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Dual task study of cognitive and postural interference: Development of a methodology for use in vestibular disorders

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Dual Task Study of Cognitive and Postural Interference:

Development of a Methodology for Use in Vestibular Disorders

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Abstract

For patients with vestibular impairments, postural stability alone can be demanding but is more taxing when an individual's attention is focused on both maintaining balance and a secondary/cognitive task simultaneously. Thus, dual task paradigms where balance must be maintained while performing postural and cognitive tasks concurrently provides an assessment on one's attentional resources available for balance. Previous studies show varying levels of dual task effects in patients with vestibular loss with little consistency between studies regarding choice of balance and cognitive tasks. The purpose of this study was to assess the feasibility of a dual task paradigm using portable instrumentation and under conditions hypothesized to be more difficult for patients with vestibular loss. Postural stability was assessed using a Romberg on foam over a Wii board where both anterior-posterior and medial-lateral sway could be quantified. The cognitive task was a Stroop test administered under cardboard google glasses, yielding an equivalent of a vision-denied condition. Participants were divided into three instructional groups. Results showed a measurable dual task effect consistent with the posture first hypothesis in which postural task was prioritized over cognitive task; however, the effect was dependent on instruction group. The clinical significance of these findings will be discussed.

I. Introduction

A majority of vestibular testing focuses on evaluating the integrity of the vestibular system (i.e. the impairment level); this leaves a gap in evaluating how the impairment affects individuals with the disorder (i.e. the functional level). Dynamic or static postural assessments such as the Romberg are functional balance tests. However, they are limited in their ability to evaluate balance in a real world setting because the patient is solely focused on maintaining balance during these assessments, a luxury not often found in the real world where multitasking is the norm. A loss of balance and higher risk of falls occurs when an individual's attention is focused elsewhere – on conversation, a text message, etc. (Beuchet et al., 2009). There is a need for a functional test of the vestibular system that shows the interactions between balance and attention.

Attention has previously been defined as the amount of information processing that an individual is able to perform at one time. One of the predominant theories surrounding attention is the theory of attentional capacity (Negahban et al., 2011; Redfern et al., 2004; Woollacott & Shumway-Cook, 2002; Yardley et al., 2001). Attentional capacity is based on the idea that there is a limited amount of attention, thus when two or more tasks are performed at the same time, the performance of one or multiple tasks degrades if together they exceed the attentional capacity of the brain. The difficulty of the tasks influences the amount of degradation. Two relatively simple tasks, like chewings gum and walking, can be performed without any degradation because the amount of attention for the two tasks is within the attentional capacity. However, when the combined tasks require more attention than is available, a degradation in performance is observed (Redfern et al., 2004).

Balance is controlled by a combination of vestibular senses, visual input, and proprioception which are all integrated centrally. Since balance is necessary for survival, when one of the three senses is inhibited, the other senses provide enough input to compensate for the loss. Balance has previously been perceived as an entirely autonomic process. However, recent research utilizing dual task paradigms has consistently shown that balance is influenced by attentional demands (Dault et al., 2001; Vuillerme & Nougier, 2004; Woollacott & Shumway-Cook, 2002)

A dual task paradigm is a methodology where two tasks, such as a postural and cognitive task, are performed simultaneously. This method has the ability to show how performing two tasks together may influence performance relative to a single task due to the allocation of attention to the competing tasks. When attentional capacity is exceeded there is a degradation in performance in either one or both tasks. When the two tasks are postural and cognitive, the degradation usually occurs in the cognitive condition as posture is prioritized; this is known as a posture first phenomenon (Andersson et al, 2003; Resch et al., 2011; Yardley et al., 2001). The posture first phenomenon theorizes that participants will prioritize postural stability over the secondary task. The secondary task is typically a cognitive task but may also be a manual task. Zijlstra et al. (2008) equated this to a "safety first theory" as participants are more likely to allocate attentional capacity to postural stability in order to prevent a fall. In support of the posture first phenomenon, Resch et al. (2011) studied the auditory-switch cognitive task performed simultaneously with the six Sensory Organization Test conditions. They found young healthy participants maintained their balance at the expense of the cognitive task for both accuracy and reaction time, thus supporting the posture first phenomenon. In contrast, Shumway-Cook et al. (1997) observed a decrement in only the postural task performance for young healthy participants as well as older adults with and without history of fall. They hypothesized that task prioritization may be influenced by the nature of the tasks, instructions, and goal of the participants. Similar to Zijlstra et al. (2008), Shumway-Cook et al. (1997) suggested that posture may be prioritized in situations with “a threat of injury”.

