the participant did not feel comfortable after one practice trial or reach 90% accuracy, they were allowed to take another, although this did not occur during the experiment.

After a short break, the participants were debriefed on the number and nature of the six trials as well as the rules for each. Each trial lasted two minutes, with a one minute break in between to allow the seated postural muscles to rest. The screen presented the instructions for the current trial to the participant before each. Trials without the cognitive task provided only the fixation cross and the instruction to stay as stable as possible for the two minutes. After the six trials, the participants were debriefed, compensated, and thanked.

Data Preparation and Analysis

Cognitive Task. The individual response cognitive task data collected from E-Prime were first aggregated to the trial level, providing a mean response time and overall accuracy for each participant in each one of the six trials. This provided a similar level of analysis to the physical data. Response time and accuracy were then analyzed by conducting paired-samples t-tests between stability levels of 75% and perfectly stable (50% was not analyzed due to the inability of many participants to complete the physical task). All analyses were evaluated at the $\alpha = .05$ level.

Physical Task. Data collected from the force plate were first run though a fourth-order, zero-phase-lag Butterworth low pass filter with an effective cutoff frequency of 10 Hz to remove non-postural noise from the data and then demeaned. The data was then used to compute two types of measures. First, the force and moment data provided by the plate was used to compute center of pressure (COP) time series. An example of this COP time series converted into a two-dimensional stabiliogram (depicting the path taken by the participant on the chair) is shown in Figure 3.

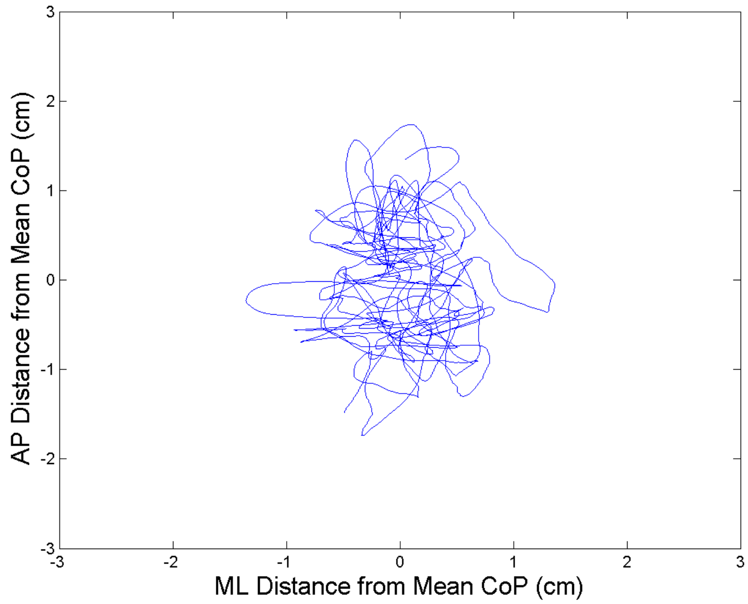

Figure 3. Example stabilogram.

From these data, measures such as velocity, root mean square (RMS) distance, and maximum distance values were derived in both the medio-lateral (ML) and antero-posterior (AP) directions (Prieto, Myklebust, Hoffmann, Lovett, & Myklebust, 1996). These were supplemented by a random-walk analysis of open-loop and closed-loop balance (Collins & De Luca, 1993), using the COP data to estimate the critical point (the duration where the system transitions between open- to closed-loop) time (s) and magnitude (cm^2) intervals as well as the short term log-log slope, known as the scaling exponent (H_S, a measure of the persistence of motion in the short term) in both the ML and AP directions, as well as the composite. The x and y values of the critical point determine the time and magnitude needed for the participant to transfer from open- to closed-loop processes. Higher values mean higher thresholds for closed-loop corrections, indicative of less postural stability (Collins & De Luca, 1993; Hendershot, 2012).

COP measures were analyzed using a two-way repeated measures ANOVA with independent variables Stability (75% and stable) with Cognitive Task (Absent and Present). All data were tested using the Shapiro-Wilk test ($p > 0.05$) to determine normality. Results that violated sphericity ($p < 0.05$ in Mauchley's sphericity test) were Greenhouse-Geisser corrected and the corrected F and p values presented.

Results

Cognitive Task Results

Descriptive statistics and the results of the paired samples t-tests are reported in Table 2. There were no significant differences found with either; in fact, the means for both accuracy and response time were very similar.

Table 2. Summary of statistics and results of paired-samples t-tests for cognitive data.

	Mean	Std. Dev.	t-value	p-value
Accuracy 75%	0.911%	0.114	0.567	0.575
Accuracy Stable	0.902%	0.108		
Response Time 75%	740.78 ms	307.65	-0.680	0.502
Response Time Stable	764.39 ms	370.66		

Physical Task Results

Center of Pressure Measures. The results of the two-way repeated measures ANOVA for the center of pressure (COP measures) in both the medio-lateral and antero-posterior directions are shown in Table 3.

Table 3. Main effects and interactions for COP-based measures. Significant effects are bolded.

		Stability		**Cognitive Task**		**Interaction**	
		F-value	p-value	F-value	p-value	F-value	p-value
ML	Velocity (cm/s)	**38.834**	**< 0.001**	0.326	0.572	0.014	0.906
	RMS (cm)	**77.700**	**< 0.001**	0.197	0.660	0.976	0.331
	Max (cm)	**94.486**	**< 0.001**	0.279	0.602	0.222	0.641
AP	Velocity (cm/s)	0.003	0.960	0.005	0.946	0.642	0.430
	RMS (cm)	**116.559**	**< 0.001**	**7.827**	**0.009**	**7.483**	**0.011**
	Max (cm)	**116.356**	**< 0.001**	0.445	0.510	0.734	0.399

The significant effect of stability was expected; the conditions were designed to differ in physical difficulty. As the RMS in the AP direction also showed a significant main effect of cognitive task and interaction, further analyses were conducted to determine the nature of this effect. We used paired-samples t-tests to determine the difference between cognitive task and no-cognitive task trials at each stability level. The results of those tests is shown in Table 4 and depicted in Figure 4.

Table 4. Post-hoc analyses for AP RMS interaction. Significant effects are bolded.

	Mean (cm)	**Std. Dev.**	**t-value**	**p-value**
No Cognitive Task 75%	0.773	0.403	**2.860**	**0.008**
Cognitive Task 75%	0.596	0.229		
No Cognitive Task Stable	0.111	0.056	-0.485	0.631
Cognitive Task Stable	0.119	0.086		

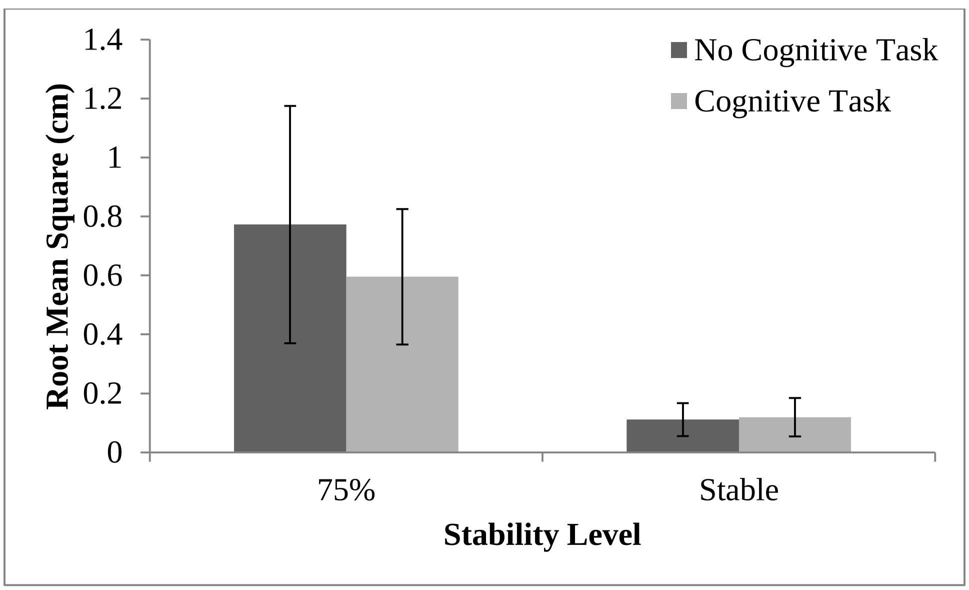

Figure 4. The interaction of cognitive task and stability level for antero-posterior data. Bars depict standard deviation.

As shown, the participants, when interacting with the cognitive task, showed less movement in the AP direction when faced with a relatively taxing physical task.

Stabilogram Diffusion Analysis. Based on the procedures outlined by Collins and De Luca (1993), the COP time series data were converted into stabilogram diffusion analyses to expand and support the basic measures suggested by Prieto et al. (1996). The stabilogram diffusion analysis (SDA) is a random-walk analysis used to determine when the participants transition from a closed-loop to an open-loop postural control process. Based on previous studies, the three most important pieces of information to be gleaned from an SDA are the critical time interval (CTI, in seconds), the critical magnitude interval (CMI, in cm^2), and the short-term log slope, a scaling exponent denoted by H_S. The results of the two-way repeated measures ANOVA for the SDA measures in the ML, AP, and composite directions is shown in Table 5.

Table 5. Main effects and interactions from SDA measures. Significant effects are bolded.

		Stability		Cognitive Task		Interaction	
		F-value	p-value	F-value	p-value	F-value	p-value
ML	CTI	**90.995**	**< 0.001**	**4.916**	**0.035**	3.813	0.061
	CMI	**5.037**	**0.033**	1.229	0.277	1.226	0.277
	H_S	**308.408**	**< 0.001**	1.115	0.300	1.505	0.230
AP	CTI	**134.605**	**< 0.001**	0.810	0.375	3.213	0.084
	CMI	**39.626**	**< 0.001**	2.046	0.163	2.033	0.165
	H_S	**242.145**	**< 0.001**	**17.457**	**< 0.001**	**8.933**	**0.006**
Comp.	CTI	**121.732**	**< 0.001**	**5.099**	**0.032**	**6.270**	**0.018**
	CMI	**12.629**	**0.001**	1.541	0.224	1.534	0.225
	H_S	**324.054**	**< 0.001**	**7.613**	**0.010**	**6.519**	**0.016**

Stability was significant for all measures, as was expected. Four variables showed a main effect of cognitive task, three of which also showed an interaction between cognitive task and stability level. To better understand these interactions, the critical time interval in the ML direction was plotted (see Figure 5) and follow-up analyses were done on the three variables showing interactions to determine where those effects were.

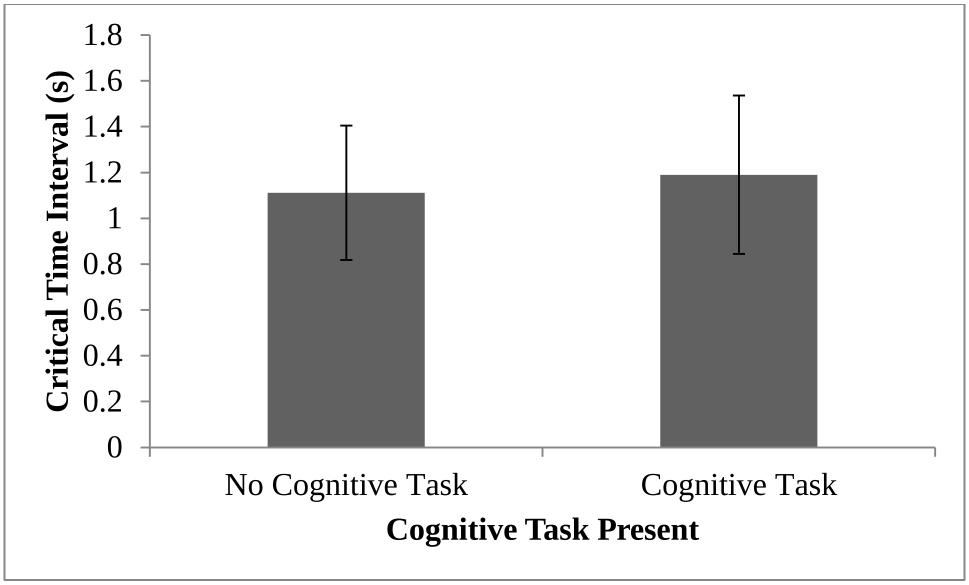

Figure 5. Critical time interval data for the cognitive task. Bars depict standard deviation.

Based on the post-hoc analysis, all three variables exhibited the same pattern; participants showed no difference in performance the fully stable condition with or without a cognitive task, but had significantly higher values for the cognitive task trials when interacting with the 75% stability condition. Figure 6, Figure 7, and Figure 8 depict these effects, the effect of stability level and cognitive task for each of the three significant interactions.

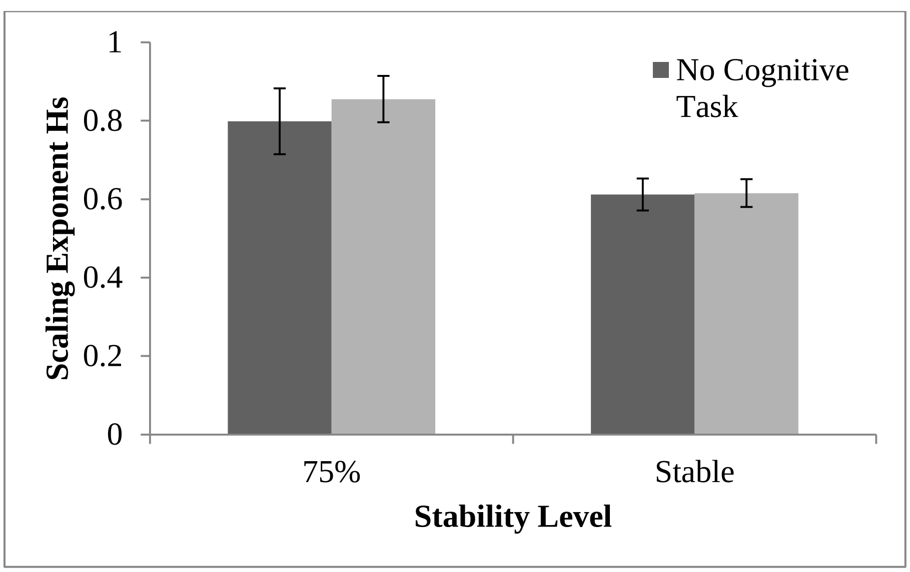

Figure 6. The interaction of stability level and cognitive task for the Scaling Exponent H_S in the AP direction. Bars depict standard deviation.

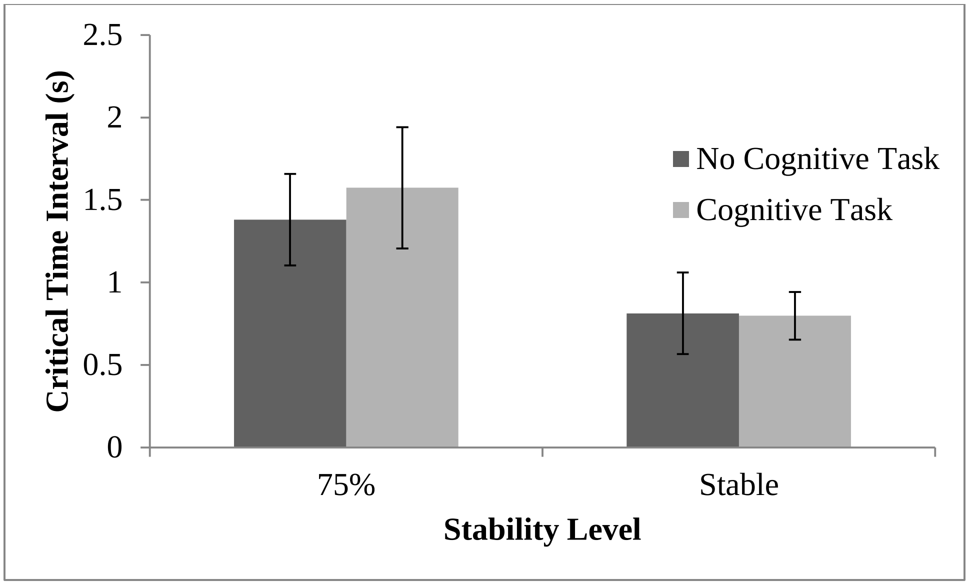

Figure 7. The interaction of stability level and cognitive task for the Critical Time Interval for both directions overall. Bars depict standard deviation.

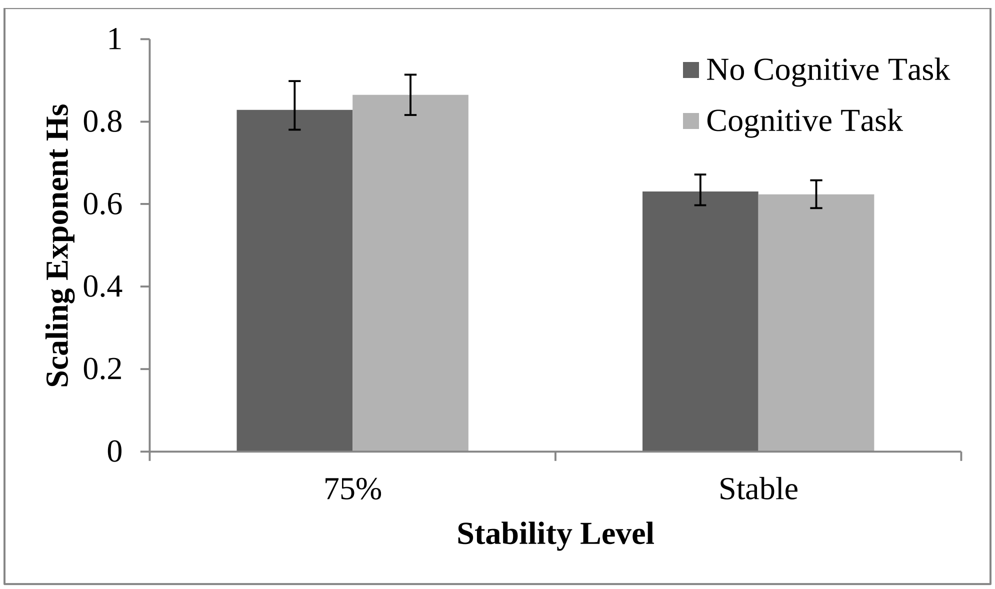

Figure 8. The interaction of stability level and cognitive task for the Scaling Exponent H_S for both directions overall. Bars depict standard deviation.

These results suggest that whereas it took the participants longer to reach the critical point (both in the ML direction and overall with less stability), they displayed significantly more persistence in both the AP direction and overall when interacting with the cognitive task during the less stable condition (see Table 6 for post-hoc analysis results).

Table 6. Post-hoc analysis on SDA data showing interaction. Significant effects are bolded.

			Mean	Std. Dev.	t-value	p-value
CTI Comp.	75%	No Cognitive Task	1.381	0.278	**-3.011**	**0.005**
		Cognitive Task	1.574	0.368		
	Stable	No Cognitive Task	0.819	0.246	0.394	0.696
		Cognitive Task	0.799	0.145		
H_S AP	75%	No Cognitive Task	0.799	0.083	**-4.259**	**< 0.001**
		Cognitive Task	0.855	0.059		
	Stable	No Cognitive Task	0.615	0.040	-0.394	0.706
		Cognitive Task	0.619	0.035		
H_S Comp.	75%	No Cognitive Task	0.830	0.069	**-3.766**	**0.001**
		Cognitive Task	0.865	0.048		
	Stable	No Cognitive Task	0.630	0.047	0.837	0.532
		Cognitive Task	0.624	0.040		

Discussion

The results from this study serve to further inform knowledge about the interactions of cognitive and physical tasks and what aspects do and do not affect the ability of the participants to perform effectively on both. Our study found no performance differences in the cognitive task between stability conditions, suggesting that either the combination of the tasks was not difficult enough or that the increased difficulty induced by the chair wobbling did not affect cognitive performance. Previous studies have suggested that, in lieu of instructions given, the first task to be negatively affected is the cognitive one, as the postural task is given a higher priority (Fraizer & Mitra, 2008).

The physical results support the results of Easton et al. (1998) (unlike those of Raper and Soames (1991)); the cognitive task in conjunction with the more difficult 75% stability condition provided a relative benefit to postural sway. This effect was found primarily in the antero-posterior direction, but could also be seen in some of the non-linear analysis overall. It should be noted, however, that the critical time point was lengthened in the medio-lateral direction and overall, suggesting that the two directions may behave differently.

These results suggest that performance of non-spatial auditory task of low difficulty are not significantly affected by seated postural instability and that postural stability may in fact be slightly aided by the distraction. One possible explanation for this affect is an increase in arousal caused by the addition of the second task. In that case, the participant interacting solely with the postural task is below optimal arousal and therefore not utilizing the full capacity of mental resources available (Yerkes & Dodson, 1908). When the second task is added, arousal increases and the participant has a higher capacity of mental resources. This increase in capacity accounts for the better postural task performance when in conjunction with the mental task; demand on the workload system may be increasing, but so is capacity. Future research should focus on determining whether difficulty plays a significant part in these interactions; whether an increase in difficulty would increase the workload past the peak arousal point and start to degrade performance.

Designers of work that requires high postural stress or the need to balance in unstable conditions should understand that, even when efforts are made to avoid creating any extra mental workload by removing cognitive tasks from the workspace, some level of auditory stimulation may actually be beneficial to balance, possibly allowing the person to focus on encoding and responding to the auditory signals instead of focusing solely on their own posture. The overall goal of future research in this field should be to identify what combinations of factors create supportive cognitive/physical dual task environments and which create interference and degradation of performance.

CHAPTER III: Comparing Different Measures of Overall Workload in a Multimodal Postural/Auditory Dual Task Environment

Abstract

Audition and balance are important aspects of many multitasking environments; auditory signals are used for myriad different alerts and alarms and balance is pivotal in the realms of factory and construction to avoid falling and risking injury or death. Furthermore, the demands of multiple tasks at once can interact, creating complex environments that require measurement of overall workload. In this study we utilized an auditory/postural dual task protocol and measured overall workload in a variety of ways: subjective (NASA-TLX) and physiological (Heart Rate Variability and EEG). The presence of the auditory task decreased postural sway, but the results of the workload measures were varied, most showing an increase in workload with the cognitive task. The need to use more than one method of workload measurement is the strongest result of this study.

Introduction

Multitasking increases workload (Altmann & Trafton, 2002; Kahneman, 1973; Wickens & McCarley, 2008), taking up large amounts of a limited pool of mental resources (Navon & Gopher, 1979). When this workload reaches the limits of the mental system, workers are overloaded and performance degrades (Kahneman, 1973). These degradations can result in slow and halting work as the operator struggles to keep abreast of the tasks, or when rework errors occur and have to be solved. This is a compounding issue; as poor work is passed on to other processes, and, ultimately, poor system functioning results because of the combined effects.

Audition and balance are two good examples of where multitasking may not be commonly considered; auditory stimuli are present in many work environments; because of the omnidirectional, always-on attributes of human audition, it is often used as a way of alerting or providing information with the need to already have an operator's attention. It is also used in the design if warning signals, as detection of a hazard and the ability to discriminate that hazard are critical in being able to respond appropriately. Balance is a requirement for many jobs from factory work to construction, either because of the tasks required or due to dangerous or precarious environments where a loss of balance might mean injury or death. Environments containing both of these stimuli have only recently been studied (Lin, 2010; Sakellari & Soames, 1996), and not in the context of a auditory stimuli needing a response. This is concerning because of the importance of both in many common work environments.

Concurrent Postural and Cognitive Tasks

Most studies discussing multitasking cover solely cognitive tasks: ones where the primary workload is assumed to be cognitive (e.g. searching for visual stimuli, remembering previous instructions, or reacting to an auditory alarm). However, postural tasks, such as balance, also consume mental resources (Siu & Woollacott, 2007; Slobounov et al., 2005; Woollacott & Shumway-Cook, 2002). Balance, then, does represent another type of task that could affect the limited mental resource bank and cause the aforementioned overload.

In the realm of postural and cognitive multitasking, this is especially important. Not only are there concerns regarding the degradation of cognitive performance, but it has been demonstrated that decreased postural performance leads to a higher risk of injury or falls (Condron et al., 2002; Hausdorff et al., 2001; Springer et al., 2006), especially among those of advanced age or with cognitive or physical disadvantages (Delbaere et al., 2010; Hauer et al., 2003; Hausdorff et al., 2006; Hausdorff et al., 2001; Liston et al., 2014; Montero-Odasso et al., 2012; Negahban et al., 2013; Swanenburg et al., 2010). This danger has created significant interest in the interactive effects of concurrent cognitive and postural tasks, but the results have been varied across the literature, and more research is needed (Fraizer & Mitra, 2008).

Cognitive and postural tasks affect each other in myriad ways, with many different aspects of the methodology and analysis identified as important factors worth consideration (Woollacott & Shumway-Cook, 2002). For example, the difficulty of a given postural task affects balance (Moghadam et al., 2011; Riley et al., 2003), as does the type of cognitive demand (e.g. spatial, verbal, or memory) (Dault et al., 2001; Kerr et al., 1985; Maylor et al., 2001). Measurement type(s)/experimental methods also seem to cause differences; as results found in some types of postural measurements may not be replicated in others (Collins & De Luca, 1993; Moghadam et al., 2011; Riley et al., 1999). For example, results seen in simple center-of-pressure path measures may not be replicated in more complex analyses such as stabilogram diffusion analysis (Miller, 2012).

The differences between studies are not just to do differences in magnitude, they also present in opposite directions, or polarity. Concurrent cognitive tasks have been shown to both aid (Broglio et al., 2005; Riley et al., 2003; Salavati et al., 2009; Vuillerme & Vincent, 2006) and/or degrade balance (Pellecchia, 2003; Qu, 2010) based on the task types, measurement, and difficulty. These differences between analysis types and inconsistencies across methods and controls represent a concern (Fraizer & Mitra, 2008). As such, more research is necessary to increase our understanding regarding how these tasks interact overall and why changes in difficulty and cognitive demand have inconsistent effects.

Multiple Tasks and Overall Workload

If the demands of the overall multitasking system were just the demands of task A and task B added together, the design of multiple task environments would be simple: add tasks for the participants until the point where they run out of mental resources, causing performance on one or both tasks to suffer (Kahneman, 1973).

Sadly, this is not the case in dual-task and multitasking environments (Altmann & Trafton, 2002; Navon & Gopher, 1979). When humans interact with two or more tasks at once, they are not truly “multitasking”. People switch from one task to the other in series (Altmann & Trafton, 2002; Wickens & McCarley, 2008). This method requires us to activate new tasks and switch between tasks, which both require mental resources. Furthermore, as operators move between tasks, those aspects (modality, timing, response characteristics, etc.) of the tasks that are similar can interfere, requiring still more mental resources to avoid interference (Fitch et al., 2011; Wickens, 1984).

Without some measure of the effects of the implicit demands of multitasking, it would be impossible to quantify the interaction of cognitive and postural tasks. Previous studies have assumed that these demands can be seen through their effects on the performance of one or both tasks (Woollacott & Shumway-Cook, 2002). The associated inference is that there are finite amount of undifferentiated resources, performance decrements happen when that limit is reached, and that the implicit demands of multitasking can be measured through the drop in performance of one or both tasks (Kahneman, 1973). This is not the case. There are indeed finite resources, but they are differentiated, allowing humans to process different types and timings of stimuli with different resource pools (Navon & Gopher, 1979; Wickens, 1984). The need, then, is for a measure of overall workload. Overall workload is defined as the workload resulting from the demands of all tasks combined with those implicit demands of the multitasking system itself.

Overview of This Study

The goal of this research is to quantify the effects of the cognitive/postural dual task environment on overall workload. To do this we developed a method pairing an auditory discrimination task with a seated balancing task. An auditory discrimination task was chosen for several reasons. First, vision is already known to have a stabilizing effect on balance (Chagdes et al., 2009; Easton et al., 1998; Raper & Soames, 1991; Stins, Michielsen, Roerdink, & Beek, 2009), a confound that might cause differential effects across stability conditions. Second, the effects of auditory fields are varied (Lin, 2010; Raper & Soames, 1991; Sakellari & Soames, 1996; Shaw et al., 2013; T. Tanaka et al., 2001), but auditory stimuli used in a task have not been studied, providing a novel task space that would provide more information regarding how different modalities affect balance.

To assess the overall workload caused by both tasks, we used three different methods. The first was heart rate, as heart rate variability (HRV) has been shown to be sensitive to mental workload; as workload increases, variability decreases (DiDomenico & Nussbaum, 2011; Hankins & Wilson, 1998). The second was the NASA Task Load Index (NASA-TLX), a self-report measure designed to assess overall workload using a breadth of scales combined into a number that increases as workload does (Hart & Staveland, 1988). Third was electroencephalography (EEG), a technique of measuring brain activity in different regions. Certain activity in certain regions of the brain, such as a drop in alpha wave (8-13 Hz) activity in the parietal lobes or an increase in theta wave (4-7 Hz) activity in the frontal lobes, has been shown to occur in conjunction with increased mental workload (Berka et al., 2007; Hankins & Wilson, 1998; Koles & Flor-Henry, 1981).

The wobble chair is a commonly used apparatus in the field of seated postural stability and can provide data on how the participant responds to postural perturbations (Hendershot, 2012; Lee & Granata, 2008; Lee et al., 2008; M. L. Tanaka et al., 2010). Because the seating is unstable and novel to the participants, it will be more attention demanding (Schneider & Shiffrin, 1977) and provide a greater chance of mental workload overload. The difficulty also better approximates the demand found in situations with challenging postures.

Seated stability is only one common measure of posture, others being standing or walking stability. Since the goal of this research is to determine the workload demands caused by a postural task, the type of postural task is not as important as the workload it contributes; these results can be generalized across other postural tasks shown to have attentional demand.

Based on prior research, we hypothesized that the performance of one or both tasks would either stay the same or suffer when both were done together; the participant would either be able to do both or would become overloaded. Regardless, the synergistic effect of multiple tasks would create not only main effects in each of the mental workload correlates (HRV, NASA-TLX, and EEG) but an interaction; when both happened together, the workload would be higher than the additive effects of each.

Based on the results of this study, an exact mechanism explaining how the two tasks interact will be better understood as well as whether, even if no performance decrements are found, there are differences in workload when a second task is added. Additionally, comparing the EEG data with that of the NASA-TLX will provide an understanding of how the two measures correlate. As NASA-TLX is non-invasive and quick to administer, this would provide workers and designers with a way to evaluate environments quickly and easily for overload.

Method

Participants

There were 24 young adult participants, 9 males and 15 females (aged 18-30). All conditions were presented to all participants, so no groups were formed. The participants were recruited from the Virginia Tech community and compensated for their time in the experiment. All participants were screened to have far visual acuity of 20/40 or better using a modified Snellen eye chart (Snellen, 1866) and no significant low back pain for the last three years, both reported by the participant themselves and confirmed through completion of the Roland-Morris low-back questionnaire (Roland & Morris, 1983). Participants were also asked to complete the modified morningness-eveningness questionnaire (Horne & Ostberg, 1976) and scheduled at a time that generally matched (before noon for morning people, afternoon for evening) their peak circadian arousal, to control for arousal's effect on balance (Horslen & Carpenter, 2011). During practice, the participants were also screened to determine whether or not they had hearing loss that might have affected the experiment by being presented with the four tones beforehand. Demographic and basic anthropometric data for the participants are shown in Table 7.

Table 7. Demographic and anthropometric data for the sample.

	Mean	Std. Dev.
Age	24.88	2.97
Height (in.)	67.21	3.28
Weight (lbs.)	155.00	23.41

Design

The experiment was within-subjects, with all subjects completing each type of trial. The two independent variables were the presence of the cognitive task (either absent of present) and the level of stability of the wobble chair (60% and 75% of gravitation gradient, as well as a fully stable condition). These conditions were fully crossed, providing six different trial types. Presentation rate of the task/non-task noise was standardized, with one set being presented every 5 seconds. Presentation order of the different trials was counterbalanced using a latin square across both stability and cognitive task to control for order effects. Neither gender nor order was significant for any dependent variable.

Materials

The experiment was divided into two major parts, the cognitive task and the physical task. Each was controlled separately by different materials and collected data independently to avoid overtaxing the computer systems. Several measures of overall workload were also collected independent of either task. See Figure 9 for a picture of the experimental layout.

Figure 9. A participant interacting with both tasks. Note that, as this is a pilot participant, the EEG cap had not yet been applied.

The Cognitive Task. This study utilizes an auditory discrimination task as the selected cognitive task. This auditory task presents the participants with two pure tones of different pitch at least an octave apart to avoid difference threshold concerns. After the second tone was presented, participants were asked to determine which tone was higher and respond using the mouse. The task was presented free-field (from two speakers placed the room) at a level well above threshold for those with no significant hearing loss (pre-screened and assessed quickly through practice). All tones were presented at equal loudness (~70 phons). The tone pairs were presented at the rate of one pair for every 5 seconds, but the beginning of the presentation was randomized to avoid participants predicting. In trials where the auditory task was absent, one second of white noise was played at the same presentation incidence rate as the tone pairs. Data, including the accuracy and response time for each trial, were collected by E-Prime 2 (PST, 2010) and stored on a Windows-based PC.

The Postural Task. The postural task was represented by a wobble chair, a device designed to induce and manipulate seated postural instability. It did this through the use of four springs, one at each of the cardinal directions, that can be moved in and out to manipulate the level of instability presented. These different levels of stability were normalized to participants' height and weight using gravitation gradient, a measure of stability provided by the chair (Hendershot, 2012). 100% of gravitation gradient implies that the chair provides all the support required by the participant whereas 75% means that the participant must contribute 25% of the effort to keep themselves stable. The levels of stability used in this experiment were infinite (the chair locked in using clamps), 75%, and 60%. The chair is depicted in Figure 10.

Figure 10. The wobble chair apparatus.

The participant was buckled into the chair and places their feet on a footrest. They were then asked to keep their hands crossed in front of them and their head forward while trying to maintain balance over the ball bearing in the center of the chair. If they lost their balance entirely, the chair contacted the plate below it, stopping the movement before the participant was in danger. Because of the difficulty of the task, trials were kept short to avoid fatigue (Miller, 2012).

Data from the physical task were collected using a force plate placed beneath the chair (at 1000 Hz). The data from this plate were recorded using National Instruments' LabVIEW (Elliott et al., 2007) on a Windows-based PC and stored for later analysis.

Overall Workload Collection. Collection of overall workload was accomplished in three different ways, the NASA Task Load Index (NASA-TLX) self-report scale, a heart monitor, and an EEG cap. The NASA-TLX worksheet (Hart & Staveland, 1988) consisted of six scales

(Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration) that the participant had to judge after each trial. For each type, the participant rated their demand on a 21-point scale. Before the trials, the participant completed a weighting procedure created to aid in determining and controlling for biases in the way the participants viewed the scales.

The heart rate monitor, a Polar RS800cx, consisted of a chest band and adjoining watch. The chest band was placed on the participant's chest and reading taken for each trial using the watch. The Polar system is a simple method of HRV collection (Quintana, Heathers, & Kemp, 2012). The collected data were then used to determine the variability for each trial.

The Mind-Fi EEG cap, designed by Cortech Solutions, was a wireless, 63-channel EEG system connected to LabVIEW for data collection. The channel map is shown in Figure 11.

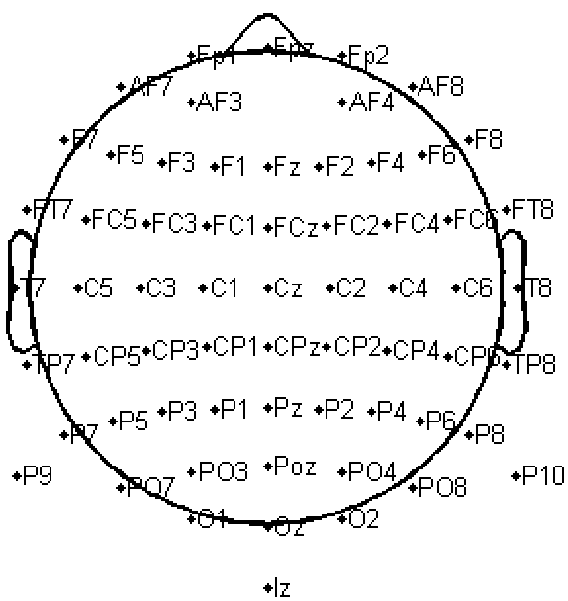

Figure 11. Channel map for the Mind-Fi EEG cap. Diagram created using EEGLab (Delorme & Makeig, 2004).

Procedure

The experiment took place over two hours on one day. Participants first gave written consent on a form. They were then asked to complete several demographics forms, the Roland-

Morris questionnaire (Roland & Morris, 1983), the Snellen eye test (Snellen, 1866), and weighed and measured. Next, to assess perceptual speed and memory span, the Digit Symbol Substitution and Reverse Digit Span tests were administered (Wechsler, 1981).

The next step was to apply the heart monitor and EEG cap. Both were added at this point to allow the electrolyte gel time to warm before the trials. After application of both, the chair was calibrated to the participant. This involved setting the height of the foot pan, adjusting the chair pan to be over the participant's center of mass, and calibrating the springs to the correct gravitational gradient for each participant.

The participants were then trained on the auditory discrimination test and given two minutes to practice without the postural task. The same was then done with the postural task. If the participant did not feel comfortable after one practice trial, they were allowed to take another. After all practice trials were completed, the participant was trained on the NASA-TLX workload scale and weighting procedure and asked to fill out the weighting cards.

After a short break, the participants were asked to complete six trials. Before the first trial, they were briefed on the nature of the six trials as well as the rules for each. Each trial lasted two minutes, with a two minute break in between to allow the torso muscles to rest and the participant to fill out a NASA-TLX form. The screen presented the instructions for the current trial to the participant before each. After the six trials, the participants were debriefed, compensated, and thanked.

Data Preparation and Analysis

Cognitive Task. Performance on cognitive tasks is usually evaluated in one of two ways based on the goals of the study: accuracy of the responses or the speed at which the participant responded. This is due to the fact that simple tasks provide only two measures to evaluate performance, whether or not the person was correct in their decision and how long it took them to arrive at the answer. The root of this problem is the speed-accuracy tradeoff and the fact that the two measures are not independent (Wickelgren, 1977). As the participant tries to speed up, they are more likely to make mistakes. Conversely, when they focus on getting the task right they may take more time to respond. Any analysis of cognitive task performance must take both into account, as well as develop precise instructions to avoid accidentally biasing results through influencing the way participants prioritize accuracy or speed. Response time and accuracy were then analyzed by conducting one-way repeated measures ANOVAs between stability levels of 60, 75%, and completely stable. All data were tested using the Shapiro-Wilk test ($p > 0.05$) to determine normality. All analyses were evaluated at the $\alpha = .05$ level. Results that violated sphericity were Greenhouse-Geisser corrected.

Physical Task. Data collected from the force plate were first run though a fourth-order, zero-phase-lag Butterworth low pass filter with a cutoff frequency of 10 Hz to remove any noise from the data. Data from the first 10 and last 5 seconds were removed to avoid lead-in or lead-out effects and all data were demeaned. The data were then used to compute two types of measures. First, the force and moment data provided by the plate were used to compute center of pressure (COP) time series (Prieto et al., 1996). An example of this COP time series converted into a two-dimensional stabiliogram (depicting the path taken by the participant on the chair) is shown in Figure 12. Many measures can be derived from these data, among them mean and root mean squared velocity in the antero-posterior (forward/backward) and medio-lateral (left/right) directions, maximum displacement from center, and overall path distance.

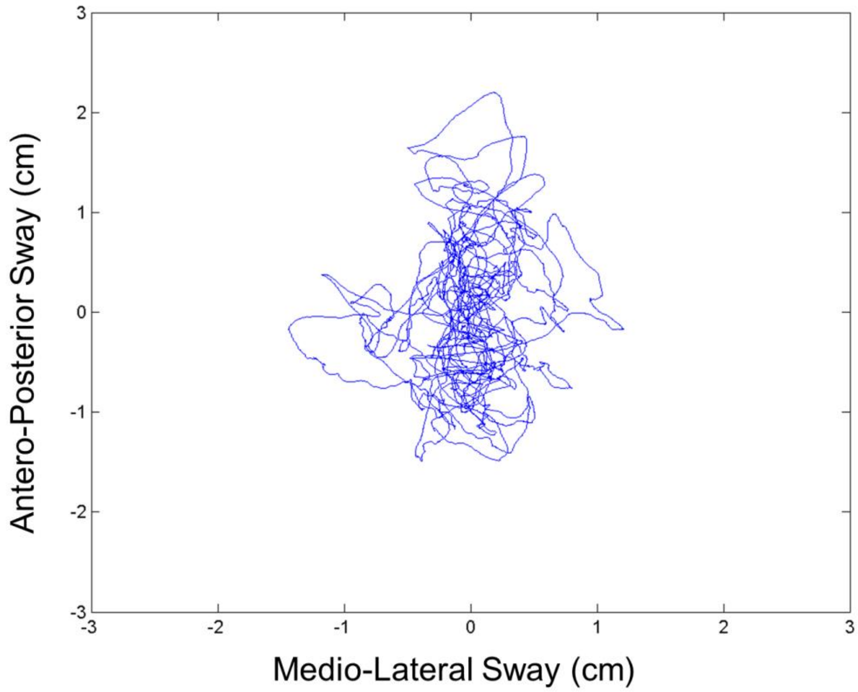

Figure 12. A stabilogram depicting the sway path of a representative participant within a trial.

These measures are very common in the literature, being the easiest to collect and understand (Fraizer & Mitra, 2008; Woollacott & Shumway-Cook, 2002). Velocity and displacement measures provide a good sense of how far and fast the participant moved during the task and differences in sway (the act of moving around) are commonly used to explain differences in dual-task environments (Davis, Marras, Heaney, Waters, & Gupta, 2002; Hendershot, 2012; Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997; Silfies et al., 2003)

One criticism leveled at these simple measures, however, is that they do not extend far into understanding the postural stability system; in particular, what mechanisms are contributing to create the patterns depicted in the stabilogram. Stabilogram Diffusion Analysis (SDA) helps to address this shortcoming (Collins & De Luca, 1993). The purpose of SDA is to divide the posture control system into two different mechanisms, a short-term, open-loop process of muscle responses to small perturbations and a longer-term, closed-loop process of conscious correction. Figure 13 depicts the two systems as well as associated measures.

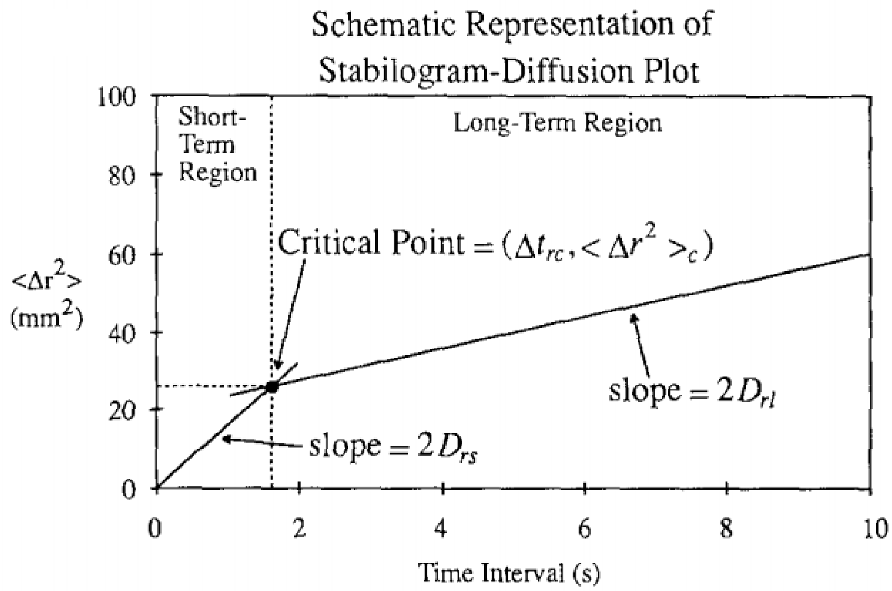

Figure 13. A schematic representation of an SDA plot depicting the two postural processes and associated measures. Reprinted from Collins and De Luca (1993) with permission.

The current research will use a subset of the measures developed in SDA analysis, based on studies that have demonstrated which measures provide information about balance: the critical time interval, the critical magnitude interval, and the short term log slope, known as the scaling exponent. These measures have been well documented to illustrate differences between postural conditions and variables such as low back pain (Collins & De Luca, 1993; Hendershot, 2012; Radebold et al., 2001).

COP time series and SDA measures were analyzed by conducting one-way repeated measures ANOVAs between stability levels of 60, 75%, and completely stable. All data were tested using the Shapiro-Wilk test ($p > 0.05$) to determine normality. All measures were checked for sphericity using Mauchly's test and Greenhouse-Geisser corrections were applied on the ANOVA results where sphericity was violated. All analyses were evaluated at the $\alpha = .05$ level.

Overall Workload Measures. NASA-TLX results were calculated using both the weighted and unweighted procedures. As the Pearson correlation between the two was .965 ($p < 0.001$), all displayed results are weighted. Weighted results were compared using a two-way repeated measures ANOVA at $\alpha = .05$.

Heart rate data from the first 10 and last 5 seconds were removed to match the postural analysis. The rest were used to calculate a trial-wide standard deviation for inter-beat interval (SDNN) (DiDomenico & Nussbaum, 2011). These values were compared using a repeated measures ANOVAs at $\alpha = .05$.

EEG data were run through a series of preprocessing processes to ensure consistent data across trials: First, data from the first 10 and last 5 seconds were removed to match the postural analyses. Second, data were filtered using a notch filter of a 2 Hz bandwidth around 60 Hz to remove mains noise. Third, all data were demeaned. Fourth, to create power spectra, overlapping samples of 2 seconds long were run though 50% overlapping Hamming windows, transformed to the frequency domain using a Fourier transform, and averaged to create an overall power spectra for each trial. Four electrodes were analyzed based on an Independent Component Analysis done during piloting using EEGLab (Delorme & Makeig, 2004) as well as similar research done in previous studies (Gevins et al., 1998); the electrodes selected were centered in components hypothesized to show workload changes (alpha waves in the parietal lobe, theta waves in the frontal lobe) (Dussault, Jouanin, Philippe, & Guezennec, 2005; Gevins & Smith, 2003). These four electrodes are P7, P8, Fz, and FCz (see Figure 11 for placement).

The relative power for each if the different conditions was analyzed by determining the amount of power at the peak frequencies of each band (6-7 Hz in the theta band for the two frontal electrodes, 8-10 Hz in the alpha band for the two parietal electrodes) (Gevins et al., 1998). To aid in normalizing the differences between alpha and theta power and emphasizing the power changes between conditions, normalized change scores were calculated using the following equation.

$$Difference\ Score = \frac{(Current\ Power - Power\ from\ No\ Task\ Stable\ condition)}{Power\ from\ No\ Task\ Stable\ condition}$$

In this way, all of the conditions were normalized to the No Task Stable condition, the condition as close to a control as can be conceived in the current method. Two-way repeated measure ANOVAs were completed on these difference scores in the alpha band for P7 and P8 and in the theta band in Fz and FCz. All analyses were done at the α = .05 level.

Results

Cognitive Task Results

Descriptive statistics and the results of the repeated measures ANOVAs are reported in Table 8. No main effects were apparent for either variable. The means for each of the different levels were very close.

Table 8. Summary of statistics and results of repeated measures ANOVAs for cognitive data (α = .05).

	Mean	Std. Dev.	F-value	p-value
Accuracy 60%	0.914%	0.205	0.176	0.839
Accuracy 75%	0.907%	0.201		
Accuracy Stable	0.909%	0.202		
Response Time 60%	1065.779 ms	283.170	0.422	0.622
Response Time 75%	1048.102 ms	314.438		
Response Time Stable	1077.143ms	299.540		

Postural Task Results

Center of Pressure Measures. The results of the two-way repeated measures ANOVA for the center of pressure (COP measures) in both the medio-lateral and antero-posterior directions are shown in Table 9.

Table 9. Main effects and interactions for COP time series measures (α = .05). Significant effects are bolded.

		Stability		Cognitive Task		Interaction	
		F-value	p-value	F-value	p-value	F-value	p-value
ML	Velocity (cm/s)	**132.24**	**< 0.001**	**16.12**	**0.001**	**3.67**	**0.041**
	RMS (cm)	**153.25**	**< 0.001**	**4.55**	**0.044**	**3.69**	**0.038**
AP	Velocity (cm/s)	**53.93**	**< 0.001**	2.37	0.138	0.90	0.413
	RMS (cm)	**158.00**	**< 0.001**	1.85	0.187	3.89	0.681

The main effect of stability in both directions was not unexpected; the differences between the conditions were designed to create differing levels of movement. This main effect shows that. Velocity and root mean square in the medio-lateral direction showed significant effects of task and interaction between task and stability. To better understand these effects, we conducted pairwise comparisons: paired t-tests comparing task versus no task at each of the three different levels of stability. These analyses are shown in Table 10 and Table 11 and in Figure 14 and Figure 15.

Table 10. Results of pairwise t-tests for velocity (α = .05). Significant effects are bolded.