Everyone is susceptible to a dual task effect, dependent on the chosen tasks, to varying degrees. Even athletes with trained balance systems, such as gymnasts, are susceptible. Vuillerme and Nougier (2004) saw a statistically significant decrease in reaction time for their two participant groups - expert gymnasts and expert athletes in non-gymnastic sports- when performing the cognitive task concurrent with a postural task. They suggested that with training, there may be decreased attentional capacity requirements, as they found a smaller dual task effect for their gymnastics experts compared to the athletes without gymnastic experience. Some groups are more susceptible to a dual task effect than others. Groups that are more susceptible are populations that experience a decrease in cognitive or postural ability, such as individuals with vestibular disorders, neurological disorders, or the elderly. Negahban et al. (2011) observed a differentiation between postural task performance in participants with multiple sclerosis compared to age-matched healthy control during a dual task condition. Additionally, Granacher et al. (2011) and Shumway-Cook et al. (1997) both examined the effects of age on a dual task study and observed a greater dual task effect with an increase in age.

Vestibular patients are hypothesized to be more susceptible to a dual task effect due to impaired vestibular sensory function. Patients with vestibular disorders typically experience acute symptoms that are self-limiting but may continue to experience a decrement in balance. Often these patient’s also report increased cognitive demands, such as feeling foggy, difficulty focusing, etc. A few studies have attempted to examine the effects of attention on balance in vestibular patients utilizing a dual task paradigm. While the balance symptoms and cognitive symptoms may subside after compensation, when tested with dual task paradigm these patients may still experience a degradation in performance (Andersson et al, 2003; Redfern et al., 2004). This degradation in performance after compensation may be due to increased cognitive processing necessary for compensation (Redfern et al., 2004).

Yardley et al. (2001) reported a decrement in both cognitive task reaction time and accuracy in a vestibular population and healthy controls with increased balance task difficulty. They did not observe a decrement in the postural stability during the dual task condition and hypothesized that the reason for their findings was because balance was prioritized in both vestibular patients and healthy controls when their balance is unstable, providing further support for the posture first theory. They found a difference in baseline controls between the vestibular patients and healthy controls but saw similar patterns of dual task effect for the two populations. Postural task difficulty limited their study, as many vestibular patients selectively dropped out of the more difficult postural conditions.

Redfern et al. (2004) evaluated dual task effect in a unique vestibular population with surgically confirmed unilateral vestibular lesions that no longer experienced symptoms of dizziness or definable postural impairments. They found that postural task difficulty adversely affected the informational processing task. Additionally, they saw a group difference in the seated cognitive task condition – the vestibular population performed slower than the control group. This is similar to Yardley et al.'s (2001) findings that there was a baseline cognitive measures shift for the vestibular participants compared to the healthy controls. Redfern et al. (2004) hypothesized that vestibular compensation requires attentional resources even when posture is unchallenged. Postural sway increased with increasing postural task difficulty similarly between the two groups. Redfern et al. (2004) highlighted the need for additional research into the interaction between cognitive resources, postural control, and vestibular compensation.

Instructions provided during a dual task paradigm provide an integral part in affecting the allocation of attentional resources. Additionally, lack of explicit instructions limits the researchers understanding of participant motivation and intrinsic allocation of attentional resources (Redfern et al., 2004). Burcal, Drabik, and Wikstrom (2014) examined the effect of instructions in a dual task paradigm by providing instructions to focus on the postural task, cognitive task, or providing no instructions at all. Interestingly, their results indicated that providing instructions improved postural control for both the postural instruction group and the cognitive task. Providing explicit instructions, regardless of the location of attentional focus, may influence postural control. There is considerable variability between most dual task paradigm research in regard to instructions. Of the experimental studies we reviewed, five studies either provided no instructions during the dual task conditions or failed entirely to report on their instructions (Andersson et al, 2003; Dault et al., 2001; Pellecchia, 2003; Resch et al., 2011; Yardley et al., 2001), while four studies specified equal attentional allocation to both tasks during the dual task condition (Granacher et al., 2011; Negahban et al., 2011; Redfern et al., 2004; Shumway-Cook et al., 1997). A single study in our review instructed participants to prioritize the postural task over the secondary task (Vuillerme & Nougier., 2004).