	Mean (cm/s)	Std. Dev.	t-value	p-value
No Cognitive Task 60%	0.811	.180	**3.056**	**0.006**
Cognitive Task 60%	0.748	.177		
No Cognitive Task 75%	0.582	.162	**2.872**	**0.009**
Cognitive Task 75%	0.529	.161		
No Cognitive Task Stable	0.253	.078	-0.296	0.770
Cognitive Task Stable	0.257	.091		

Table 11. Results of pairwise t-tests for Medio-lateral RMS distance (α = .05). Significant effects are bolded.

	Mean(cm)	Std. Dev.	t-value	p-value
No Cognitive Task 60%	.564	.198	1.833	0.080
Cognitive Task 60%	.520	.147		
No Cognitive Task 75%	.432	.136	**2.327**	**0.029**
Cognitive Task 75%	.386	.135		
No Cognitive Task Stable	.068	.039	-1.497	0.148
Cognitive Task Stable	.081	.051		

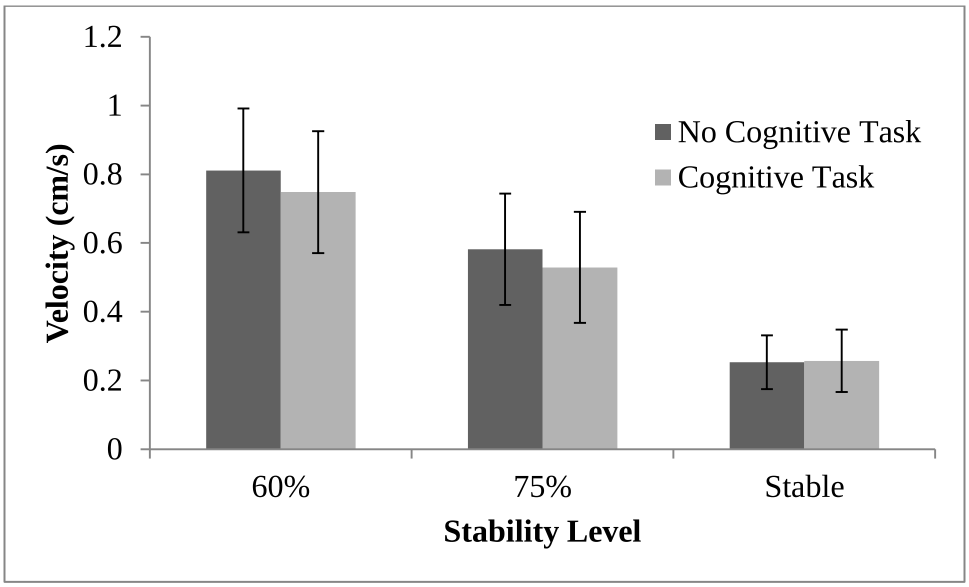

Figure 14. Medio-lateral velocity comparing task vs. no task for each of the different stability levels. Errors bars depict standard deviation.

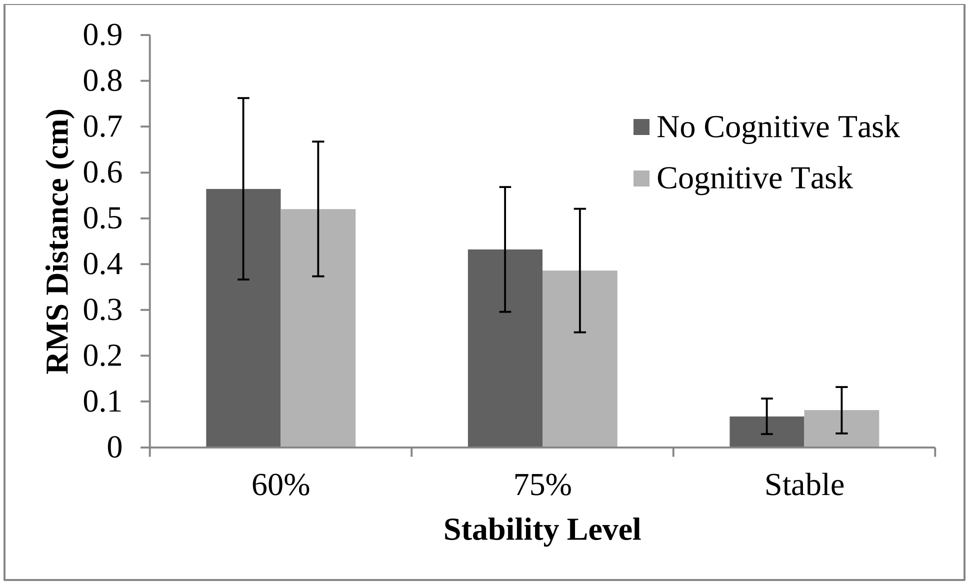

Figure 15. Medio-lateral RMS distance comparing task vs. no task for each of the different stability levels. Errors bars depict standard deviation.

Based on these results, the auditory discrimination task used in this study was associated with more stable behavior in the less stable conditions. When the chair was perfectly stable, no differences were found between postural behavior with and without the cognitive task.

Stabilogram Diffusion Analysis. Based on the procedures outlined by Collins and De Luca (1993), the COP time series data were converted into stabilogram diffusion analyses to expand and support the basic measures suggested by Prieto et al. (1996). The results of the two-way repeated measures ANOVA for the SDA measures in the ML, AP, and composite directions is shown in Table 12.

Table 12. Main effects and interactions from SDA measures (α = .05). Significant effects are bolded.

		Stability		Cognitive Task		Interaction	
		F-value	p-value	F-value	p-value	F-value	p-value
ML	CTI	**94.68**	**< 0.001**	0.09	0.762	1.62	0.211
	CMI	**34.01**	**< 0.001**	2.46	0.130	1.88	0.178
	H_S	**215.89**	**< 0.001**	0.09	0.770	0.26	0.746
AP	CTI	**84.10**	**< 0.001**	0.12	0.727	1.86	0.169
	CMI	**50.12**	**< 0.001**	0.60	0.446	1.12	0.335
	H_S	**173.84**	**< 0.001**	0.07	0.795	1.71	0.197
Comp.	CTI	**68.99**	**< 0.001**	3.05	0.094	0.30	0.678
	CMI	**67.75**	**< 0.001**	3.42	0.077	1.51	0.233
	H_S	**264.05**	**< 0.001**	0.05	0.823	2.03	0.081

Again, stability displayed significant effects for all SDA measures, but, unlike the COP time series, no effects were clear for the cognitive task or interaction. This means that the differences between auditory noise and an auditory discrimination task had no measurable effects on the closed and open-loop processes of the participants in this study.

Overall Workload Measures

NASA-TLX and Heart Rate Variability. The results of the weighted NASA-TLX and HRV ANOVAs are shown in Table 13.

Table 13. Main effects and interactions from NASA-TLX and HRV measures (α = .05). Significant effects are bolded.

	Stability		Cognitive Task		Interaction	
	F-value	p-value	F-value	p-value	F-value	p-value
NASA-TLX	**37.45**	**< 0.001**	**17.99**	**< 0.001**	3.12	0.066
HRV	3.06	0.067	**20.93**	**< 0.001**	0.77	0.468

Both NASA-TLX and Heart Rate Variability show significant main effects of stability. NASA-TLX also showed a main effect of cognitive task (HRV was close but not significant) but neither showed interactions. The differences across conditions for the weighted NASA-TLX scores are depicted in Figure 16.

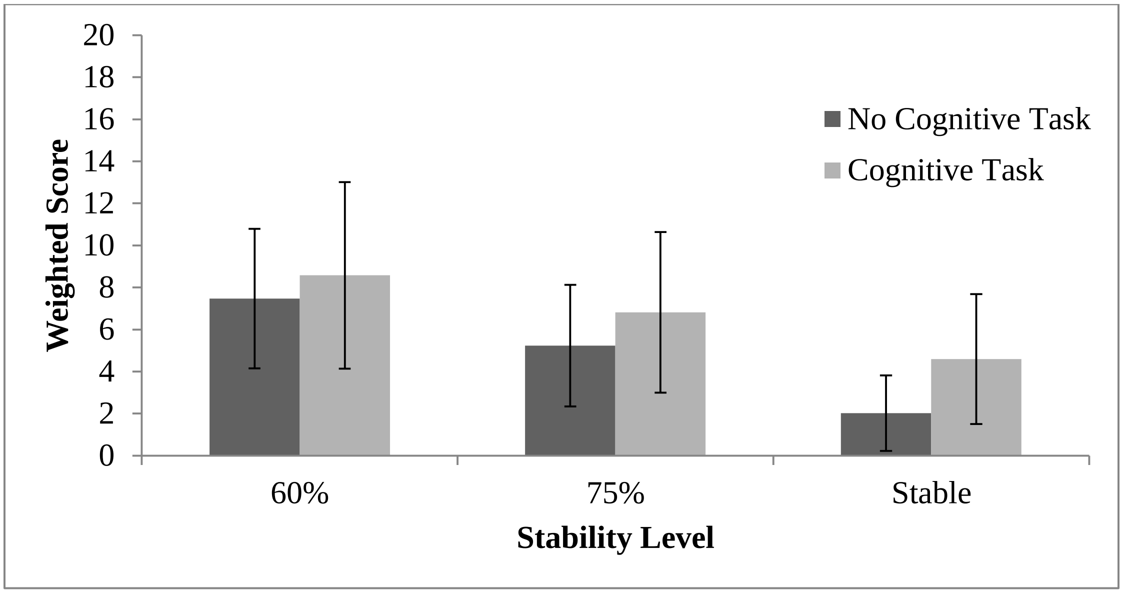

Figure 16. NASA-TLX weighted scores comparing task vs. no task for each of the different stability levels. Errors bars depict standard deviation.

The differences in the NASA-TLX scores show that both stability and task make a distinct difference in subjective workload ratings. Post-hoc paired t-tests showed that only the differences between task and no task in 75% and perfectly stable were significant ($t = -3.60$, $p = 0.002$; $t = -4.26$, $p < 0.001$, respectively), whereas 60% did not attain significance, possibly due to larger between-subject variability ($t = -2.00$, $p = 0.058$). In all conditions, however, the addition of the task increased the mean, as did increasing platform instability.

To better understand the NASA-TLX results, we decided to analyze the individual scales to determine what differences existed. A repeated measures MANOVA using Wilks' Lambda was run first to determine what main effects and interactions existed for the scales as a whole. Based on the significant results main effects in stability ($F = 8.45$, $p < 0.001$) and task ($F = 7.42$, $p = 0.001$) and their interaction ($F = 3.61$, $p < 0.001$), all three models merited further analysis.

Based on these results, individual ANOVAs were run to determine individual effects. These analyses are shown in Table 14.

Table 14. Main effects and interactions from NASA-TLX scales (α = .05). Significant effects are bolded.

	Stability		**Cognitive Task**		**Interaction**	
	F-value	p-value	F-value	p-value	F-value	p-value
Mental Demand	**9.23**	**0.001**	**45.37**	**< 0.001**	3.21	0.056
Physical Demand	**70.60**	**< 0.001**	2.13	0.130	0.84	0.418
Temporal Demand	**5.85**	**0.006**	**23.05**	**< 0.001**	< 0.01	0.998
Performance	**18.95**	**< 0.001**	0.25	0.626	2.97	0.062
Effort	**41.53**	**< 0.001**	**6.23**	**0.021**	**7.13**	**0.002**
Frustration	**13.90**	**< 0.001**	2.02	0.169	0.15	0.857

All six scales showed significance for stability, which is especially interesting for the mental demand scale. Mental demand, temporal demand, and effort showed significance for the cognitive task as well, with effort also having a significant interaction. To better understand these effects, we graphed the three scales with at least two significant main effects and conducted post-hoc paired t-tests for effort comparing task vs. no task for each level of stability (Figure 17, Figure 18, and Figure 19 as well as Table 15).

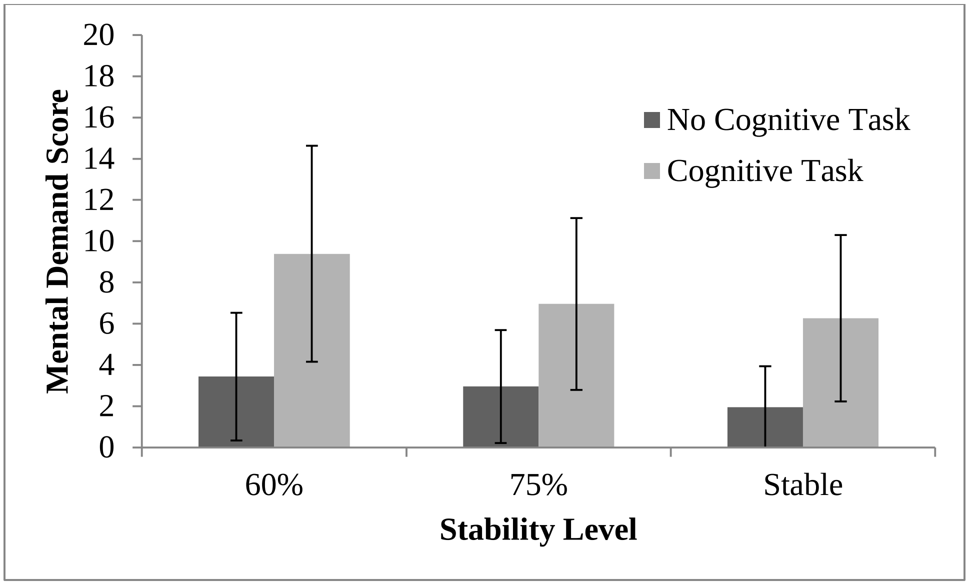

Figure 17. NASA-TLX Mental Demand scale scores comparing task vs. no task for each of the different stability levels. Errors bars depict standard deviation.

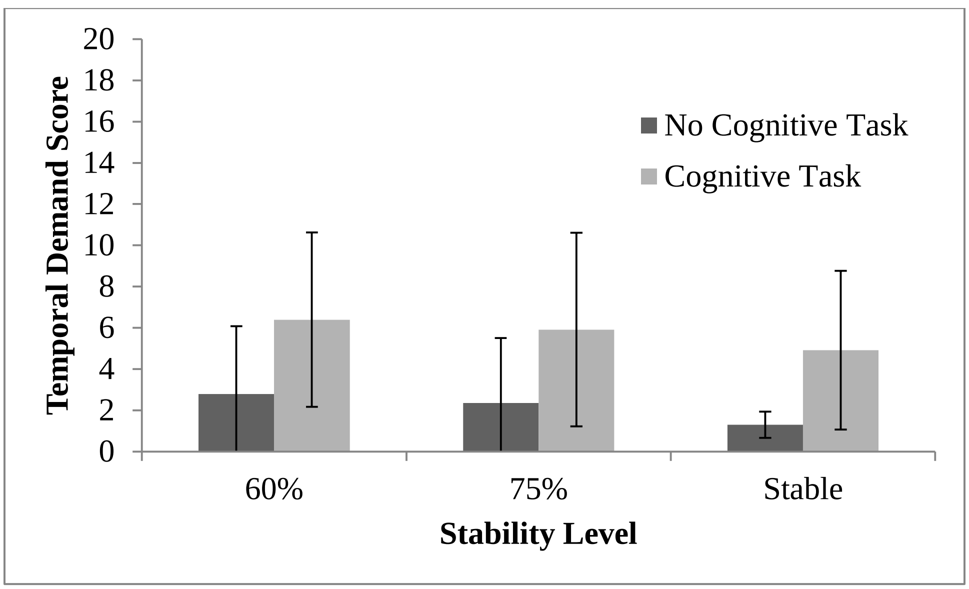

Figure 18. NASA-TLX Temporal scale scores comparing task vs. no task for each of the different stability levels. Errors bars depict standard deviation.

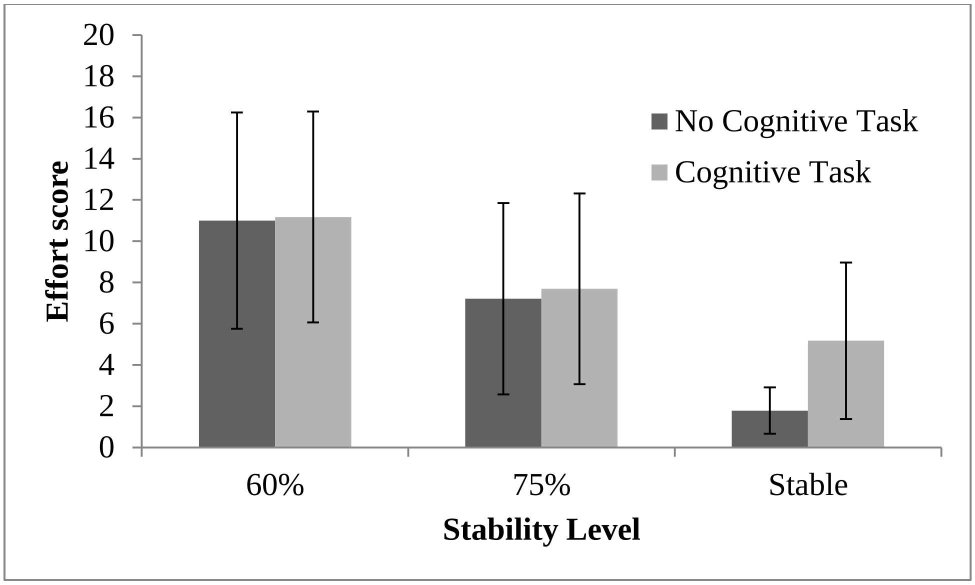

Figure 19. NASA-TLX Effort scale scores comparing task vs. no task for each of the different stability levels. Errors bars depict standard deviation.

Table 15. Post-hoc analyses for NASA-TLX Effort scale. Significant effects are bolded.

	Mean	Std. Dev.	t-value	p-value
No Cognitive Task 60%	11.00	5.12	0.217	0.830
Cognitive Task 60%	11.17	5.00		
No Cognitive Task 75%	7.13	4.56	0.996	0.329
Cognitive Task 75%	7.83	4.57		
No Cognitive Task Stable	1.75	1.11	**4.557**	**< 0.001**
Cognitive Task Stable	5.42	3.90		

Mental and temporal demand show trends in both stability and cognitive task, with the addition of the auditory task and the addition of instability increasing both. Effort shows the same trends, albeit largely driven by the significant difference between cognitive task and no cognitive task in the stable condition.

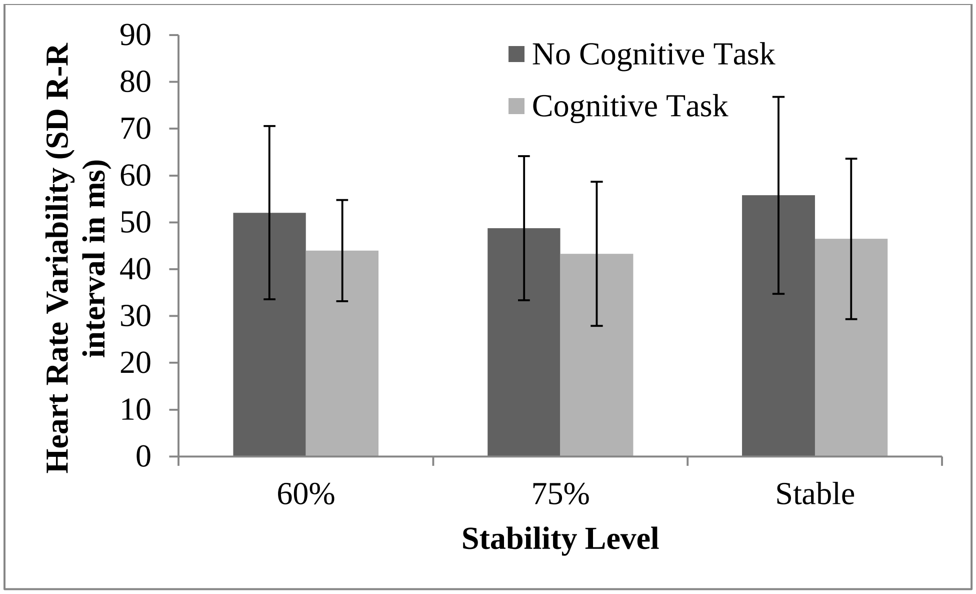

Figure 20. Heart rate variability comparing task vs. no task for each of the different stability levels. Errors bars depict standard deviation.

Post-hoc results for HRV were simpler, as shown in Figure 20, with significant differences between task and no task found in all three stability levels, 60%, 75%, and perfectly stable ($t = 3.30$, $p = 0.003$; $t = 2.81$, $p = 0.010$; and $t = 3.21$, $p = 0.004$, respectively). The cognitive task, then, was associated with a drop in HRV.

EEG Results. ANOVA main effects and interactions are shown for the four electrodes chosen in Table 16.

Table 16. Main effects and interactions from Alpha/Theta activity (α = .05). Significant effects are bolded.

		Stability		Cognitive Task		Interaction	
		F-value	p-value	F-value	p-value	F-value	p-value
Alpha	P7	**6.71**	**0.003**	2.01	0.170	0.31	0.733
	P8	1.99	0.148	**9.20**	**0.006**	2.31	0.111
Theta	Fz	1.39	0.258	0.08	0.786	0.35	0.619
	FCz	3.48	0.064	< 0.01	0.963	0.14	0.790

To further explore the main effects of stability and cognitive task, we graphed the difference scores of the two electrodes that showed main effects to determine what trends existed (Figure 21 and Figure 22).

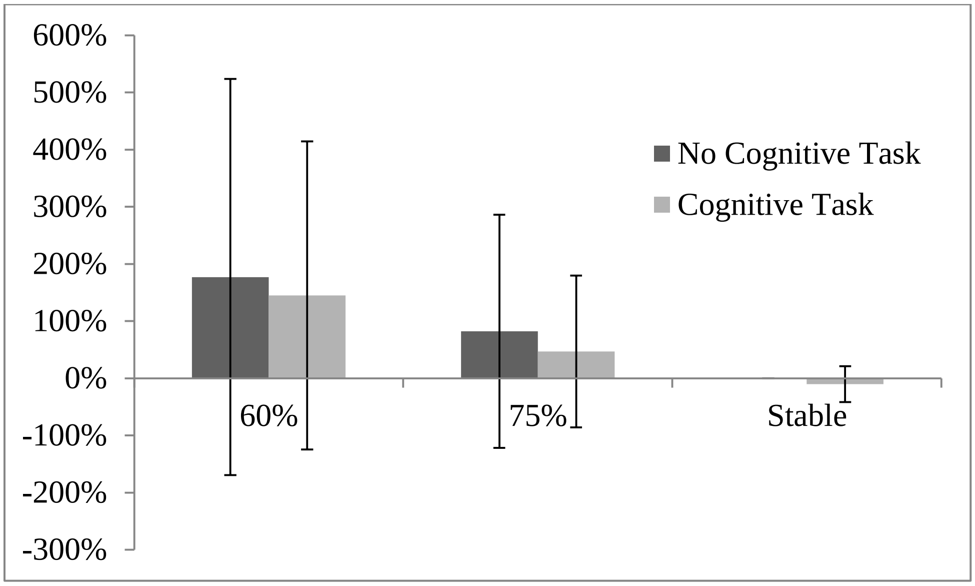

Figure 21. P7 Alpha power differences comparing task vs. no task for each of the different stability levels. Errors bars depict standard deviation.

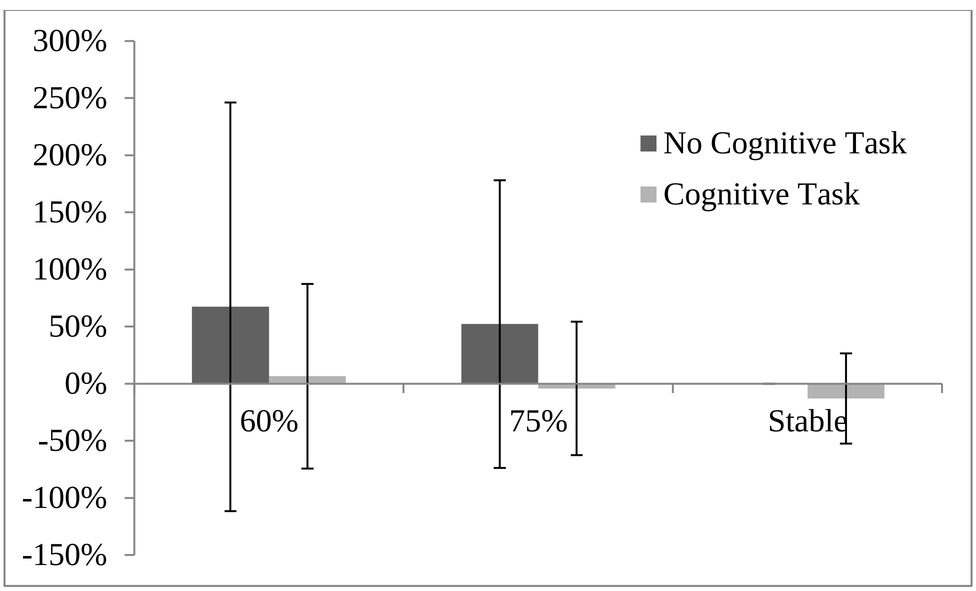

Figure 22. P8 Alpha power differences comparing task vs. no task for each of the different stability levels. Errors bars depict standard deviation.

The trend for both electrodes is that alpha power increases with increased instability, but decreases when a task is added. The significance of this effect differed from the side of the brain, with the left side showing a significant difference between stability conditions and the right side showing a significant difference between task and no task.

To determine whether the three workload measures were similar, we ran bivariate correlations on the NASA-TLX scores, HRV values, and EEG data. No significant correlations between measure types were found.

Discussion

The goal of this research was to quantify the effects of the cognitive/postural dual task environment on overall workload. The varied nature of the different measures give credence to the importance of looking at many different types of workload measure to see how each is affected by the same sets of experimental manipulations.

Summary of Findings

At the task level, we saw no effect for either response time or accuracy of the cognitive task; participants performed similarly across all levels. The presence of the cognitive task, however, aided balance in the medio-lateral direction in the unstable conditions, lending credence to the idea that the two tasks do not have strictly additive demands. Given this effect, we might expect to see decreased workload in the three overall workload measures when the auditory task was present, as postural performance was better.

The NASA-TLX and Heart Rate Variability measures did not support this hypothesis. NASA-TLX consistently showed increased workload for both presence of the cognitive task and greater levels of platform instability. There was no interaction, however; both tasks increased subjective workload but the combination did not create differing results. Delving further into individual scale results; the physical demand reported by participants was only sensitive to physical differences, whereas mental demand was sensitive to both stability and the cognitive task. Furthermore, effort was not affected by cognitive task while the participant was unstable; it was only when the platform was completely stable that the addition of the cognitive task significantly increased effort.

The HRV results differed; whereas the addition of a cognitive task did indeed show a drop in HRV (expected, as HRV has been shown to drop in response to increased mental workload (Hankins & Wilson, 1998)), it was not significantly affected by postural stability (although the effect was close to significant), suggesting that increased postural load may cause a different effect than cognitive workload. Again, the lack of an interaction suggested that the combination of the tasks did not have synergistic effects (or that such effects have very small effect size).

The EEG results mirrored, in a way, the HRV results. Again, the expected decrease in alpha waves (shown to be correlated to mental workload (Gevins et al., 1998) was found when the auditory task was added, but alpha wave activity generally increased with more difficult postural conditions. This is again a conflicting result, suggesting that alpha wave activity in posturally unstable situations may be managed by a mechanism other than mental workload.

Conclusions

These results underscore the need to understand the similarities and differences between different measures of workload and how different measurements may result in different conclusions. Based on our results, it is clear that cognitive and physical tasks do interact in a complex way, causing higher levels of subjective workload coupled with better performance in the postural task. The lack of a correlation between the three different measures of overall workload was especially concerning, as it shows the significantly differing results that can be gleaned based on the way data is collected.

There were, however, themes across the data. All of the separate measures of overall workload responded in the expected manner when a cognitive task was added; EEG alpha activity decreased, HRV decreased, and NASA-TLX overall and mental demand scores increased. The addition of the postural task was more complex, with some measures indicating increased workload (NASA-TLX), some indicating decreased workload (EEG, COP measures), and some not showing a significant effect (HRV). These similarities and differences speak to the importance of the collection methodology and the danger of drawing conclusions based solely on one type of data.

The differences between the performance and workload measures might be explained by a mediating variable, arousal. In this case, the addition of the auditory task may be increasing both workload and arousal, causing increases in both the demand on the system and its capacity (Yerkes & Dodson, 1908). This would mean that measures of mental workload might increase (as they generally did) while measures of performance (a measurement of capacity-demand) would decrease (which occurred for the postural task). This possibility merits further study, as arousal was not measured outside of trying to control it with screening procedures.

Further research should expand on the types of tasks measured to determine whether similar differences exist across different cognitive tasks or whether the auditory/postural dual-task structure used in this experiment is unique. Designers looking to avoid mental overload should take care when using only one of the aforementioned analysis types, as they may be collecting an incomplete picture of the multitasking environment and making incorrect assumptions about how the operator is interacting with the system. For example, the task performance measures from this study suggest that auditory tasks aid unstable balance, whereas the NASA-TLX and HRV results both correlated with higher workload. Using only one of the measures would have generated an incomplete view of the system.

Those managing the design of complex systems containing both cognitive and postural tasks should be wary of the way they evaluate the overall workload of the operators. Looking at the performance of the individual tasks is insufficient in determining how the operator interacts with the series of tasks they manage; analyses must be done at the system level to determine the interactions of the two different tasks, both at the physiological and psycho-social levels. The auditory task we chose was matched with a postural benefit but showed workload increases in the overall measures, something that might give pause to adding more tasks in high-demand situations. Regardless, the focus should be on the overall system, not individual task performance.

CHAPTER IV: The Effects of Types of Cognitive Demands on Overall Workload in a Postural/Cognitive Dual Task Environment

Abstract

Multitasking environments pitting cognitive and physical tasks against each other are common and have a high chance of being dangerous. Furthermore, the demands of multiple tasks at once can interact, creating complex environments in need of measurement of overall workload. In this study we paired a breadth of cognitive tasks with a postural balance task in a dual task protocol to measure overall workload in a variety of ways: subjective (NASA-TLX) and physiological (Heart Rate Variability and EEG). The difficulty and spatial nature of the cognitive task were what decreased cognitive but increased postural performance. The results of the workload measures were varied, most showing an increase in workload with the cognitive tasks and some showing an effect of increased cognitive difficulty. The differences between tasks show the necessity of measuring overall workload; preferably in more than one manner.

Introduction

Distracted driving, installing parts on an assembly line, and riveting structural beams into place on a construction site all share two important features. One, they all require the operator to multitask, interacting with two or more cognitive or physical tasks at once. Two, they are all potentially dangerous, oftentimes deadly. In 2011, distracted driving accounted for 10% of crash fatalities and over three hundred thousand injuries (NHTSA, 2013). In that same year, non-fatal injuries in manufacturing and construction reached over half a million and almost two hundred thousand, respectively (BLS, 2012).

Multitasking increases workload (Altmann & Trafton, 2002; Kahneman, 1973; Wickens & McCarley, 2008), taking up large amounts of a limited pool of mental resources (Navon &

Gopher, 1979). When this workload reaches the limits of the mental system, workers are overloaded and performance degrades (Kahneman, 1973). These degradations can result in slow and halting work as the operator struggles to keep abreast of the tasks, or when rework errors occur and have to be solved. This is a compounding issue; as poor work is passed on to other processes, and, ultimately, poor system functioning results because of the combined effects.

Overload is not just concerning in a productivity sense, it can have disastrous effects. Multitasking overload contributed to the deaths of 290 people aboard Iran Air Flight 655 when an AEGIS cruiser mistook them for a fighter jet and shot them down (Cooke & Durso, 2007). These issues often go unnoticed or attributed to "operator error", as overload may happen when expectations shift unexpectedly and the operators are unprepared (Cooke & Durso, 2007; Wickens & McCarley, 2008).

Even when not resulting in a catastrophe, overload must be avoided across many different jobs spanning many different hazards. As almost every operator multitasks, all are susceptible to overload. For example, maintaining posture is an important task for many professions. Errors in balance can lead to falls to the floor or from heights, contact with dangerous or hard surfaces, or loss of control of machinery or tasks performed. If posture were to contribute to workload, it could contribute to and be affected by overload, possibly causing a higher error rate and unsafe conditions even when the individual tasks being performed are themselves assumed to be safe.

The Synergy of Multiple Tasks

There are two possible ways that two tasks interact in the brain. The first is that the demands of two tasks are purely additive; task one's demands plus task two's demands equals the overall demand of the system. If this were true, operators would be able to handle both tasks up until the point where they run out of mental resources, causing performance on one or both tasks to suffer (Kahneman, 1973). The alternative is that there is some interaction between tasks, something that makes the demands of the overall system different than just the demands of the individual tasks. In this case, depicted in Figure 23, more would need to be known to understand the overall demand on the system.

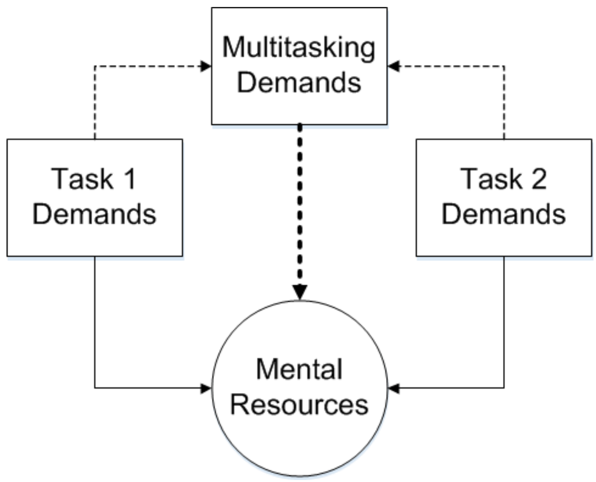

Figure 23. A simplified model of the demand sources on mental resources during dual-tasking.

The answer to this comes with a better understanding of the term “multitasking”. The use of “multitasking” when discussing human behavior is a slight misnomer. Humans do not interact with multiple tasks simultaneously, they interact with one task and then another in a serial fashion. This means that they have two quickly switch between tasks in active attention, requiring some set of mental resources to be busy focusing on these actions (Altmann & Trafton, 2002; Wickens & McCarley, 2008). Furthermore, as this switching occurs, characteristics of the tasks that are similar can interfere, requiring more effort to tell the tasks apart. (Fitch et al., 2011; Wickens, 1984).

This need to quantify the demands on multitasking itself makes a measure of overall workload extremely important to understanding the multitasking system. Overall workload is defined as the workload resulting from the demands of all tasks combined with those implicit demands of the multitasking system itself. Previous studies have taken the view that the demands are additive, that the effects of each task can be seen on the performance of the other (Woollacott & Shumway-Cook, 2002). The associated inference is that the demands are additive, performance decrements happen when that limit is reached, and that the implicit demands of multitasking can be measured through the drop in performance of one or both tasks (Kahneman, 1973). There are indeed finite resources, but they are differentiated, allowing humans to process different tasks with different resource pools (Navon & Gopher, 1979; Wickens, 1984). Overall workload, then, must be quantified as another variable above and beyond individual task performance to effectively characterize how the two tasks interact.

Different Demands, Different Results

One of the most difficult parts of describing dual-task environments is the differences found based upon the tasks and protocols used, as well as the measures taken and the way the data is analyzed (Fraizer & Mitra, 2008; Woollacott & Shumway-Cook, 2002). Many studies choose two tasks, compare them, and then use one or possibly two measures of performance, making larger generalizations about what those results mean (Davis et al., 2002; Riley et al., 2003; Swan et al., 2007). Because of this, cognitive and physical tasks have been shown to affect each other in different ways, with many different aspects of the methodology and analysis identified as important factors worth consideration (Fitch et al., 2007; Woollacott & Shumway-Cook, 2002). For example, the difficulty of a given postural task affects balance (Moghadam et al., 2011; Riley et al., 2003), as does the type of cognitive demand (e.g. spatial, verbal, or memory) (Dault et al., 2001; Kerr et al., 1985; Maylor et al., 2001).

Measurement type(s)/experimental methods also seem to cause differences; as results found in some types of postural measurements may not be replicated in others (Collins & De Luca, 1993; Moghadam et al., 2011; Riley et al., 1999). For example, results seen in simple center-of-pressure path measures may not be replicated in more complex analyses such as stabilogram diffusion analysis (Miller, 2012).

Overview of the Current Study

The goal of this research is to characterize the differential effects of different task demands using overall workload measures of cognitive/postural dual-task environments. To do this, we paired a common postural task (wobble chair) at different levels of difficulty with a set of different cognitive tasks of different demand types, modalities, and difficulties. This variety of demands, as well as several measures of performance and overall workload, will help us to better understand how cognitive and postural tasks interact and the effects they have on overall workload measures.

We utilized two types of measures of overall workload, physiological and self-report. Electroencephalography (EEG) and heart rate variability (HRV), both physiological measures, have been shown to help in the understanding of workload (Berka et al., 2007; Hankins & Wilson, 1998; Kothe & Makeig, 2011; Krause et al., 1996; Shaw et al., 2013; Zarjam et al., 2013). EEG is a measure of brain activity (Schwarz-Ottersbach & Goldberg, 1986) and has previously also been used to understand and postural control (Sipp et al., 2013; Slobounov et al., 2005), making it a clear choice to help understand overall workload in a multimodal setting. HRV is a common physiological measure of mental workload (DiDomenico & Nussbaum, 2011) and a viable candidate for dual-task measures.

NASA-TLX, a self-report workload measure, will also be employed. NASA-TLX assesses six different aspects of workload found to contribute to overall workload: mental demand, physical demand, temporal demand, performance, effort, and fatigue (Hart & Staveland, 1988). NASA-TLX is a very commonly used workload measure and provides a non-invasive way to quickly assess subjective ratings of workload during of immediately after tests for both cognitive and physical tasks (Mehta & Agnew, 2011). It also addresses both cognitive and physical stresses separately as well as measures that might be affected by either or both. Together, these two measures provide a breadth of knowledge regarding overall workload, how it affects both brain function *and* subjective experience of the operators.

Based on previous research, we hypothesize that increased difficulty of either cognitive or physical tasks will increase the measures of overall workload. Tasks with spatial components will aid balance, whereas those without spatial components will hurt it. Different measures of overall workload should correlate; as they all purport to measure the same thing. Based on the results, we hoped to better explain why studies seem to get conflicting or inconsistent information about dual-task cognitive/postural studies as well as aid in showing how different measures depict the effects in different ways.

Method

Participants

Twenty participants took part in this study (12 males, 8 females). The participants were recruited from the Virginia Tech community and screened based on several criteria: age (18-30), handedness (right-handed only), no history of lower back pain (assessed using the Roland-Morris Low Back Questionnaire (Roland & Morris, 1983)), greater than 20/40 vision (assessed using a modified Snellen eye chart (Snellen, 1866)), and no recent use of stimulants/depressants. Participants were also asked to fill out the Morningness-Eveningness Questionnaire (Horne & Ostberg, 1976) before scheduling their appointment and scheduled as close to their peak time as possible to control for arousal's effect on balance and brain activity (Horslen & Carpenter, 2011). Because one task also used auditory stimuli, participants were played all possible stimuli during practice to determine whether all could be heard. Demographic data for the participant sample is shown in Table 17.

Table 17. Demographic and anthropometric data for the sample.

	Mean	Std. Dev.
Age	22.95	2.65
Height (in.)	69.20	4.58
Weight (lbs.)	162.35	31.57

Design

This study was conducted within-subjects; each participant received all possible task conditions over their time in the study. There were two independent variables, the difficulty of the physical task (60 and 75% stability, as well as perfectly stable) and the cognitive task presented (Simple Response, Choice Response, Auditory Discrimination, Visual Search, or None). These conditions were fully crossed, three physical conditions by five cognitive conditions for a total of fifteen different trials. Trial presentation order was counterbalanced using a latin square to control for order effects. Neither gender nor order was significant for any dependent variable.

During each trial, three different types of dependent variables were collected, cognitive performance data (response time and accuracy), physical performance data (forces and moments in three-dimensional space), and overall workload data (NASA-TLX self-report subjective workload ratings, heart rate variability, and selected EEG activity). Postural data were still collected during perfectly stable trials, as the participant still sat upon the force plate.

Materials and Apparatuses

The materials and apparatuses for this study were largely divided into three parts; the cognitive tasks, the postural task, and the workload collection materials. Each type is discussed next, including the materials used, the tasks created, and the justifications for decisions made.

The Cognitive Tasks. The cognitive tasks used in this study were selected to represent a wide variety of task demands, including demands that have previously been shown to have effects on posture. The four tasks used in this study were a simple reaction time task, a choice response time task, an auditory discrimination task, and a visual search task. All four tasks were presented using the software E-Prime 2 (PST, 2010) through the speakers and screen shown in Figure 24. The auditory discrimination task utilized the speakers, whereas the rest were presented entirely on the screen. All tasks were presented for exactly 5 seconds, with new individual responses being presented somewhere randomly within the 5-second span to avoid participants being able to predict when the task was to appear. E-Prime 2 collected accuracy and response time data for each trial.

Figure 24. The participant interacting with a task. Note the screen and the speakers below it.

The simple reaction time task was designed to create a baseline for the amount of information presented to the participant. In this task, for each individual response, the participant was presented with a focus cross for between 1 and 3 seconds. Once the random interval ended, the focus cross turned into an X. The participant was instructed to respond by pressing the left mouse button as fast as possible. Reaction time was recorded.

The choice response time task was designed to include two different additions that have been shown to have a possible effect on balance. First, the need for a choice increased the implicit difficulty of the task, increasing the chance of overload. Second, the responses the participants were asked to provide were on different areas of the screen, creating a spatial aspect of the task, something that has been shown to benefit balance (Kerr et al., 1985). In this task, the same focus cross is provided to the participants, but at the end of the interval, the X is randomly presented either on the left or on the right. The participant pressed the left mouse button if the X was on the left, and the right button if on the right.

The auditory discrimination task was designed to explore modalities outside of the interaction of vision and balance, as vision has been shown to have a stabilizing effect and changing visual stimuli may change that effect (Chagdes et al., 2009; Easton et al., 1998; Raper & Soames, 1991; Stins et al., 2009). Secondly, the auditory discrimination task provided a non-spatial task that was similar to the choice response time task. In this task, the focus cross was presented throughout the trials. Once in each 5-second window, a pair of tones would be played. Once the second tone had started, the participant was asked to press the left mouse button of the second tone was higher in pitch than the first and the right if lower. The tones (500, 1000, 2000, and 4000 Hz) were played binaurally in a free field at equal loudness of 70 phons.

The final task, the visual search task, was designed to provide a more complex information requirement for the participants. While the response complexity was limited by the response device (two-button computer mouse), the complexity of the stimuli were now. To then end, we created a conjunctive search task that would require greater effort to determine the correct response and see how that changed their behavior. By nature of being a visual search task, the visual search task had a spatial component, requiring participants to view the whole screen to determine the answer. It provided, then, a comparison against the choice response time task; between simple and complex stimuli. In this task, the participants were first presented with a focus cross. After the random interval, a field of blue squares and orange triangles appeared, much like in Figure 25. The participant was instructed to press the left mouse button if an orange square was present (and the right if it was not).

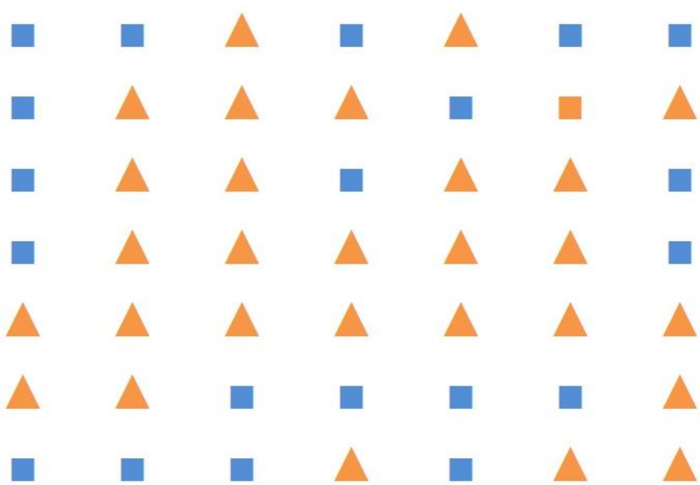

Figure 25. Search stimulus for the visual search task. The orange square is row 2, column 6, near the upper right corner.

Together, these cognitive tasks provided a variety of conditions to compare against each other in the context of dual-task workload. Comparisons and contrasts can be made because of the similarities (spatial tasks) or differences (information complexity/modality) between the tasks to discern which aspects of the tasks might be creating the effects seen in the results.

The Postural Task. The postural task was administrated through the use of the wobble chair, a platform designed to measure and model trunk stability by generating an unstable seated surface that could be normalized to individual participants (Lee & Granata, 2008; M. L. Tanaka et al., 2010). The wobble chair is shown in Figure 26. While seated in the chair, the participant is buckled in and rests their feet on the footrest (which is attached to the chair pan and moves with the body). The chair is calibrated to each participant individually to ensure the participants center of mass is over the top of the pivot of the chair and that the difficulty is normalized by placing the springs in positions relative to the height and weight of the participant (Hendershot, 2012).

Figure 26. The wobble chair apparatus.

The major benefit of this platform is that it allows for manipulation of the difficulty of the postural task through the sliding of the springs that support the chair pan. Once calibrated, the springs can be set to provide different levels of percent gravitation gradient, that is, the percent of the stability that the participant needs provided by the chair. The conditions used in this experiment were 60% (60% stability provided by the chair, 40% by the participant), 75%, and perfectly stable with no wobble. 60% was chosen because it was near the limit of healthy participants (Hendershot, 2012) and 75% provided a midpoint and comparison to other similar studies.

The data from the chair was collected at 1000 Hz by an AMTI force plate placed under the springs. The force place collected force and moment data in three directions, antero-posterior, medio-lateral, and superior-inferior. These data were collected using National Instruments' LabVIEW platform (Elliott et al., 2007) and translated into center of pressure measures, discussed later.

Overall Workload Collection. As the goal of this study was to understand the different overall workload characteristics of the different dual-task interactions, we wanted to utilize several different measures of overall workload so as to show the differences between methods and possible sources of confusion and misattribution of effects in previous studies. To that end, we chose three different measures, the NASA Task Load Index (NASA-TLX) self-report workload scale, heart rate variability (HRV), and electroencephalography (EEG).

The NASA-TLX scales are designed to assess workload in a wide variety of contexts irrespective of task type or modality (Hart & Staveland, 1988). The procedure involves asking the participant to rate their workload on six different scales (Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration) after each trial. These ratings are combined with a weighting scale created by asking the participant at the beginning of the trials to compare each pair of scales and choose the one that they think best measures overall workload.

This combination creates a weighted score that is used to characterize overall workload. NASA-TLX can be administered using a computer, but in this study we used the pen and paper variety.

Heart rate variability is a measure of the variations in the inter-beat interval of the heart rate; that is the difference in milliseconds between the same points on consecutive beat cycles. The most common measure of HRV is SDNN, the standard deviation of the inter-beat interval (defined as the time between successive R-wave peaks in an electrocardiogram). SDNN has been shown to correlate negatively with mental workload; as mental workload increases, SDNN decreases (DiDomenico & Nussbaum, 2011; Hankins & Wilson, 1998). To take measurements of HRV in this study, we used a Polar RS800X exercise watch, a commonly used platform in simple HRV analysis (Quintana et al., 2012).

EEG data are another common measure of mental workload. Activity in certain frequency bands has been shown to correlate with different workload levels, such as a decrease in alpha wave activity in the parietal region and an increase in theta wave activity in the frontal region (Gevins & Smith, 2003; Gevins et al., 1998). The EEG mechanism used in this study was Cortech Systems' MIND-Fi cap, a 64-electrode wireless EEG system designed to be used with LabVIEW for data collection and analysis. The map of the 64 electrodes is shown in Figure 27. Data from four electrodes were collected at 512 Hz and analyzed, P7 and P8 in the parietal lobe for alpha activity and Fz and FCz in the frontal lobe for theta activity. These electrodes were chosen based on previous studies (Gevins & Smith, 2003) as well as power analyses in the regions to determine where the center of power band activity was emanating.

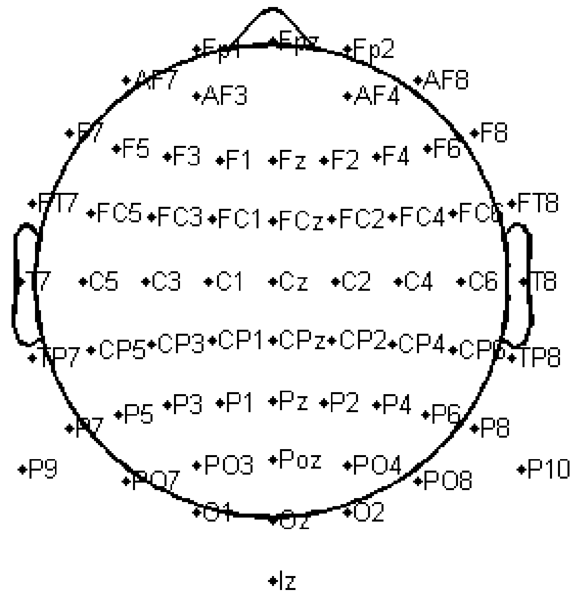

Figure 27. Channel map for the Mind-Fi EEG cap. Diagram created using EEGLab (Delorme & Makeig, 2004).