Although there are several studies examining dual task effects in various populations, there is a lack of uniformed methodology making comparisons across studies difficult. A review study by Zijlstra et al. (2008) found a total of 606 dual task studies, 114 of which analyzed dual task effect in older patients, only 19 studies met their inclusion criteria, and they were unable to make any conclusion regarding the added value of dual task effect due to inability to make a complete comparison between studies. One reason is the lack of uniform methodology across studies. Thus, in order to further vestibular research regarding dual task effect, cognitive requirements of vestibular compensation, and possibly implement a dual task paradigm in a vestibular clinic, it is necessary to develop standards for testing. Previous research has shown that the dual task paradigm must be difficult enough to prevent a ceiling effect, without being too difficult that the population of interest is unable to perform the task (Andersson et al, 2003; Pellecchia, 2003; Yardley et al., 2001).

Our long-term goal is to design a dual task postural stability paradigm that will have utility in a vestibular population. In order to ensure the methodology is appropriate for testing in a vestibular clinic, a vision denied condition is necessary to further challenge the vestibular system. Further, many vestibular patients are older and have concomitant hearing loss. Therefore, we wanted to choose a cognitive task that was visual and could be done under goggles. In addition, we focused on creating a low cost, portable test that will allow for versatility and wide implementation of testing. This study investigates 1. Does our chosen methodology create a dual task effect in a young, healthy population and 2. Do instructions influence the ability to create a dual task effect.

II. Methods

Participants

A total of 25 healthy young participants, age 20 to 23, voluntarily participated in this study. Since our primary purpose is to facilitate the creation of a methodology for use with different clinical populations in the future, a control population without cognitive impairments or balance impairments/advantages was necessary to ensure a dual task effect occurs in a control population with the methodology of choice. Another important consideration while creating a methodology is to ensure a ceiling effect does not occur with normal healthy adults, while a floor effect does not occur in populations of interest for future studies. Participants were excluded from analysis if they met any of the following exclusion criteria: 1. history of vestibular disorder, 2. hearing loss, 3. history of cognitive impairments (i.e. concussion, neurological disorder, etc), 4. lower extremity injury in the past 5 years or unhealed lower extremity injury, or 5. visual color perception impairments. The protocol was approved by the James Madison University IRB board protocol number 201515.

Cognitive task

The Stroop task, a well-researched information processing task, was used as the cognitive task due to the flexibility to change the difficulty level for future studies. See Figure 1 for examples of the Stroop test with the correct answer. The Stroop task was displayed on an iPod and performed under cardboard goggles with extended sides to eliminate peripheral visual input. The use of cardboard goggles ensures the cognitive task acted as a vision denied condition which is essential for future testing of a vestibular population. One word-color combination was displayed on a white

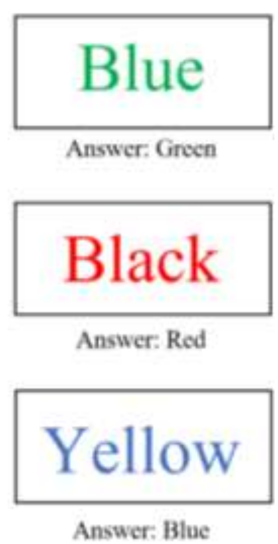

Figure 1: Stroop Test Examples. Participants were instructed to repeat the font color.

screen at a time. A website was specifically designed for use in this study to display the Stroop test. Five pre-set lists were developed to facilitate scoring for accuracy. Each word-color combination was pseudo-randomized to ensure that a word or color did not appear twice in a row. The order of the lists was randomized and only repeated following completion of all 5 lists.

Participants were instructed to verbally state the color of the text and utilized a handheld remote control to advance through the words. Scoring of the cognitive task was measured via average reaction time, and accuracy. A secondary computer duplicating the iPod screen was used to facilitate accuracy scoring and recorded the average reaction time. Participants were instructed to proceed to the next word without correcting an error if the error was noticed. Participants were notified that the Stroop test was scored for both accuracy and reaction time.