Procedure

The study took place over three hours in one session. Before the session, the participant was asked to fill out are report the results of the Morningness-Eveningness Questionnaire (Horne & Ostberg, 1976) to determine their optimal time for participating. When they arrived, the participants were briefed on the study and asked to sign a consent form. They then completed several demographics and abilities tests, including measuring height and weight, the Snellen eye chart (Snellen, 1866), the Reverse Digit Span memory test (Wechsler, 1981), and the Digit Symbol Substitution perceptual speed test (Wechsler, 1981). After these were complete, the EEG cap and HR monitor were explained and applied to the participants to give them time to get used to the apparatus.

The wobble chair was then calibrated to the participant, centering the participant and preparing the apparatus for practice. Practice consisted of five two-minute sessions, one each for each of the different cognitive tasks and a final one practicing the postural task. Participants were asked to be as stable as possible for all trials and to respond as fast and as accurately as possible during the cognitive tasks. While the cognitive tasks were practiced the chair was locked. If the participant was uncomfortable with their performance after a task, they were allowed to take another two-minute practice trial. After all five practice trials, the participants were asked to read the definitions of all six NASA-TLX scales and to complete the weighting procedure using flashcards.

After a short break, participants were then briefed on the number and nature of trials: fifteen trials, five each (one of each different cognitive task as well as one with no task) at three different levels of stability (60%, 75%, and stable). In between each trial, the participant took a break of at least one minute to allow the trunk muscles to rest, the computer to finish processing samples, and the participant to fill out a NASA-TLX scale sheet. The definitions of each scale were left available for the participants to review during ratings. Participants were granted a longer break for water or the restroom if needed. After all fifteen trials, the participants were debriefed, compensated, and thanked.

Data Preparation and Analysis

Cognitive Task Data. Response time and accuracy data from the four cognitive tasks were collected and aggregated to give a trial-level average (percent correct for accuracy, arithmetic mean time for response time). The reason that both response time and accuracy were measured and analyzed is because they form a tradeoff; participant might mentally prioritize one to the detriment of the other (Wickelgren, 1977). Repeated measures ANOVAs ($\alpha = .05$) were run on response time and accuracy to determine main effects of task type and stability, as well as the interaction of both. All data were tested using the Shapiro-Wilk test ($p > 0.05$) to determine normality. Results that violated sphericity were Greenhouse-Geisser corrected. Task type effects were expected, as the tasks were designed to be different. Follow-up pairwise t-tests were planned where appropriate.

Postural Task Data. The data collected from the force plate used to measure postural performance were first converted into center of pressure data. Center of pressure measures are commonly used in characterizing and quantifying postural performance (Prieto et al., 1996). This method involves using force and moment data to create a time series of points that depict in two-dimensional space where the center of pressure of the participant was centered at every sample. Once these COP data are obtained, they were demeaned, allowing the deviations to emanate from the central point of the participant's balance. To remove the effects of starting and ending of a trial, the first 10 and the last 5 seconds were not analyzed. A graph of these points showing the path of the participant over a trial is called a stabilogram. An example stabilogram is shown in Figure 28. From these points, we derived velocity and root-mean-square (RMS) distance away from the mean in both the medio-lateral (left to right) and antero-posterior (front to back) directions for each trial. These data were then analyzed using two-way repeated measures ANOVAs ($\alpha = .05$) crossing cognitive task type and stability to determine what types of tasks affected balance and in what directions. Follow-up analyses were done where appropriate.

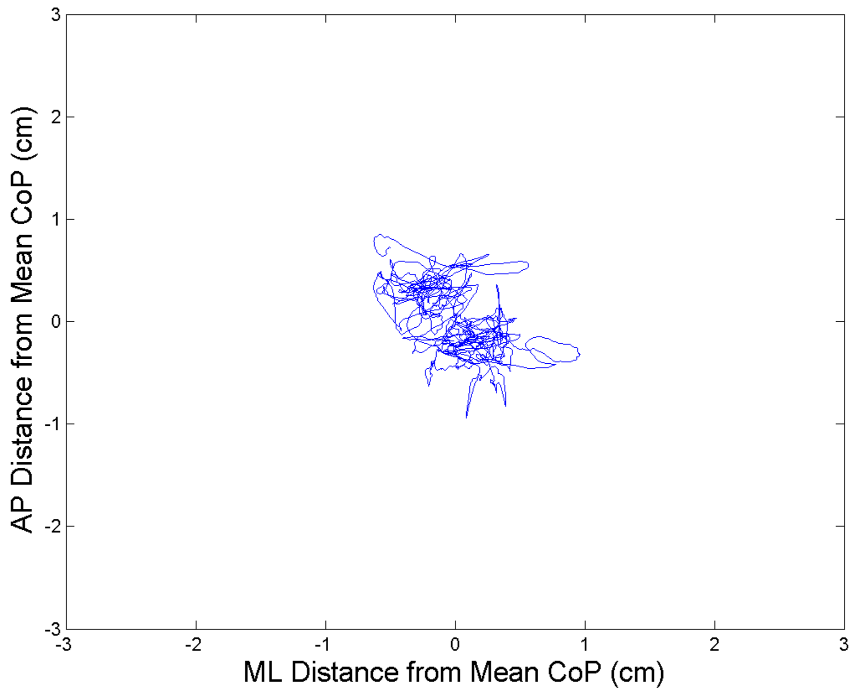

Figure 28. Example stabilogram showing the sway path of a participant. Antero-posterior distance is given along the y-axis and medio-lateral along the x-axis.

Measures like this are commonly used to describe balance both by itself and in the context of cognitive tasks (Fraizer & Mitra, 2008; Woollacott & Shumway-Cook, 2002).

Another common way of quantifying posture is to look at the open- and closed-loop systems responsible for keeping stable. This is managed using COP time series data and is known as Stabilogram Diffusion Analysis (SDA) (Collins & De Luca, 1993). SDA describes the two competing mechanisms that control posture, a short-term open-loop process that corrects small jitters and shifts and a longer-term one that corrects more consciously deliberate sways. The stability of the overall system can be described using aspects of this analysis, depicted in Figure 29. The three measures most commonly used to describe postural performance are the critical time interval (the x value of the critical point on the graph), the critical magnitude interval (the y value of the critical point on the graph), and the short term slope of the log-log graph, known as the scaling exponent (H_s) (Moghadam et al., 2011; Riley et al., 2003).

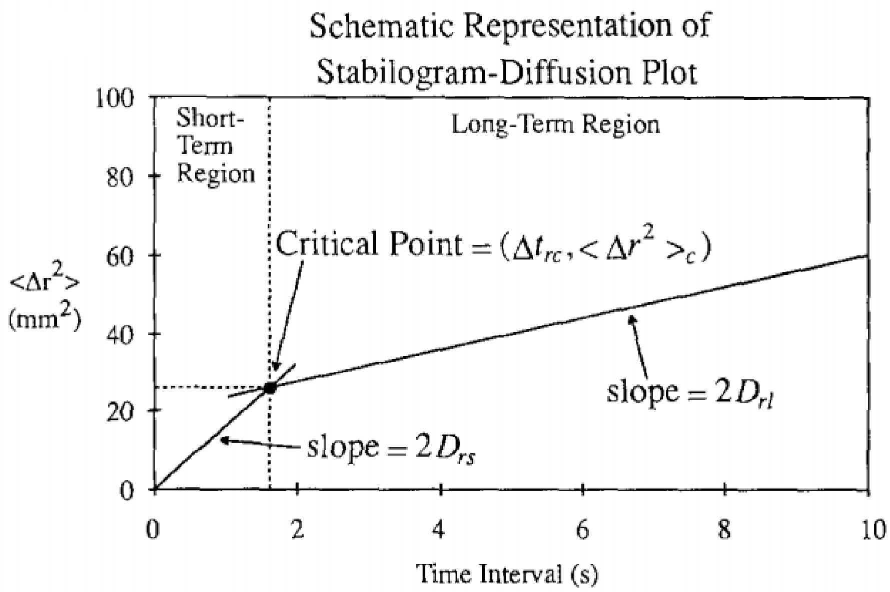

Figure 29. A schematic representation of an SDA plot depicting the two postural processes and associated measures. Reprinted from Collins and De Luca (1993) with permission.

To understand the open- and closed-loop processes in our study, we ran SDA on each trial and analyzed the three aforementioned variables for the medio-lateral and antero-posterior directions. These data were analyzed using two-way repeated measures ANOVAs ($\alpha = .05$) crossing cognitive task type and stability. All data were tested using the Shapiro-Wilk test ($p > 0.05$) to determine normality. Results that violated sphericity were Greenhouse-Geisser corrected. Follow-up analyses were done where appropriate.

Overall Workload Data. NASA-TLX and HRV (SDNN) data were collected after each trial and then analyzed using a two-way repeated measures ANOVA ($\alpha = .05$) crossing cognitive task type with stability. All data were tested using the Shapiro-Wilk test ($p > 0.05$) to determine normality. Results that violated sphericity were Greenhouse-Geisser corrected. HRV data for the first 10 and last 5 seconds were not analyzed to maintain consistency with the postural data. For NASA-TLX, both weighted scores and individual scale data were analyzed to determine differences between tasks both overall and within individual demands. Follow-up analyses were conducted where appropriate.

EEG data were first demeaned and low-pass filtered (4th order Butterworth) at 30 Hz to remove high frequency noise from the signals. The first 10 and last 5 seconds of each trial's data were removed to maintain consistency with the postural data. For each of the electrodes selected, power spectra were then calculated using the following method: overlapping samples of 2 seconds long were run though 50% overlapping Hamming windows, transformed to the frequency domain using a Fourier transform, and averaged.

The relative power for each if the different conditions was analyzed by determining the amount of power at the peak frequencies of each band (6-7 Hz in the theta band for the two frontal electrodes, 8-10 Hz in the alpha band for the two parietal electrodes) (Gevins et al., 1998). To aid in normalizing the differences between alpha and theta power and emphasizing the power changes between conditions, change scores were calculated using the following equation.

$$Difference\ Score = \frac{(Current\ Power - Power\ from\ No\ Task\ Stable\ condition)}{Power\ from\ No\ Task\ Stable\ condition}$$

In this way, all of the conditions were normalized to the No Task Stable condition, the "control" with no task. Two-way repeated measure ANOVAs ($\alpha = .05$) crossing cognitive task type and stability were conducted on these difference scores for P7 and P8 in the alpha band and for Fz and FCz in the theta band.

In addition to the EEG power analysis, we wanted to determine if there were differences in the event-related potentials (ERPs) generated by the different tasks. Based on the literature, the p3b, a positive peak elicited in dual-task studies around 300-550 milliseconds after stimulus presentation is commonly used to understand mental workload (Huffmeijer, Bakermans-Kranenburg, Alink, & van Ijzendoorn, 2014; Kok, 2001). Because the p3b is highest in amplitude in the parietal regions and due to our relatively low number of samples for an ERP study, we averaged across sets of seven electrodes, centered at P3 and P4 on opposite side of the parietal lobe. The P3 bunch comprised P3, P1, PO3, P5, CP5, CP3, and CP1. The P4 bunch comprised P4, P2, PO4, P6, CP6, CP4, and CP2. To prepare the EEG data for ERP analysis, we first filtered the data (4th order Butterworth) at 30 Hz to remove high frequency noise from the signals. Then the data were time-locked to the onset of each individual cognitive event (e.g. the appearance of the squares and triangles in the visual search task); all samples one second before to two seconds after each onset (see Figure 30 for an example) were isolated and averaged across trial and the seven electrodes. P3b activity was defined as the average activation between 300-550 ms (Huffmeijer et al., 2014) and a two-way repeated measures ANOVA was done comparing p3b activity across cognitive tasks and stability levels.

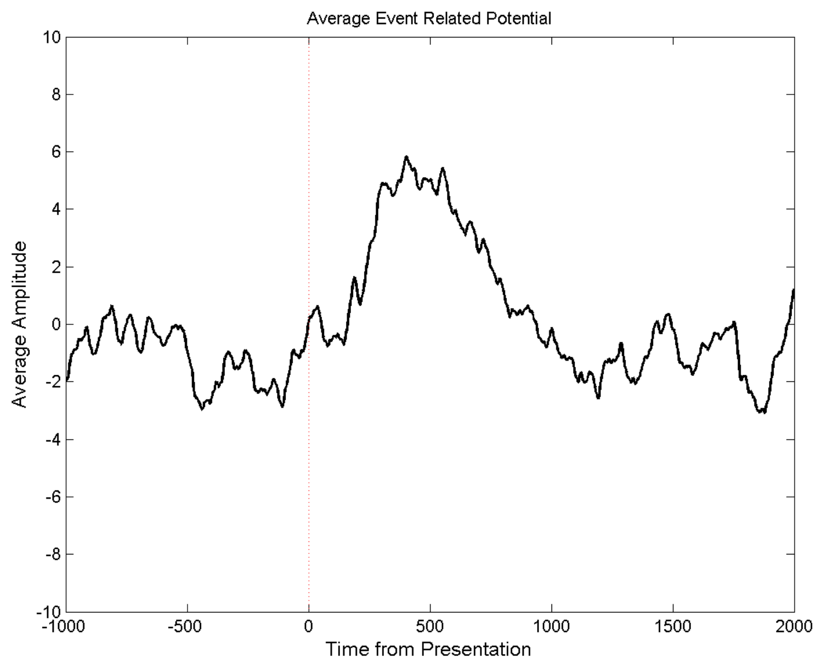

Figure 30. An ERP graph showing moderate p3b activity between 300 and 550 ms. Mean amplitude is in millivolts.

Results

Cognitive Task Results

The results of the two-way repeated measures ANOVAs crossing cognitive task by stability are shown in Table 18. Based on the results, a main effect of cognitive task type was found for both response time and accuracy. The results are graphed in Figure 31 and Figure 32.

Table 18. Results of ANOVAs for cognitive data ($\alpha = .05$). Significant effects are bolded.

	Stability		Cognitive Task		Interaction	
	F-value	p-value	F-value	p-value	F-value	p-value
Accuracy	0.02	0.979	**16.35**	**< 0.001**	0.17	0.915
Response Time	1.84	0.178	**236.44**	**< 0.001**	1.68	0.200

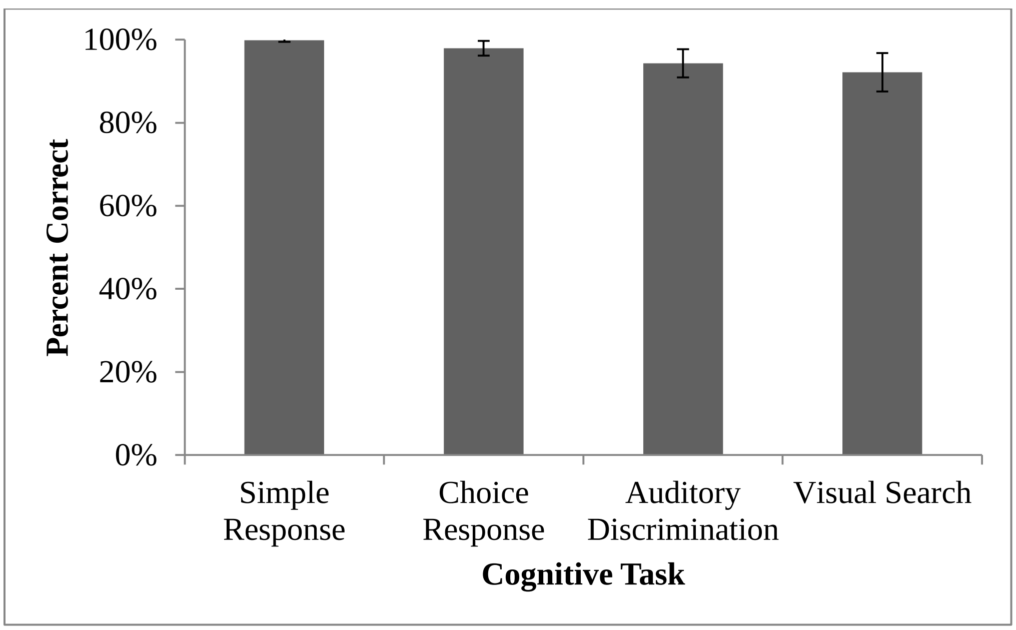

Figure 31. Task accuracy for all four cognitive tasks. Error bars depict standard deviation.

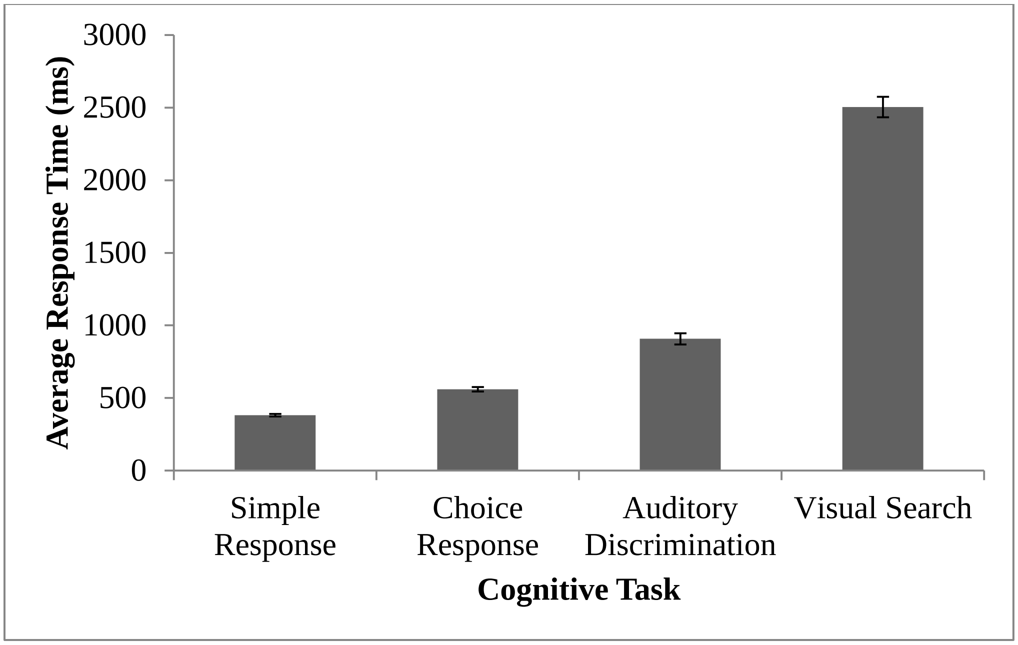

Figure 32. Average response time for all four cognitive tasks. Error bars depict standard deviation.

In both cases, accuracy decreased and response time increased from easier to more difficult tasks. The simple response task only required one response, whereas the rest required two. Of the two response tasks, choice response was the simplest and showed the lowest response time and highest accuracy. The visual search task had the most complex stimuli and showed both a high response time and the lowest (albeit still > 90%) accuracy. No effect of stability was found, however.

Postural Task Results

Center of Pressure Measures. The results of the repeated measures crossing cognitive task type with stability are shown in Table 19.

Table 19. Main effects and interactions for COP time series measures (α = .05). Significant effects are bolded.

		Stability		Cognitive Task		Interaction	
		F-value	p-value	F-value	p-value	F-value	p-value
ML	Velocity	**37.60**	**< 0.001**	1.82	0.178	1.04	0.371
	RMS	**69.94**	**< 0.001**	0.94	0.428	**2.78**	**0.027**
AP	Velocity	2.46	0.132	1.33	0.269	1.57	0.226
	RMS	**76.90**	**< 0.001**	**4.22**	**0.010**	**2.20**	**0.031**

Three of the four measures showed a main effect of stability, which was similar to other studies. RMS distance in the antero-posterior direction showed an effect of cognitive task, and both antero-posterior and medio-lateral distance showed an interaction. To better understand these differences, we investigated further by graphing each effect and then running one-way repeated ANOVAs for each stability level to determine where differences lay. Figure 33 and Figure 34 depict the differences shown by the effects, whereas Table 20 shows the results of the one-way repeated measures ANOVAs for each stability level for each variable. Based on these results, the differences between tasks happen in the antero-posterior direction when the chair is unstable (at 60% and 75% stable).

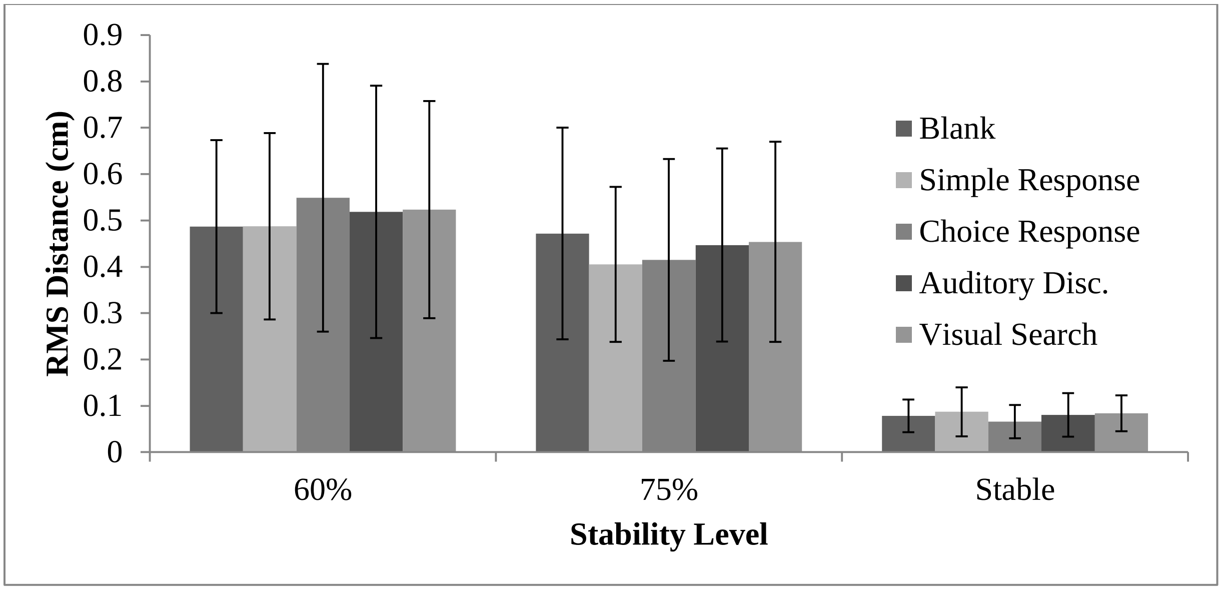

Figure 33. RMS distance in the medio-lateral direction for all five tasks at each stability level. Error bars depict standard deviation.

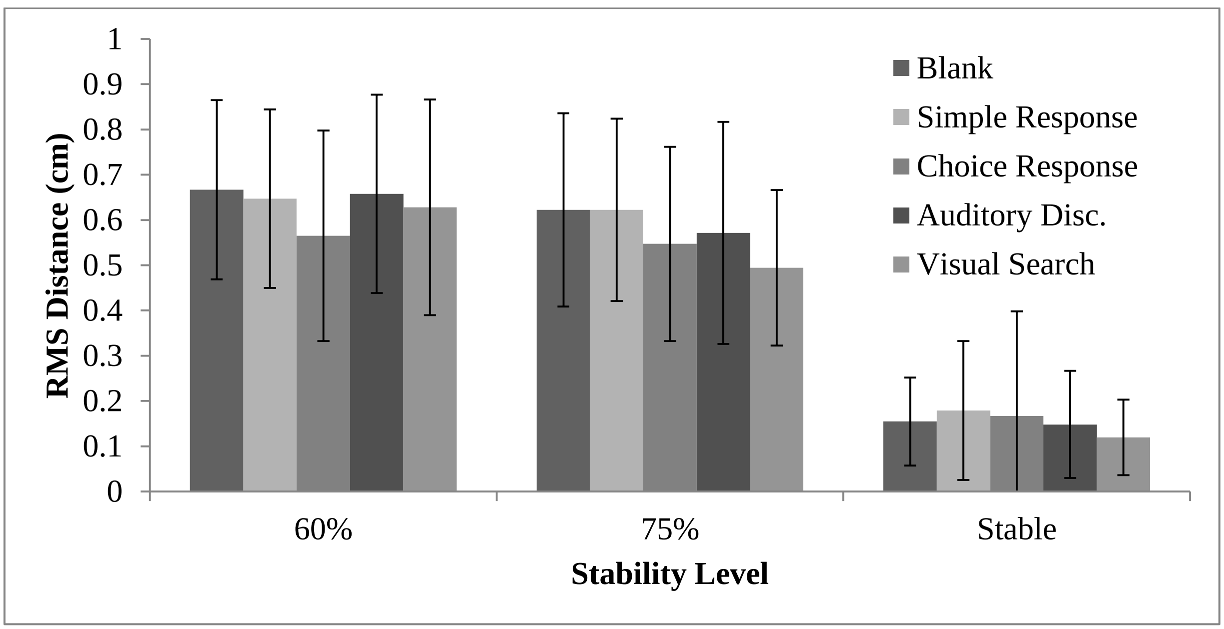

Figure 34. RMS distance in the antero-posterior direction for all five tasks at each stability level. Error bars depict standard deviation.

Table 20. Results of repeated measures ANOVAs for RMS at each stability level (α = .05). Significant effects are bolded.

	60% Stable		75% Stable		Fully Stable	
	F-value	p-value	F-value	p-value	F-value	p-value
ML RMS	1.96	0.150	2.12	0.094	1.20	0.317
AP RMS	**3.27**	**0.036**	**5.02**	**0.003**	0.87	0.434

We wanted to determine what the differences between tasks were at these two levels of instability, so we conducted pairwise t-tests between each cognitive task for 60 and 75% stable for AP RMS. The results of these tests are shown in Table 21. At 60%, the choice response time task shows significantly less AP RMS distance than everything but the simple task (and even there a trend is apparent). At 75%, the visual search task (the other task with a spatial component), is shown to be significantly lower than everything but the choice task (again with a trend there) and the choice task showed significant decrease from blank and simple response.

Table 21. Pairwise comparisons for AP RMS at 60% and 75% Stability (α = .05). Significant effects are bolded.

	60% Stable		**75% Stable**	
	t-value	p-value	t-value	p-value
Blank vs. Simple	0.63	0.536	-0.01	0.995
Blank vs. Choice	**4.07**	**0.001**	**2.44**	**0.025**
Blank vs. Auditory	0.31	0.758	1.26	0.222
Blank vs. Visual	1.74	0.098	**3.95**	**0.001**
Simple vs. Choice	1.93	0.069	**2.19**	**0.041**
Simple vs. Auditory	-0.34	0.738	1.44	0.168
Simple vs. Visual	.48	0.640	**4.65**	**< 0.001**
Choice vs. Auditory	**-3.06**	**0.006**	-0.73	0.475
Choice vs. Visual	**-2.70**	**0.014**	2.00	0.060
Auditory vs. Visual	0.83	0.415	**2.40**	**0.027**

Stabilogram Diffusion Analysis. Based on the procedures outlined by Collins and De Luca (1993), the COP time series data were converted into stabilogram diffusion analyses to expand and support the basic measures suggested by Prieto et al. (1996). The results of the two-way repeated measures ANOVA for the SDA measures in the ML, AP, and composite directions is shown in Table 22.

Table 22. Main effects and interactions from SDA measures (α = .05). Significant effects are bolded.

		Stability		Cognitive Task		Interaction	
		F-value	p-value	F-value	p-value	F-value	p-value
ML	CTI	**65.21**	**< 0.001**	1.81	0.153	**2.27**	**0.041**
	CMI	**11.83**	**< 0.001**	2.34	0.135	1.43	0.253
	H_S	**191.79**	**< 0.001**	0.35	0.820	0.38	0.866
AP	CTI	**150.36**	**< 0.001**	2.25	0.102	**3.54**	**0.008**
	CMI	**27.45**	**< 0.001**	**3.56**	**0.050**	2.12	0.114
	H_S	**262.85**	**< 0.001**	1.51	0.217	0.60	0.726
Comp.	CTI	**117.96**	**< 0.001**	2.16	0.094	2.10	0.073
	CMI	**17.71**	**< 0.001**	3.00	0.091	2.01	0.155
	H_S	**258.82**	**< 0.001**	0.12	0.960	0.73	0.620

Again, stability is significant for all measured variables, which is good because it shows that there are postural differences between stability levels. The critical magnitude in the antero-posterior direction showed significance for cognitive task whereas the critical time interval showed an interaction in both the medio-lateral and antero-posterior direction (although no effect of cognitive task). These results are graphed in Figure 35, Figure 36, and Figure 37.

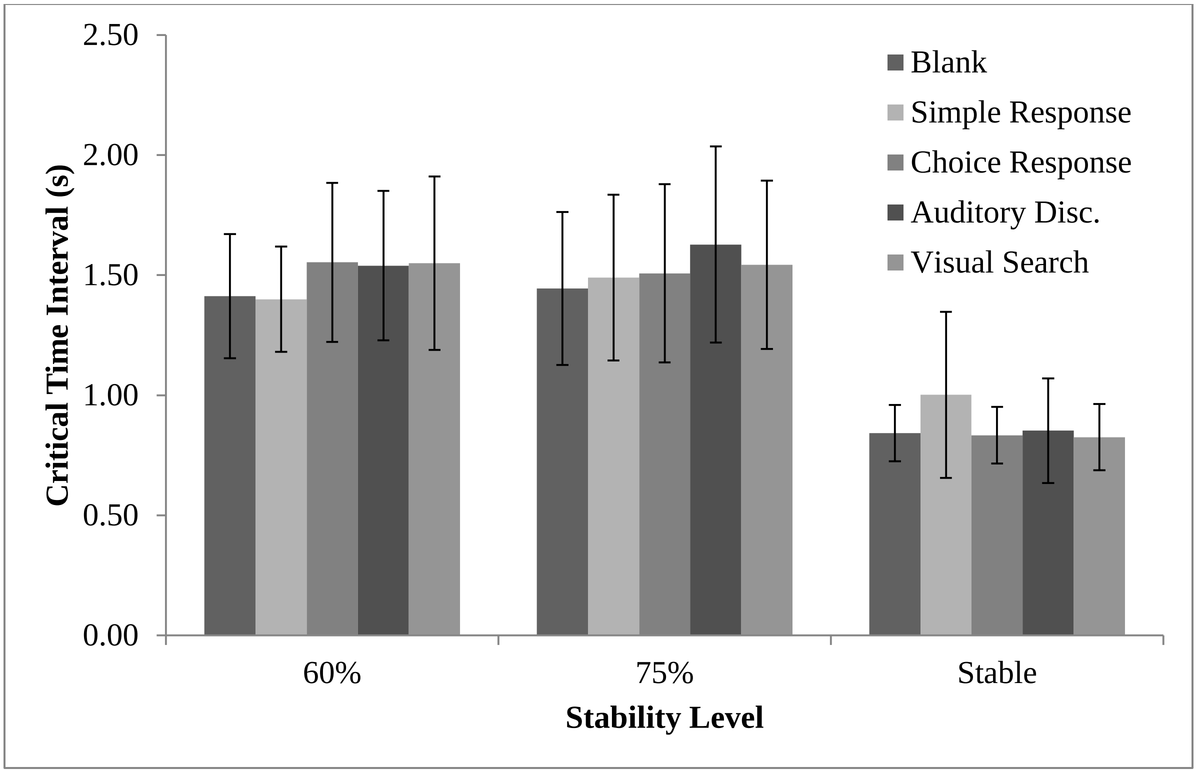

Figure 35. Critical time interval in the medio-lateral direction for the cognitive tasks at each stability level. Bars depict standard deviation.

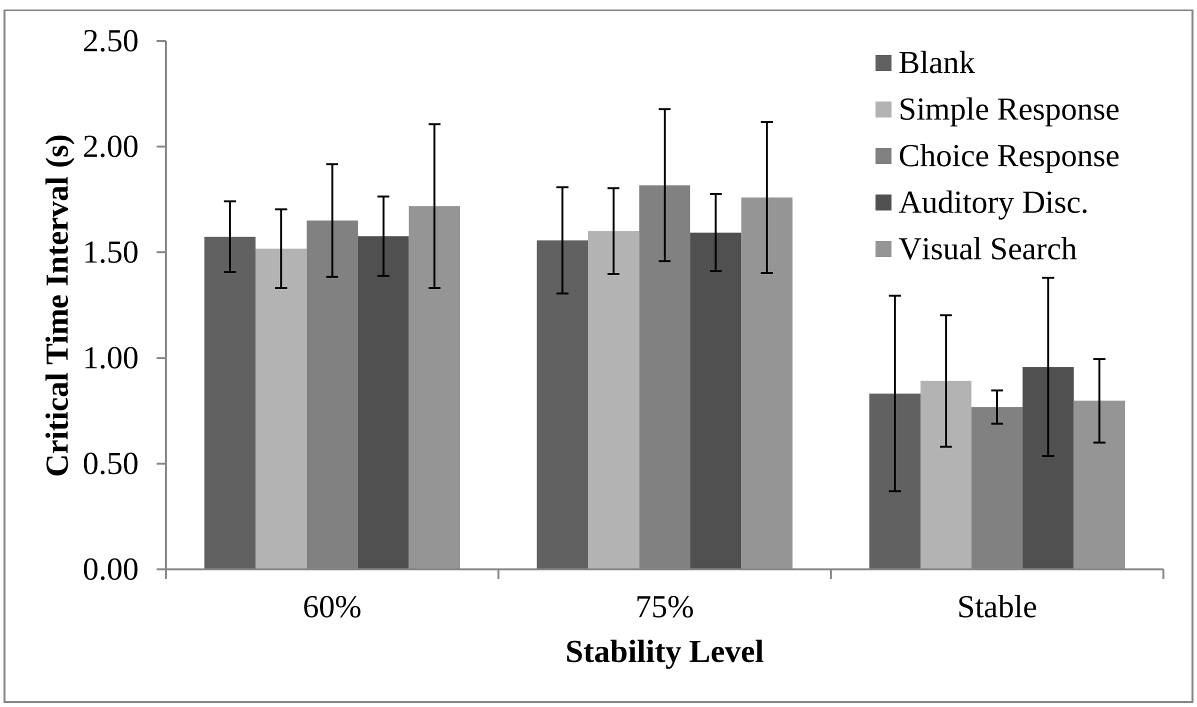

Figure 36. Critical time interval in the antero-posterior direction for the cognitive tasks at each stability level. Bars depict standard deviation.

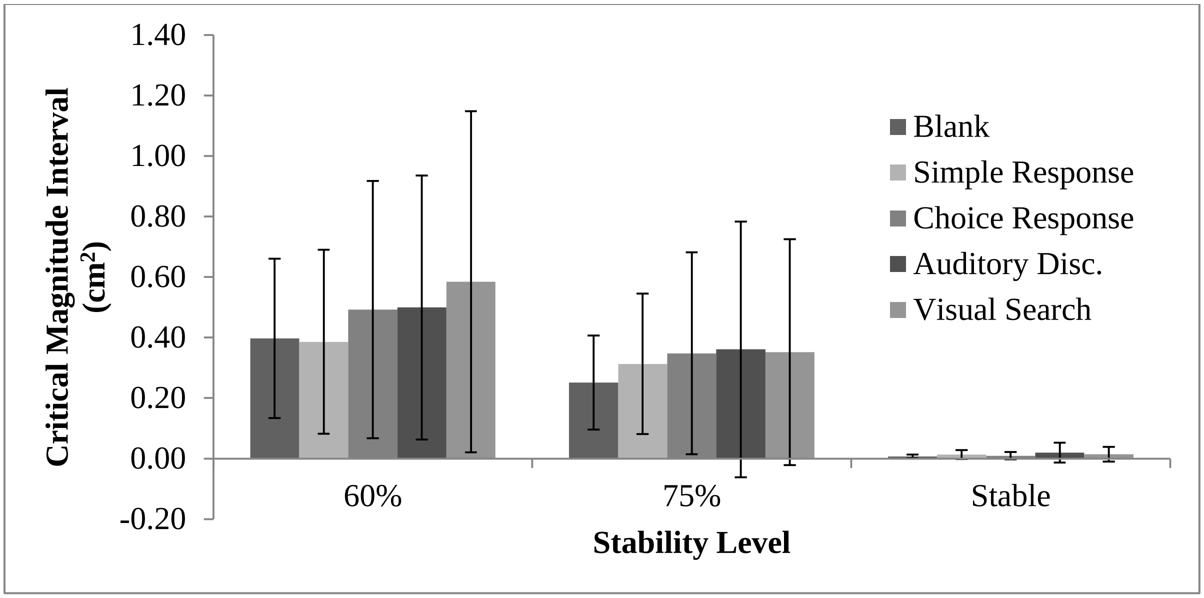

Figure 37. Critical magnitude interval in the antero-posterior direction for the cognitive tasks at each stability level. Bars depict standard deviation.

Based on these results, we wanted to see where the AP CMI results came from; whether there were any differences between stability levels. To this end, we ran one-way repeated measures ANOVAs on task for each of the stability levels to determine where the differences lay. The main effect of cognitive task was significant at 60% (F = 4.18, p = 0.022), but not at 75% and stable (F = 1.28, p = 0.290; F = 1.75, p = 0.186, respectively). We then did pairwise t-tests at 60% to determine where the differences between tasks existed (see Table 23 for results).

Table 23. Pairwise comparisons for AP Critical Magnitude Interval (α = .05). Significant effects are bolded.

	t-value	p-value
Blank vs. Simple	.486	.633
Blank vs. Choice	-1.887	.075
Blank vs. Auditory	-1.897	.073
Blank vs. Visual	**-2.311**	**.032**
Simple vs. Choice	**-2.230**	**.038**
Simple vs. Auditory	**-2.567**	**.019**
Simple vs. Visual	**-2.698**	**.014**
Choice vs. Auditory	-.135	.894
Choice vs. Visual	-2.002	.060
Auditory vs. Visual	-1.247	.228

The tasks separated into two groups, generally; the simple response task was comparable to no task at all in AP CMI. The other three tasks were similar as well, with a non-significant trend for a higher CMI as task difficulty increased. It should be noted that the choice response and auditory discrimination are comparable in difficulty and showed almost identical results.

It is clear that stability has an effect on SDA measures; the more stable the condition the faster the transition from the open-loop process to the closed loop process (meaning a better performing participant). The effect of mental tasks on these measures definitely exists but is more varied, with some tasks causing more change than others. Like previous studies, mental tasks decreased overall movement but increased SDA values.

Overall Workload Results

NASA-TLX and Heart Rate Variability. The results of the weighted NASA-TLX and HRV ANOVAs are shown in Table 24.

Table 24. Main effects and interactions from NASA-TLX and HRV measures ($\alpha = .05$). Significant effects are bolded.

	Stability		**Cognitive Task**		**Interaction**	
	F-value	p-value	F-value	p-value	F-value	p-value
HRV	**4.09**	**0.027**	0.73	0.538	1.04	0.405
NASA-TLX	**30.97**	**< 0.001**	**16.36**	**< 0.001**	1.17	0.332

HRV showed a significant effect of stability but not one of cognitive task. To investigate this effect, we graphed the HRV results, as shown in Figure 38. The large amount of between-subject variability made differentiating between tasks difficult, but there was an increase in variability from 60% to 75% to stable.

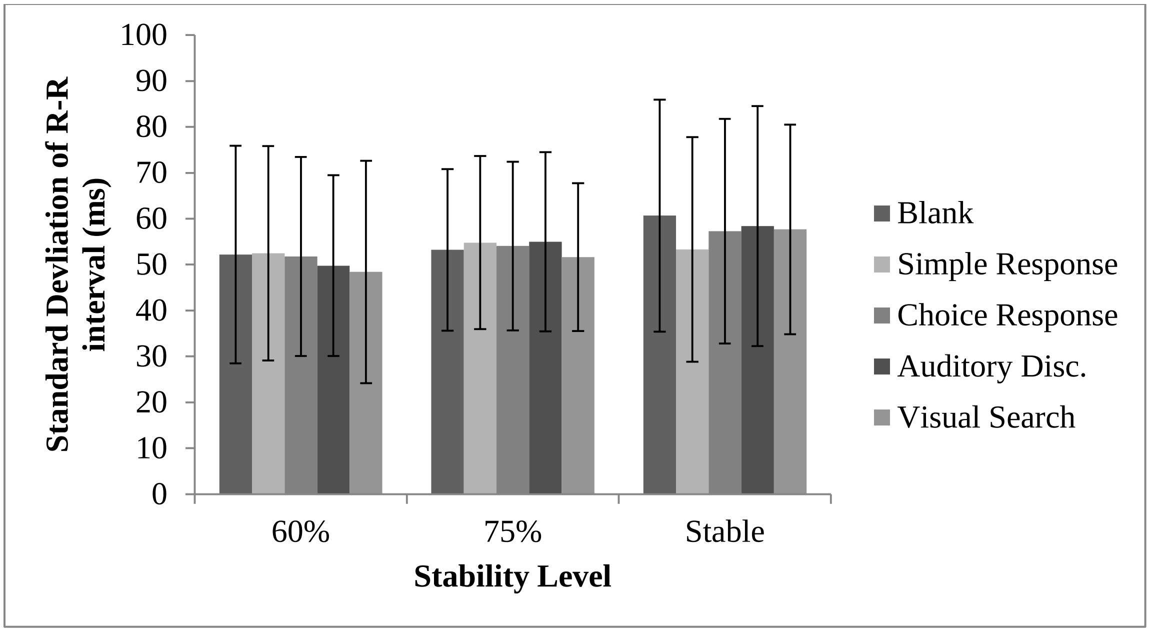

Figure 38. Heart rate variability for the cognitive tasks at each stability level. Bars depict standard deviation.

NASA-TLX showed significant effects of both stability and cognitive task, but not an interaction. The NASA-TLX data are depicted in Figure 39. The trends show that, as mental difficulty increased, perceived workload increased.

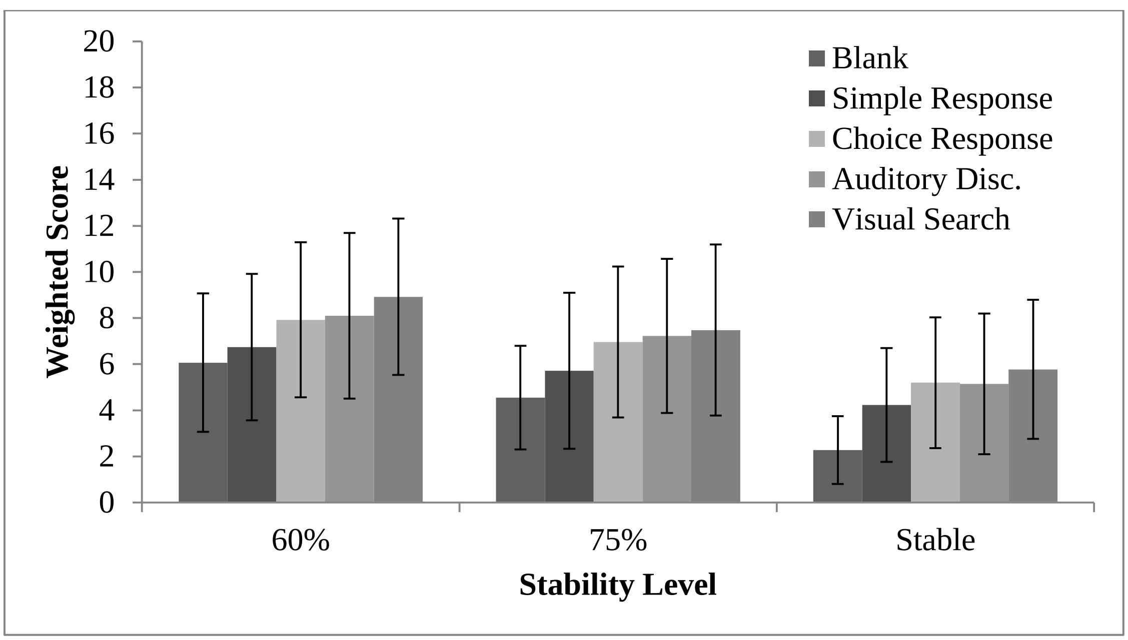

Figure 39. Weighted NASA-TLX scores for the cognitive tasks at each stability level. Bars depict standard deviation.

To better understand participants' perceived workload, we broke down the NASA-TLX scores into their individual scales, determining how cognitive and postural tasks had effects on the individually. First, we ran a MANOVA including all six scales (Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration). Based on significant main effects of stability ($F = 5.99$, $p < 0.001$) and cognitive task ($F = 4.91$, $p < 0.001$), we ran individual two-way ANOVAs for each scale to determine effects. Table 25 shows the results of these analyses.

Table 25. Main effects and interactions from NASA-TLX scales ($\alpha = .05$).

	Stability		**Cognitive Task**		**Interaction**	
	F-value	p-value	F-value	p-value	F-value	p-value
Mental Demand	**8.09**	**0.001**	**19.60**	**< 0.001**	0.78	0.575
Physical Demand	**41.14**	**< 0.001**	0.66	0.570	0.63	0.638
Temporal Demand	1.50	0.236	**20.35**	**< 0.001**	0.70	0.638
Performance	**12.28**	**< 0.001**	**5.76**	**0.001**	1.66	0.145
Effort	**33.43**	**< 0.001**	**6.97**	**0.001**	**3.13**	**0.015**
Frustration	**10.61**	**< 0.001**	**4.52**	**0.007**	0.69	0.615

Of most interest are: the fact that mental demand changes with both cognitive task and stability (whereas physical demand changes only with stability as expected) and that effort shows an interaction between cognitive task and stability. These two scales are depicted in Figure 40 and Figure 41. The trend in mental demand matches the overall trend of the weighted scores, with both task difficulty and stability increasing mental demand score. The effort results were more varied, so we ran one-way repeated measures ANOVAs on task for each of the stability levels to determine where the differences lay. No differences were found at 60% ($F = 1.77$, $p = 0.164$), but there were differences between tasks at 75% and stable ($F = 4.29$, $p = 0.006$; $F = 10.88$, $p < 0.001$, respectively).

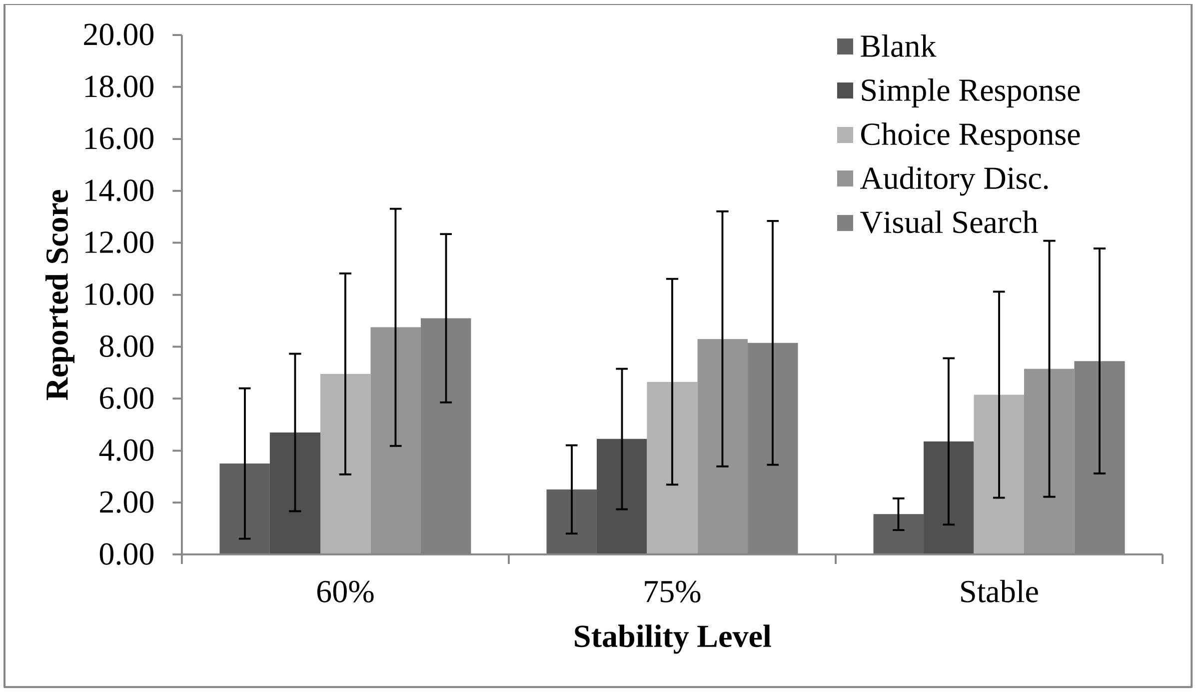

Figure 40. NASA-TLX mental demand for the cognitive tasks at each stability level. Bars depict standard deviation.