Postural tasks

Two levels of balance tasks were performed – narrow stance on a firm surface and narrow stance on a compliant surface. Narrow stance was the stance used in the Romberg test as described by the NIH toolbox (Agrawal et al, 2011). A Wii balance board was converted to a force place with real-time center of pressure (COP) data using BrainBLoX software. The Wii board

Acronym Cheat Sheet
for Test Conditions and Measurements

Single task conditions
VS – Verbal Stroop alone
NW – Narrow Stance on Firm Surface alone
NF – Narrow Stance on Compliant Surface alone

Dual task conditions
VS-NW – Narrow Stance on Firm Surface
VS-NF – Narrow Stance on Compliant Surface

Cognitive Test Measurements
Accuracy
Reaction Time

Postural Test Measurements
FPML – Medial Lateral sway measured from a Force Plate
FPAP – Anterior Posterior sway measured from a Force Plate
AAP – Anterior Posterior sway measured from an Accelerometer

Table 1: Acronym Cheat Sheet for Test Conditions and Measurements

recorded COP displacement in cm in two planes - anterior-posterior (AP), and medial-lateral (ML). COP displacement was sampled over a 30 second interval for each trial at a sampling rate of 60-70 frames per second.

An accelerometer attached to the participant's waist recorded anterior-posterior sway. For safety considerations, participants wore a gait belt and a research assistant spotted the participant throughout each trial. The accelerometer was attached midline at the participant's waist level on the gait belt. The accelerometer acted as a measurement of hip strategy while the force plate measured ankle strategy to ensure both strategies were represented. Due to equipment set-up, accelerometer data recorded for 40 seconds. The last 10 seconds was discarded prior to analysis to produce a 30 second trial. RMS was obtained from the first 30 seconds of the accelerometer data to produce an average COP sampled at a rate of 200 degrees per second.

Task conditions and measurements with the paired acronym are outlined in Table 1 for reference.

Instructions

Participants were randomly sorted into three instructional groups; one group was instructed to focus primarily on the postural task, the second group was instructed to focus on the cognitive task, the third group was instructed to give each task equal focus. Participants were informed of the general purpose of the study but were blind to the instructional component. General instructions regarding performing the Stroop test and the postural tasks were identical between participants and were presented prior to the instructional group specific instructions.

Procedure

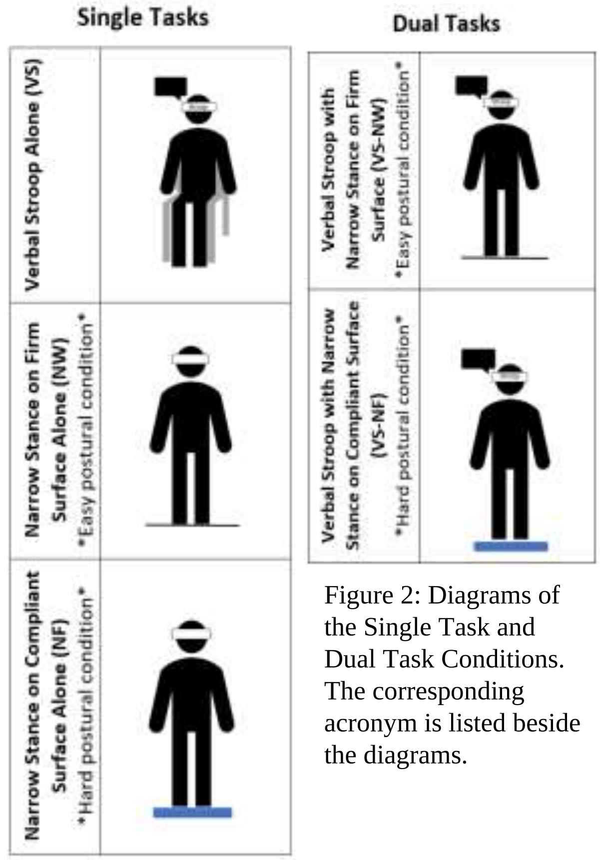

Figure 2: Diagrams of the Single Task and Dual Task Conditions. The corresponding acronym is listed beside the diagrams.

Four practice Stroop trials were performed at the beginning of the session to prevent learning effect. All participants started with the set of three single task conditions – Stroop test while sitting down, narrow stance on firm surface while looking at a white screen, and narrow stance on a compliant surface while looking at a white screen. Following single tasks, instructions specific to each instruction group were reiterated and then participants completed the dual tasks conditions. Single tasks order, and dual task order was randomized. Recording for each trial was initiated once the participant assumed the correct position and indicated they were ready. Each trial lasted 30 seconds and participants were given at least a 30 second break between trials.