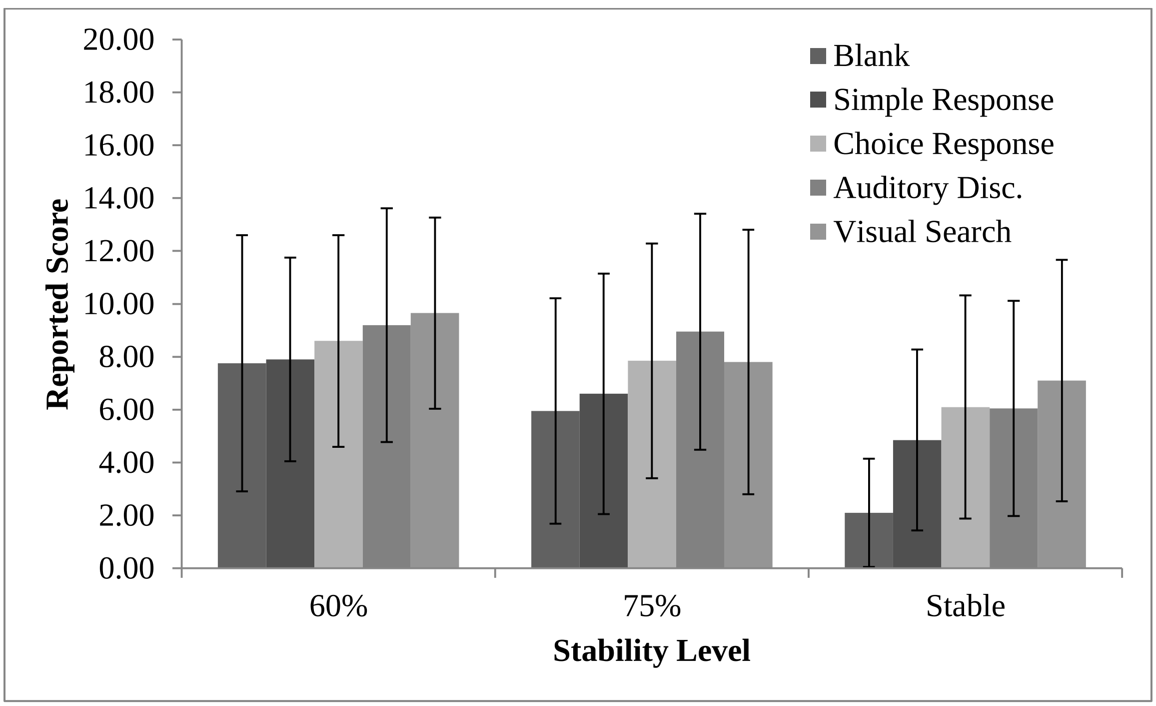

Figure 41. NASA-TLX effort scores for the cognitive tasks at each stability level. Bars depict standard deviation.

Table 26. Pairwise comparisons for NASA-TLX effort scale (α = .05).

	75% Stable		**Fully Stable**	
	t-value	p-value	t-value	p-value
Blank vs. Simple	-0.86	.402	**-3.51**	**.002**
Blank vs. Choice	**-2.48**	**.023**	**-4.20**	**.000**
Blank vs. Auditory	**-3.57**	**.002**	**-3.98**	**.001**
Blank vs. Visual	**-2.24**	**.037**	**-4.84**	**.000**
Simple vs. Choice	-1.72	.101	-1.71	.104
Simple vs. Auditory	**-2.45**	**.024**	-1.78	.092
Simple vs. Visual	-1.82	.085	**-3.71**	**.001**
Choice vs. Auditory	-1.45	.163	0.07	.946
Choice vs. Visual	0.06	.951	-1.29	.212
Auditory vs. Visual	1.31	.207	-1.20	.243

Based on these results, participants reported significantly less effort in most conditions when they were not doing a task versus when they were at 75% and fully stable. Simple response was also reported to be significantly less effortful than one task in each condition. All the rest of the tasks were the same regardless of demand type or difficulty.

We also wanted to determine how perceived workload correlated with actual performance at the scale level, that is, whether participants mental demand and physical demand scores correlated with their cognitive and postural performance, respectively. Table 27 shows the results of these analyses. Based on these results, actual physical performance correlated with perceived physical demand (with higher demand matching lower performance), but mental performance did not correlate with perceived mental demand.

Table 27. Pairwise Spearman correlations for NASA-TLX vs. performance measures (α = .05).

	Correlation	
	rho-value	p-value
TLX MD vs. Accuracy	< -0.01	0.964
TLX MD vs. Response Time	-0.07	0.260
TLX PD vs. ML RMS	**0.56**	**< 0.001**
TLX PD vs. AP RMS	**0.57**	**< 0.001**

EEG Results. ANOVA main effects and interactions are shown for the four electrodes chosen in Table 28. Significant effects are bolded.

Table 28. Main effects and interactions from Alpha/Theta activity (α = .05).

		Stability		**Cognitive Task**		**Interaction**	
		F-value	p-value	F-value	p-value	F-value	p-value
Alpha	P7	1.16	0.319	0.59	0.615	1.86	0.142
	P8	2.37	0.134	**3.59**	**0.034**	1.80	0.180
Theta	Fz	1.14	0.332	0.78	0.499	1.24	0.302
	FCz	**3.98**	**0.050**	0.51	0.662	1.12	0.342

Alpha power differences showed a main effect of cognitive task for electrode P8 (shown in Figure 42), whereas theta power differences showed a main effect of stability for electrode FCz (shown in Figure 43).

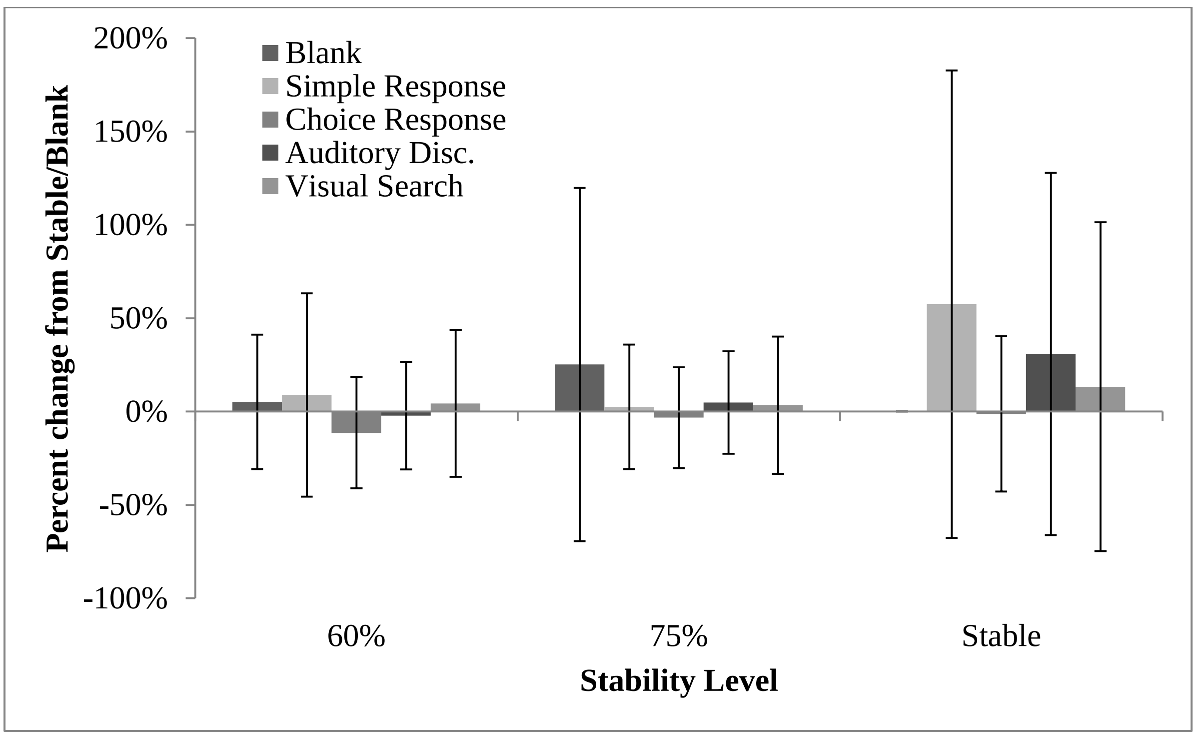

Figure 42. P8 Alpha power differences for the cognitive tasks at each stability level. Bars depict standard deviation.

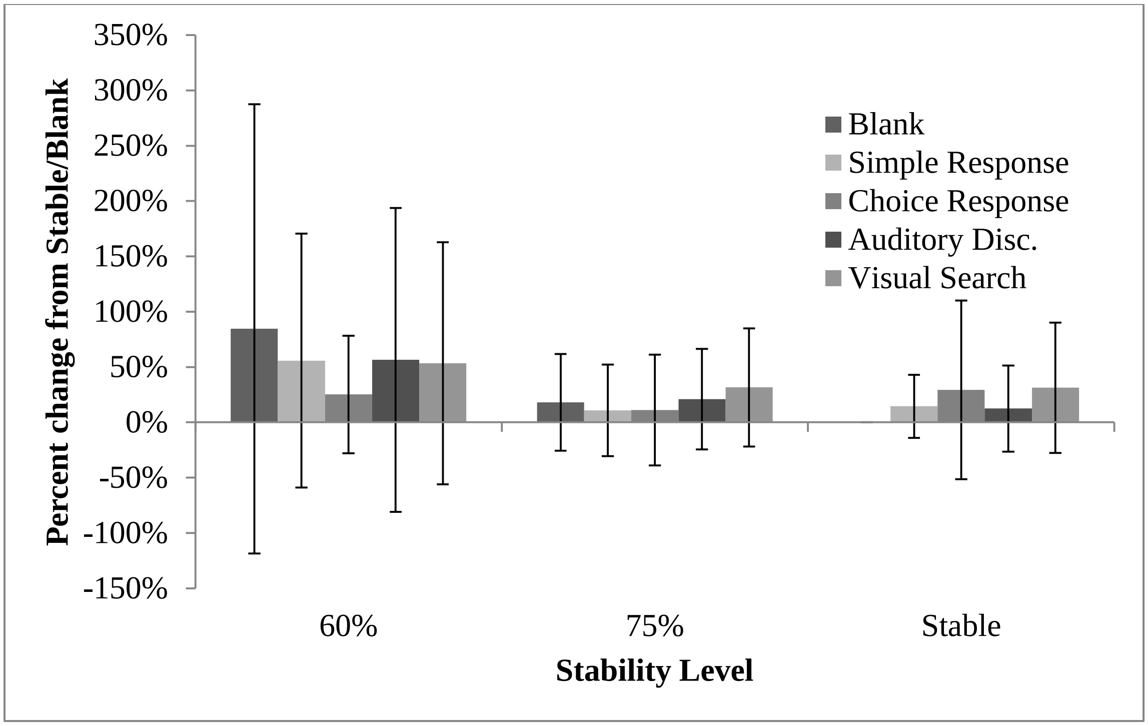

Figure 43. FCz Theta power differences for the cognitive tasks at each stability level. Bars depict standard deviation.

The results of the p3b two-way repeated measures ANOVAs are shown in Table 29. Significant effects are bolded. Cognitive task type was significant for each of the activity types, but not stability. The different tasks are graphed in Figure 44.

Table 29. Results of repeated measures ANOVAs for p3b ERP activity (α = .05).

	Stability		Cognitive Task		Interaction	
	F-value	p-value	F-value	p-value	F-value	p-value
P3-Centered Bunch	0.23	0.799	**7.67**	**< 0.001**	1.60	0.129
P4-Centered Bunch	0.19	0.827	**6.00**	**0.001**	0.97	0.460

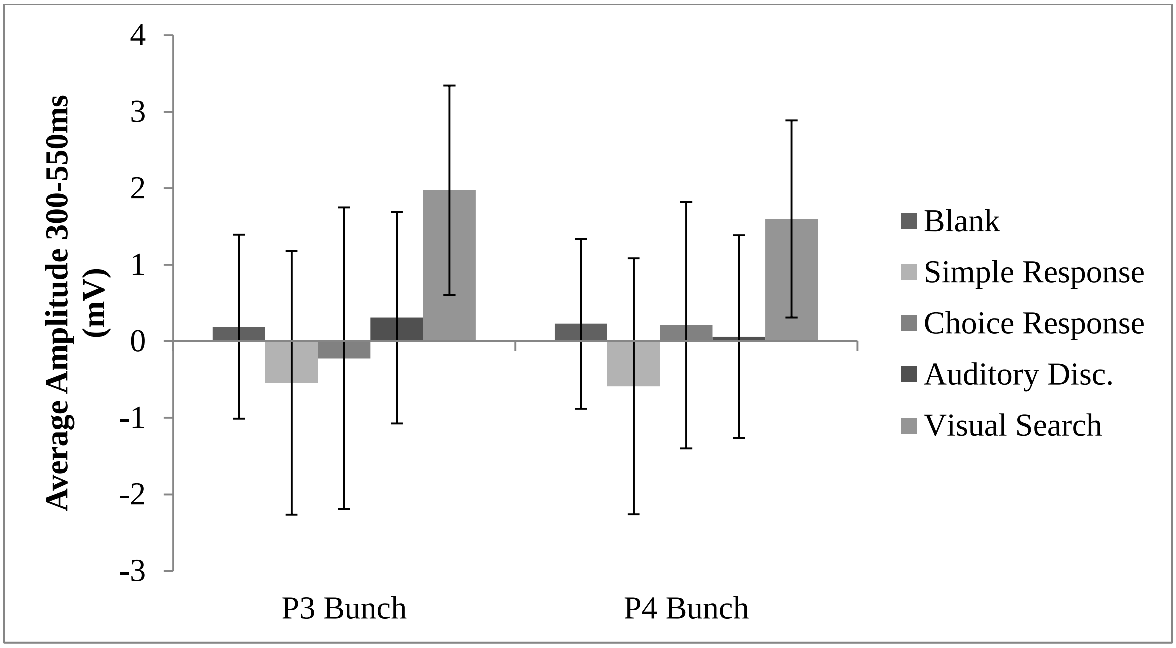

Figure 44. P3b activity for the cognitive tasks. Bars depict standard deviation.

Post-hoc one-sample t-tests showed that only the visual search task showed significant differences from zero, meaning that only the visual search task had discernible p3b activity.

Discussion

Summary of Findings

The effect of the cognitive and postural tasks on our mental workload correlates were varied, but showed some patterns. In the realm of task performance, each type of task was most sensitive to changes in its own type (cognitive measures showed changes across cognitive tasks; postural measures almost all showed an effect of stability). The postural measures did show some sensitivity to task type, with several antero-posterior measures showing changes: root-mean-square distance decreased with the introduction of tasks in unstable conditions. Furthermore, tasks with spatial components (the choice response and visual search) task created the greatest increase in stability; the AP RMS distance for these tasks were the least at 60% and

75% stable This is a similar finding to previous studies that showed the benefit of spatial tasks over non-spatial ones (Dault et al., 2001; Kerr et al., 1985; Maylor et al., 2001).

Heart rate variability decreased as instability increased. As the literature states that a decrease in HRV correlates with mental workload, this suggests that increased postural stress does indeed increase mental workload. The NASA-TLX results support this conclusion, with both instability and increased cognitive task difficulty being predictors of overall score increases. Furthermore, the mental demand results mirrored those of the overall scores, showing that the participants reported increases in mental demand even across postural conditions.

The EEG and ERP results were more varied. The P8 Alpha activity differences showed an effect of cognitive task, but the between-subject variability made it hard to understand why this difference happened. The FCz Theta activity differences showed an effect of stability, with the less stable conditions showing more activity. This may be due to an increase in mental workload, but FCz is also near the motor cortex and might also be reflecting increased activity due to more muscle activation. The ERP analyses of p3b artifact activity showed that only the visual search task showed significant activity. This may be due to the more difficult stimuli.

Conclusions

The myriad measures of overall mental workload in this study show the importance of measuring several different types of tasks in several different ways. We found different results with each of the different measure types (albeit with patterns emerging), a result that depicts in insufficiency of any individual method. Based on our results, though, it is clear that mental and postural tasks do interact in such a way as to increase mental workload. This interaction is complex, being mediated at some points by cognitive task difficulty, others by certain cognitive task aspects (spatial vs. non-spatial), and still others by the stability level of the participant.

The significant results from every measure we used are important, though; all of these measures are useful and usable measures of overall workload in a cognitive/postural dual-task environment; the results we found in task performance match others that have been found in previous studies so the effects seen in HRV, NASA-TLX, and EEG/ERP could be generalized to those other studies.

There is some merit to the idea that these differences may be due to changes in arousal between conditions; that different tasks arouse participants at varying levels and therefore affect both the mental demands on the system but also the overall capacity (Yerkes & Dodson, 1908). In the previous studies with just one task, the increase in workload measures at the same time the postural task performance increased suggested that both demand and capacity were increasing; that the task was simple enough that the participants were increasing in arousal when presented with two tasks at once and that capacity was rising faster than demand. The results of this study may change that suggestion, as postural performance was the best when paired with spatial cognitive tasks, regardless of difficulty. It is possible that these tasks were more arousing, but there is no outward reason to think so. It is clear that several different mechanisms are affecting the different measures, but arousal may very well be one of those.

Those managing the design of complex systems containing both cognitive and postural tasks should be wary of the way they evaluate the overall workload of the operators. Looking at the performance of the individual tasks is insufficient in determining how the operator interacts with the series of tasks they manage; analyses must be done at the system level to determine the interactions of the two different tasks, both at the physiological and psycho-social levels. In designing multitasking environments, the focus should be on the overall system, not individual task performance.

CHAPTER V: Conclusions

Multitasking increases workload (Altmann & Trafton, 2002; Kahneman, 1973; Wickens & McCarley, 2008), using up limited mental resources (Navon & Gopher, 1979). If task demands are allowed to exceed an operator's capacity, that operator will get overloaded and performance degradation will result. Workload concerns are not limited to cognitive tasks, however; posture and other physical tasks take mental workload (Mehta & Agnew, 2011; Woollacott & Shumway-Cook, 2002). Because balance tasks carry with them the dangers of falling, traumatic injury, or work-related musculoskeletal disorders, overload where postural tasks are included is an especially large concern.

The major gap in the literature to this point was the lack of measures of overall workload. The assumption of many cognitive/postural dual-task studies was that humans have one undifferentiated set of mental resources to call upon and that changes in workload that approached overload could be seen in the relative performance levels of the two tasks. As mental resources are differentiable and multitasking creates its own set of demands (Altmann & Trafton, 2002; Navon & Gopher, 1979; Wickens, 1984), there was a need for understanding how the overall mental workload was being affected by the interaction between the two tasks. The focus of this research was to apply the concept of overall workload to the cognitive/postural dual-task environment. First, we set out to determine what effects we would find comparing one specific task and how measuring overall workload might affect the results. Second, we measured overall workload on that one task to determine the effects of the two tasks on overall workload and make sure there were few observer effects of the added apparatuses. Third, we measured the effect of a range of different types of cognitive demands comparing how different task aspects and difficulty would affect the measures of workload. The overall goal was to determine the importance of measuring overall workload as a methodology as well as determine how performance results and workload results differed, if at all.

Research Summary and Contributions

Research Summary

The results from the first study helped to create results baseline for our protocol, providing task performance results that could be compared with and without mental workload measures. We found no differences in the cognitive task performance between stability conditions, suggesting that either the combination of the tasks was not difficult enough or that the increased difficulty induced by the chair wobbling did not affect the task completion. The physical results support the results of Easton et al. (1998) (unlike those of Raper and Soames (1991)); the cognitive task in conjunction with the more difficult 75% stability condition provided a relative benefit to postural sway. These results suggest that non-spatial auditory tasks of low difficulty are not significantly affected by seated postural instability and that postural stability may in fact be slightly aided by the distraction.

The second study showed that cognitive and physical tasks do interact in a complex way, causing higher levels of perceived workload coupled with better performance in the postural task. The lack of a correlation between the three different measures of overall workload was especially concerning, as it shows the significantly differing results that can be gleaned based on the type of data collected. All of the separate measures of overall workload showed increases in workload when a cognitive task was added; EEG Alpha activity decreased, HRV decreased, and NASA-TLX overall and mental demand scores increased. Results with the addition of the postural task were more complex, with some measures indicating increased workload (NASA-TLX), some indicating decreased workload (EEG, COP measures), and some not showing a significant effect (HRV). These similarities and differences speak to the importance of the measurement method and the danger of drawing conclusions based solely on one measure.

The third study found different results using the different measure types. Based on our results, though, it is clear that mental and postural tasks do relate in such a way as to increase mental workload. This interaction is complex, being mediated at some points by cognitive task difficulty, others by certain cognitive task aspects (spatial vs. non-spatial), and still others by the stability level of the participant. Much like the first study, a secondary task decreased postural sway while increasing SDA measures in the antero-posterior direction suggesting better performance but longer open-loop control times. The results from the overall workload measures were varied, however. NASA-TLX showed similar results as the second study, adding an effect of overall task difficulty increasing overall scores. HRV in the third study dropped as instability increased, showing an increase in mental workload with increased instability, but was not sensitive to cognitive task differences. Alpha activity showed varied differences across cognitive tasks, whereas theta activity increased in the presence of postural instability, a workload-increasing effect not found in the second study. These differences may be due to differences between samples or environmental changes (such as magnetic interference), but all of the changes pointed to similar effects: whereas an added task decreased postural sway, both cognitive and postural tasks appeared to increase one or more measures of mental workload.

The similarities and differences we found in the three measures of overall mental workload were the some of the most informative results of this research. One of the goals was to determine where the interactions where between cognitive and postural tasks and how the effects of multitasking would cause changes to the overall workload of the system. What we found was that different measures of mental workload responded in different ways based on the combination of cognitive and postural demands, as well as differently across studies.

NASA-TLX was the most consistent of the three. We found that both cognitive and postural demands increased overall subjective scores of workload, as well as the amount of "mental demand" the participants reported. We also found interactions in effort for both study 2 and 3, showing that the added effort reported caused by the mental task was the highest when no physical task was present; no differences were apparent when the participant was balancing at 60% in either study. This consistency may also be due to the "perceived" nature of NASA-TLX; participants' perception of their performance and workload do not necessarily correlate. In these studies, perception of postural demand correlated with postural performance, but the same result was not seen with mental performance and perceived mental demand. This may have to do with the sensitivity of the different tasks, with all participants performing well enough on the mental tasks that differences in the perceived mental workload would not be reflected.

Heart rate variability showed significance across the cognitive (and almost postural) dimension in study 2 and across the postural dimension in study 3, both showing an increase in the respective demand correlated with a decrease in HRV (and therefore an increase in workload). It should be noted that the postural dimension approached significance in study 2 as well, so the added number of trials to compare may have increased the power in study 3 to show that effect. The lack of a cognitive effect in study 3 is confusing, but may be due to fewer participants per task and a larger number of tasks that may have lessened the power of the analysis.

The EEG results were simultaneously the most varied and the hardest to interpret; study 2 showed alpha differences in both cognitive and postural dimensions (albeit in different lobes), the cognitive dimension showed a decrease in alpha activity from baseline (as expected for a workload increase), but the postural dimension showed an increase, an effect that might suggest less workload. In study 3, the cognitive effects for alpha waves showed varied results for the different tasks, with many increasing (suggesting less workload) and many staying similar to baseline. The theta band, however, showed increased activity with increased postural stress, which would be expected for higher workload. These results together with the ERP analysis that showed that only the visual search task elicited p3b activity above baseline suggest a very subtle interaction that is very susceptible to environmental and participant noise.

Revisiting the Proposed Multitasking Model

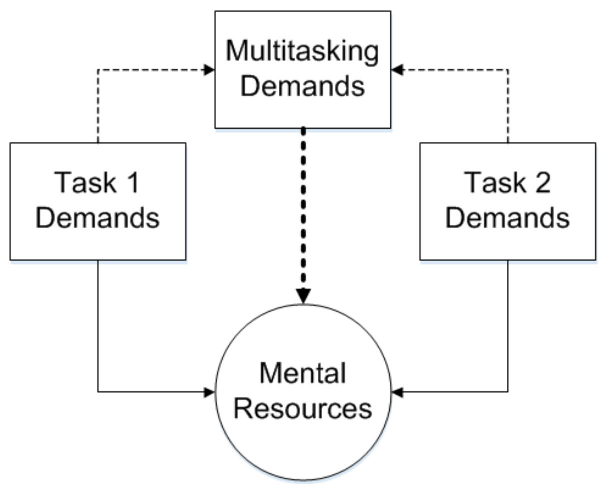

Figure 45. The simplified model of the demand sources on mental resources during dual-tasking proposed in the introduction.

Based on the results of this research, the proposed model of demand sources on mental resources (Figure 45) is valuable but is only one part of the story. The changes in how different cognitive tasks affected postural performance based on difficulty and type showed that the multitasking environment is more complex than the addition of the demands of each task. This model by itself cannot explain why the postural performance got *better* with the addition of several cognitive tasks across the study; it suggests that multiple tasks would only make performance worse faster.

The implicit assumption based on this simplified model is that the mental resources available to the participant are finite, that is, participants bring the same amount of capacity to every condition and only demand fluctuates. This is untrue; many aspects of cognition affect capacity (Kahneman, 1973), chief among them arousal (Yerkes & Dodson, 1908). In this way, the number, amount, and types of demands leading from the three boxes in the model not only directly affect the demand on the system, they indirectly affect the capacity by changing the arousal level of the participant.

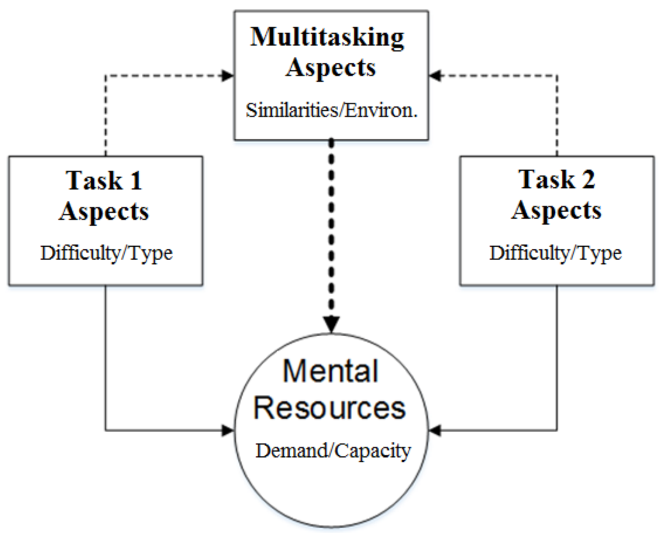

Figure 46. An updated simplified model of the interaction of multiple tasks on mental resources.

In the updated model (Figure 46), the aspects of each task affect the demand and capacity or mental resources due to the difficulty, arousal, and type of task. When two or more tasks are combined, similarities between the tasks and the environment in which they interact have their own effects on the demand and capacity of the mental resources. This includes the arousal of adding a second task, as well as other possible sources of change such as distraction. Some participants reported this, that the addition of the second task removed them overthinking the single task. Both had important effects on our experiment and need to be included into any model of multitasking.

While this model is more complex, it better reflects the complexity of the way different tasks affect each other and overall mental resources. It also underscores the need to determine how different aspects interact; how different task types and overlap might result in a very different set of results.

Contributions

- Measures of workload provide essential information about cognitive/postural multitasking
    - Task performance and overall workload supported different outcomes
    - NASA-TLX, HRV, and EEG all provided useful data that supported earlier findings
    - Multiple measures of workload provide a better understanding of overall system
- Task performance and workload equally important in understanding multitasking
    - Task performance depicts current state, workload possible interaction effects
        - Need multiple points to show trends (What happens if we…?)
    - Difficulty and nature of tasks important (spatial vs. non-spatial; stable vs. unstable)
- Data rich dual-tasking methodology
    - Able to vary difficulty and task type
    - Collected myriad types of both event-dependent and –independent data
        - Task measures (Speed, Accuracy, Postural Sway, SDA Measures)
        - Workload measures (NASA-TLX, HRV, EEG Power, ERP)
    - Compared several tasks at once; correlate measures of workload to determine similarities

Based on the differences found between the different measures, the importance of measuring overall workload as well as individual task performance in cognitive/postural dual-task research cannot be overstated. The results of the first study seem to paint a clear picture: the addition of an auditory task to unstable seating decreases postural sway. Based solely on this result, it might be concluded that workload did not increase. Using the same protocol while measuring mental workload however, we found that workload did in fact increase both subjectively and objectively, even when similar postural benefit was found. Even as performance seemed to improve, the participant moved nearer to possible overload and performance decrement (a condition we did not induce in this research).

Furthermore, the procedures and measures used for overall workload were both informative and appropriate for this and similar protocols. This research provides a proof-of-concept for a data rich dual-task protocol that generates data about both tasks, performance, and overall workload results that can show differences between tasks and postural stresses. This methodology could be applied in other cognitive/postural or physical dual-task environments to learn more about the interactions between tasks.

Research Limitations and Future Directions

Many of the limitations of this research can be addressed in future research, allowing for some of the challenges faced to be rectified. First, the breadth of tasks used in study 3 was designed to provide a set of different demands, but many other common cognitive or multimodal demands were not discussed; future research should look at memory, arithmetic, proprioception, and haptic response, as these are common demands that need to be addressed. Second, this research used one specific postural task to induce postural stress, the wobble chair. Since this is a measure of seated stability, other studies research standing stability and gait would be merited to see whether similar methodologies result in similar results. This research represented a first foray into measuring overall workload and therefore was constrained to one method, future studies would do well to test others.

Of major issue throughout this work were the individual differences between both participants and environment throughout testing. Significant effort was put into controlling for many sources of variance; all of the participants were scheduled near their peak arousal period, all testing was done at once to minimize changes in the environment, abilities tests were giver to determine outliers in memory and perceptual speed, and condition orders were counterbalanced to avoid order effects. Nonetheless, significant error was seen in many analyses, chief among them the HRV and EEG data. One possible source of error was the variation between participants' depressant and stimulant habits; caffeine, alcohol, and tobacco use can all have effects on EEG activity, both in the short term and in the long term due to deprivation effects (Knott, 2001). Participants were asked not to use any of these before the experiment, but some may have been affected by the deprivation. Assumedly this did not affect them between task conditions but contributed to the between-subject noise. Another source of error determined during data collection was the high amount of magnetic and wireless interference coming from other sources in the building, causing artifacts in both the HRV and EEG data that varied from participant to participant and sometimes trial to trial. Some of this noise was removable, but not all. Future research should be conducted in an environment conducive to EEG collection, both devoid of noise and light from unwanted sources but also from magnetic and wireless interferences.

Finally, and possibly due to the low power of the EEG analysis caused by the low number of trials, the main contribution of this research is to show the importance of measuring overall workload when addressing dual-task cognitive/postural environments. To best understand the effects individual tasks have on each other, future research should focus on creating more trials, both to increase the power level of analyses where the effect size is small (such as EEG and ERP analyses), but also to avoid many of the same environmental and individual differences seen on out study. The complexity of the effects found in this research underscore the importance of looking at the multitasking environment as more than the sum of its parts; individual task demands may combine in many different ways and individual environments must be tested above and beyond individual measures of performance for each of the composite tasks.

Final Conclusions

The greatest contribution of this study is the demonstration of the need to measure overall workload in cognitive/postural multitasking environments. The goal was to determine what effects the tasks had on overall workload. The results showed that, even when performance measures may show an increase in performance, workload may be rising and approaching the dangerous condition of overload. Furthermore, the methodology developed and the overall workload measures used depict a complex system that requires multiple approaches to effectively quantify. The goal of any designer should be to be wary of the interactive effects of tasks together and to measure workload on the system as a whole.

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APPENDIX A: STUDY 1 CONSENT FORM

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Informed consent form for participants of Research Project Involving Human Subjects

Title of the Project:
The Influence of Mental Workload on Trunk Stability and Neuromuscular Control

Principal Investigator:
Dr. Michael Agnew, ISE faculty, Department of Industrial and Systems Engineering, mjagnew@vt.edu, (540) 231-0083
Co-Investigator:
Ralph Cullen, PhD student, Department of Industrial and Systems Engineering, rhcullen@vt.edu, (404) 913-1486

I. **The Purpose of this Research/Project**
The purpose of this study is to investigate how mental workload affects the postural stability of those with and without low back pain. We will be comparing the differences in physical stability between trials with and without mental demands and how those effects change in those with low back pain.
II. **Procedures**
If you choose to participate in the evaluation activities, we will ask you to sign one informed consent document (this document). You will keep a copy for yourself.
The procedure for this experiment will last up to 2 hours on one day. After you have signed the consent form, you will be asked to fill out a brief demographics questionnaire and complete several paper surveys. Following this, you will be introduced to the test procedures, so you understand what each test session will entail. Next, we will calibrate the wobble chair used in this experiment to your center of balance. You will then complete a series of two-minute trials sitting on the wobble chair at varying levels of stability (50%, 75%, and 100% stable). For half of the trials, one of several mental workload tasks will be present for you to complete using a computer. A break will be provided after each trial. After the trials, you will be compensated.
III. **Risks**
There are no more than minimal risks for participating in this study, other than you would encounter during a normal day. Neither our research team nor Virginia Tech have funds set aside for medical treatment should that be required during the experiment. Participants in a study are considered volunteers, regardless of whether they receive payment for their participation. Under Commonwealth of Virginia law, workers compensation does not apply to volunteers. Appropriate health insurance is recommended for yourself.
IV. **Benefits of the Project**
You will likely not gain any direct benefits as a result of your participation in this study. The results of this study may help in future research to prevent occupational injuries and to identify individuals at increased risk of injury.
V. **Extent of Anonymity and Confidentiality**
We assure confidentiality to all participants. However, anonymity cannot be guaranteed, because we will need to have your signatures on the Informed Consent document. We will also have to keep your name and your assigned ID number so we can match your data. At the end of the study any documents with identifying information will be destroyed. Your name will not be associated with the content of this study, but you will be assigned a three- digit number to protect your privacy. Your name will not be recorded in combination with your data; these two pieces of information will be stored separately in locked cabinets and within databases. Your number is ____, and this number is also on your folder.

All data will be collected by the researchers only. No one other than the researchers will have access to the data, unless it is aggregated first. All responses will be coded so as not to include the name of the participant. The information you provide will have your name removed and only a three- digit participant number will identify you during analyses and any written reports of the research.

This study is being conducted solely for educational and research purposes. Consistent with these academic purposes, any results would be freely publishable. However, to protect your identity, neither personal nor institutional names nor site names or distinguishing information will be used in any published works.

VI. **Compensation**

There is a $10 per hour compensation for participation in this experiment.

VII. **Freedom to Withdraw**

Participation in the evaluation is voluntary and the decision about whether you wish to participate is strictly your own. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. Withdrawal from the evaluation activities will not result in any adverse effects, and you will be compensated for any participation prior to withdrawing.

VIII. **Approval of Research**

This research project has been approved by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University.

IX. **Participant's Responsibilities**

Upon signing this form below, I voluntarily agree to participate in this study. I have no restrictions to my participation in the study.

X. **Participant's Permission**

I have read and understand the Informed Consent and conditions of this study. All of my questions have been answered. I give my consent to participate.

______________________	______________________	______________________
Participant's Printed Name	Participant's Email Address	Participant's Phone Number

______________________	______________________
Participant's Signature	Date

Should I have any questions about the evaluation or its conduct, I may contact:

Ralph Cullen	Email: rhcullen@vt.edu	Phone: (404) 913-1486
Dr. Michael Agnew	Email: mjagnew@vt.edu	Phone: (540) 231-0083
Dr. David M. Moore, Chair, IRB	Email: moored@vt.edu	Phone: (540) 231-4991

APPENDIX B: STUDY 2 AND 3 CONSENT FORM

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Informed consent form for participants of Research Project Involving Human Subjects

Title of the Project:
Multimodal Multitasking: Effects on Overall Workload

Principal Investigator:
Dr. Michael Agnew, ISE faculty, Department of Industrial and Systems Engineering, mjagnew@vt.edu, (540) 231-0083
Co-Investigator:
Ralph Cullen, PhD candidate, Department of Industrial and Systems Engineering, rhcullen@vt.edu, (404) 913-1486

I. **The Purpose of this Research/Project**
The purpose of this study is to investigate how mental and physical demands affect overall workload. You will be asked to interact with several cognitive tasks while sitting on an unstable chair. During this time, we will use an EEG cap to collect information about how your brain responds to the task.
II. **Procedures**
If you choose to participate in the evaluation activities, we will ask you to sign one informed consent document (this document). You will keep a copy for yourself.
The procedure for this experiment will last up to 3 hours on one day. After you have signed the consent form, you will be asked to fill out a brief demographics questionnaire and complete several paper surveys. Following this, you will be introduced to the test procedures, so you understand what each test session will entail. Next, we will place the EEG cap on your head and calibrate the wobble chair used in this experiment to your center of balance. You will then complete a series of two-minute trials sitting on the wobble chair at varying levels of stability (60%, 75%, and 100% stable). For half of the trials, one of several mental workload tasks will be present for you to complete using a computer. A break will be provided after each trial. After the trials, you will be compensated.
III. **Risks**
There are no more than minimal risks for participating in this study, other than you would encounter during a normal day. Neither our research team nor Virginia Tech have funds set aside for medical treatment should that be required during the experiment. Participants in a study are considered volunteers, regardless of whether they receive payment for their participation. Under Commonwealth of Virginia law, workers compensation does not apply to volunteers. Appropriate health insurance is recommended for yourself.
IV. **Benefits of the Project**
You will likely not gain any direct benefits as a result of your participation in this study. The general goal here is to examine how different demand types affect the way humans multitask. The results of this study may help in future research to prevent occupational injuries and errors and to identify individuals at increased risk of injury.
V. **Extent of Anonymity and Confidentiality**
We assure confidentiality to all participants. However, anonymity cannot be guaranteed, because we will need to have your signatures on the Informed Consent document. We will also have to keep your name and your assigned ID number so we can match your data. At the end of the study any documents with identifying information will be destroyed. Your name will not be associated with the content of this study, but you will be assigned a three- digit number to protect your privacy. Your name will not be recorded in combination with your data; these two pieces of information will be stored separately in locked cabinets and within databases. Your number is ____, and this number is also on your folder.

All data will be collected by the researchers only. No one other than the researchers will have access to the data, unless it is aggregated first. All responses will be coded so as not to include the name of the participant. The information you provide will have your name removed and only a three- digit participant number will identify you during analyses and any written reports of the research.

This study is being conducted solely for educational and research purposes. Consistent with these academic purposes, any results would be freely publishable. However, to protect your identity, neither personal nor institutional names nor site names or distinguishing information will be used in any published works.

VI. **Compensation**

There is a $10 per hour compensation for participation in this experiment.

VII. **Freedom to Withdraw**

Participation in the evaluation is voluntary and the decision about whether you wish to participate is strictly your own. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. Withdrawal from the evaluation activities will not result in any adverse effects, and you will be compensated for any participation prior to withdrawing.

VIII. **Approval of Research**

This research project has been approved by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University.

IX. **Participant's Responsibilities**

Upon signing this form below, I voluntarily agree to participate in this study. I have no restrictions to my participation in the study.

X. **Participant's Permission**

I have read and understand the Informed Consent and conditions of this study. All of my questions have been answered. I give my consent to participate.

____ ______________________

Participant's Printed Name Participant's Email Address Participant's Phone Number

_________________________ __________________

Participant's Signature Date

Should I have any questions about the evaluation or its conduct, I may contact:

Ralph Cullen	Email: rhcullen@vt.edu	Phone: (404) 913-1486
Dr. Michael Agnew	Email: mjagnew@vt.edu	Phone: (540) 231-0083
Dr. David M. Moore, Chair, IRB	Email: moored@vt.edu	Phone: (540) 231-4991

APPENDIX C: REVERSE DIGIT SPAN

REVERSE DIGIT SPAN

In this test you will be asked to remember digits presented orally and then to write them down in reverse order. After you hear each set of digits write your answer on the answer sheet provided. Please wait until all the digits are presented before writing your answer.

EXAMPLE:

(You will hear.)	(You should write:)
5 – 8 – 2	2 – 8 – 5
4 – 2 – 7 – 3 – 1	1 – 3 – 7 – 2 – 4

Adapted from Wechsler (1981) with permission.

Reverse Digit Span
Answer Sheet

1. ____
2. ____
3. ____
4. ____
5. ____
6. ____
7. ____
8. ____
9. ____
10. ____
11. ____
12. ____
13. ____
14. ____

APPENDIX D: DIGIT SYMBOL SUBSTITUTION

Digit-Symbol Substitution

In this task you will be asked to write symbols that correspond to the numbers 1 through 9. The numbers and their symbols are:

1	2	3	4	5	6	7	8	9
–	⊥	⊐	∟	⊔	O	∧	X	=

When you turn the page, there will be rows of numbers. Each number has an empty box below it. Your task is to write the corresponding symbol below each number. Please try the following:

The numbers and their corresponding symbols will be given to you again on the next page. You will have 90 seconds to write as many symbols as possible. Please start with the top row and work from left to right, <u>without skipping any boxes</u>.

Please do not turn the page until instructed to do so.

Adapted from Wechsler (1981) with permission.

1	2	3	4	5	6	7	8	9
—	⊥	⊐	∟	⊔	○	∧	X	=

2	1	3	7	2	4	8	1	5	4	2	1	3	2	1	4	2	3	5	2	3	1	4	6	3

1	5	4	2	7	6	3	5	7	2	8	5	4	6	3	7	2	8	1	9	5	8	4	7	3

6	2	5	1	9	2	8	3	7	4	6	5	9	4	8	3	7	2	6	1	5	4	6	3	7

9	2	8	1	7	9	4	6	8	5	9	7	1	8	5	2	9	4	8	6	3	7	9	8	6

APPENDIX E: ROLAND-MORRIS LBP QUESTIONNAIRE

RATING SCALE FOR LOW BACK PAIN

When your back hurts, you may find it difficult to do some of the things you normally do. This list contains some sentences that people have used to describe themselves when they have back pain. When you read them, you may find that some stand out because they describe you. As you read the list, think of yourself. When you read a sentence that describes you, mark the box next to it. If the sentence does not describe you, then leave the space blank and go on to the next one. **Remember, only mark the sentence if you are sure that it describes you**.

- ☐ I stay at home most of the time because of the pain in my back.
- ☐ I change position frequently to try and make my back comfortable.
- ☐ I walk more slowly than usual because of the pain in my back.
- ☐ Because of the pain in my back, I am not doing any of the jobs that I usually do around the house.
- ☐ Because of the pain in my back, I use a handrail to get upstairs.
- ☐ Because of the pain in my back, I lie down to rest more often.
- ☐ Because of the pain in my back, I have to hold on to something to get out of a reclining chair.
- ☐ Because of the pain in my back, I ask other people to do things for me.
- ☐ I get dressed more slowly than usual because of the pain in my back.
- ☐ I only stand up for short periods of time because of the pain in my back.
- ☐ Because of the pain in my back, I try not to bend or kneel down.
- ☐ I find it difficult to get out of a chair because of the pain in my back.
- ☐ My back hurts most of the time.
- ☐ I find it difficult to turn over in bed because of the pain in my back.
- ☐ My appetite is not very good because of the pain in my back.
- ☐ I have trouble putting on my socks (or stockings) because of the pain in my back.
- ☐ I only walk short distances because of the pain in my back.
- ☐ I sleep less because of the pain in my back.
- ☐ Because of the pain in my back, I get dressed with help from someone else.
- ☐ I sit down for most of the day because of the pain in my back.
- ☐ I avoid heavy jobs around the house because of the pain in my back.
- ☐ Because of the pain in my back, I am more irritable and bad tempered with people.
- ☐ Because of the pain in my back, I go upstairs more slowly than usual.
- ☐ I stay in bed most of the time because of the pain in my back.

Adapted from Roland and Morris (1983) with permission.

APPENDIX F: MORNINGNESS-EVENINGNESS QUESTIONNAIRE

MORNINGNESS-EVENINGNESS QUESTIONNAIRE

Adapted from Horne and Ostberg (1976) with permission.

For each question, please select the answer that best describes you by circling the point value that best indicates how you have felt in recent weeks.

1. Approximately what time would you get up if you were entirely free to plan your day?
[5] 5:00 AM-6:30 AM (05:00-06:30 h)
[4] 6:30 AM-7:45 AM (06:30-07:45 h)
[3] 7:45 AM-9:45 AM (07:45-09:45 h)
[2] 9:45 AM-11:00 AM (09:45-11:00 h)
[1] 11:00 AM-12 noon (11:00-12:00 h)

2. Approximately what time would you go to bed if you were entirely free to plan your evening?
[5] 8:00 PM-9:00 PM (20:00-21:00 h)
[4] 9:00 PM-10:15 PM (21:00-22:15 h)
[3] 10:15 PM-12:30 AM (22:15-00:30 h)
[2] 12:30 AM-1:45 AM (00:30-01:45 h)
[1] 1:45 AM-3:00 AM (01:45-03:00 h)

3. If you usually have to get up at a specific time in the morning, how much do you depend on an alarm clock?
[4] Not at all
[3] Slightly
[2] Somewhat
[1] Very much

4. How easy do you find it to get up in the morning (when you are not awakened unexpectedly)?
[1] Very difficult
[2] Somewhat difficult
[3] Fairly easy
[4] Very easy

5. How alert do you feel during the first half hour after you wake up in the morning?
[1] Not at all alert
[2] Slightly alert
[3] Fairly alert
[4] Very alert

6. How hungry do you feel during the first half hour after you wake up?
[1] Not at all hungry
[2] Slightly hungry
[3] Fairly hungry
[4] Very hungry

7. During the first half hour after you wake up in the morning, how do you feel?
[1] Very tired
[2] Fairly tired
[3] Fairly refreshed
[4] Very refreshed

8. If you had no commitments the next day, what time would you go to bed compared to your usual bedtime?
[4] Seldom or never later
[3] Less that 1 hour later
[2] 1-2 hours later
[1] More than 2 hours later

9. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week, and the best time for him is between 7-8 AM (07-08 h). Bearing in mind nothing but your own internal "clock," how do you think you would perform?
[4] Would be in good form
[3] Would be in reasonable form
[2] Would find it difficult
[1] Would find it very difficult

10. At approximately what time in the evening do you feel tired, and, as a result, in need of sleep?
[5] 8:00 PM-9:00 PM (20:00-21:00 h)
[4] 9:00 PM-10:15 PM (21:00-22:15 h)
[3] 10:15 PM-12:45 AM (22:15-00:45 h)

[2]	12:45 AM-2:00 AM (00:45-02:00 h)
[1]	2:00 AM-3:00 AM (02:00-03:00 h)

11. You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last two hours. You are entirely free to plan your day. Considering only your "internal clock," which one of the four testing times would you choose?
[6]	8 AM-10 AM (08-10 h)
[4]	11 AM-1 PM (11-13 h)
[2]	3 PM-5 PM (15-17 h)
[0]	7 PM-9 PM (19-21 h)

12. If you got into bed at 11 PM (23 h), how tired would you be?
[0]	Not at all tired
[2]	A little tired
[3]	Fairly tired
[5]	Very tired

13. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which one of the following are you most likely to do?
[4]	Will wake up at usual time, but will not fall back asleep
[3]	Will wake up at usual time and will doze thereafter
[2]	Will wake up at usual time, but will fall asleep again
[1]	Will not wake up until later than usual

14. One night you have to remain awake between 4-6 AM (04-06 h) in order to carry out a night watch. You have no time commitments the next day. Which one of the alternatives would suit you best?
[1]	Would not go to bed until the watch is over
[2]	Would take a nap before and sleep after
[3]	Would take a good sleep before and nap after
[4]	Would sleep only before the watch

15. You have two hours of hard physical work. You are entirely free to plan your day. Considering only your internal "clock," which of the following times would you choose?
[4]	8 AM-10 AM (08-10 h)
[3]	11 AM-1 PM (11-13 h)
[2]	3 PM-5 PM (15-17 h)

[1] 7 PM-9 PM (19-21 h)

16. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week. The best time for her is between 10-11 PM (22-23 h). Bearing in mind only your internal "clock," how well do you think you would perform?

[1] Would be in good form
[2] Would be in reasonable form
[3] Would find it difficult
[4] Would find it very difficult

17. Suppose you can choose your own work hours. Assume that you work a five-hour day (including breaks), your job is interesting, and you are paid based on your performance. At approximately what time would you choose to begin?

[5] 5 hours starting between 4-8 AM (05-08 h)
[4] 5 hours starting between 8-9 AM (08-09 h)
[3] 5 hours starting between 9 AM-2 PM (09-14 h)
[2] 5 hours starting between 2-5 PM (14-17 h)
[1] 5 hours starting between 5 PM-4 AM (17-04 h)

18. At approximately what time of day do you usually feel your best?

[5] 5-8 AM (05-08 h)
[4] 8-10 AM (08-10 h)
[3] 10 AM-5 PM (10-17 h)
[2] 5-10 PM (17-22 h)
[1] 10 PM-5 AM (22-05 h)

19. One hears about "morning types" and "evening types." Which one of these types do you consider yourself to be?

[6] Definitely a morning type
[4] Rather more a morning type than an evening type
[2] Rather more an evening type than a morning type
[1] Definitely an evening type

APPENDIX G: NASA-TLX RATING SHEET

Adapted from Hart and Staveland (1988) with permission.

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High