Data Analysis

Two measurements were obtained from the cognitive task trials – 1. average reaction time per item and 2. percentage accuracy. Three measurements were obtained from the postural task trials – 1. Medial-lateral plane COP displacement on the force plate (FPML) 2. Anterior-posterior plane COP displacement on the force plate (FPML) 3. COP representing anterior-posterior sway for the accelerometer (AAP). RMS was derived from the three postural measurements recordings. Repeated measure ANOVA was used for statistical comparison of the different tasks for each instruction group.

III. Results

The postural instruction group was made up of 9 participants (9 females, 0 males) with ages ranging from 20 to 23 with an average age of 20.89. The cognitive instruction group was a group of 9 participants (9 females, 0 males) ages 20 to 22 with an average age of 20.78. The neutral instruction group had 7 participants (6 females, 1 male) with ages ranging from 20 to 23 with an average age of 20.86.

Cognitive/Stroop Test Assessment

The two metrics of cognition from the Stroop test are reaction time and accuracy. For the cognitive task analysis, the three conditions that were analyzed were Stroop test alone (VS; i.e. single task condition), and the two dual-task conditions of the Stroop with narrow stance on firm surface (VS-NW) and Stroop with narrow stance on compliant surface (VS-NF). The descriptive results (mean and standard deviation) for the reaction time and accuracy measurements for each instruction group across all 3 analyzed conditions are shown in Table 2.

Table 2: Descriptive Results from the Stroop Test – reaction time and accuracy mean and standard deviation by instructional groups and conditions.

	Postural Instruction Group	
Condition	Reaction Time (ms)	Accuracy (percentage)
NW	1042 ± 183	100 ± 0.00
VS-NW	1114 ± 217	99.51 ± 1.45
VS-NF	1117 ± 179	98.71 ± 1.95

	Cognitive Instruction Group	
Condition	Reaction Time (ms)	Accuracy (percentage)
VS	997 ± 82	100 ± 0.00
VS-NW	996 ± 94	99.32 ± 2.05
VS-NF	993 ± 140	99.70 ± 0.90

	Neutral Instruction Group	
Condition	Reaction Time (ms)	Accuracy (percentage)
VS	1172 ± 247	100 ± 0.00
VS-NW	1138 ± 251	100 ± 0.00
VS-NF	1085 ± 209	99.63 ± 0.97

*=p<0.05

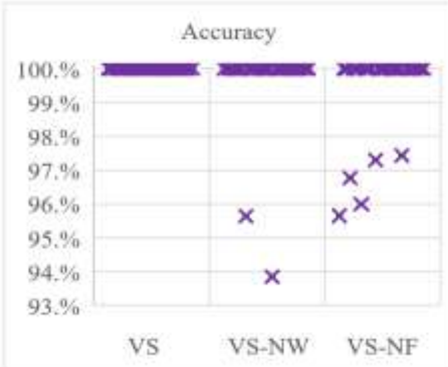

Figure 3: Stroop Test Accuracy Graph. Each X represents a participant's accuracy score.

High Stroop test accuracy scores (Figure 3) were obtained for all instructional groups across the single task condition and both dual-task conditions. The minimum accuracy score was 93% with an average accuracy score over 98% for all tasks in all instruction groups.

To assess the presence of a dual task effect, a repeated measure ANOVA was used to compare the Stroop test results between the single and dual task conditions, separately for each of the instruction groups. For accuracy of the Stroop test, no dual task effect was observed as no statistical significance was found for accuracy scores for any instruction groups (postural instruction group ($F(7.595,23.627)=2.572$, $p=0.115$); cognitive instruction group ($F(2.112, 27.973)=0.604$, $p=0.488$); neutral instruction group ($F(0.626, 3.757)=1.00$, $p=0.356$)).

For the measurement of reaction time, a dual task effect was observed for the postural instruction group ($F(32606.190, 28945.832)= 9.012$, $p=.004$) with a significant increase in average reaction time (i.e. worse performance) between the single task and dual task on firm surface (increase of 74.8 msec/word (95% CI, 18.0 to 131.6), and between the

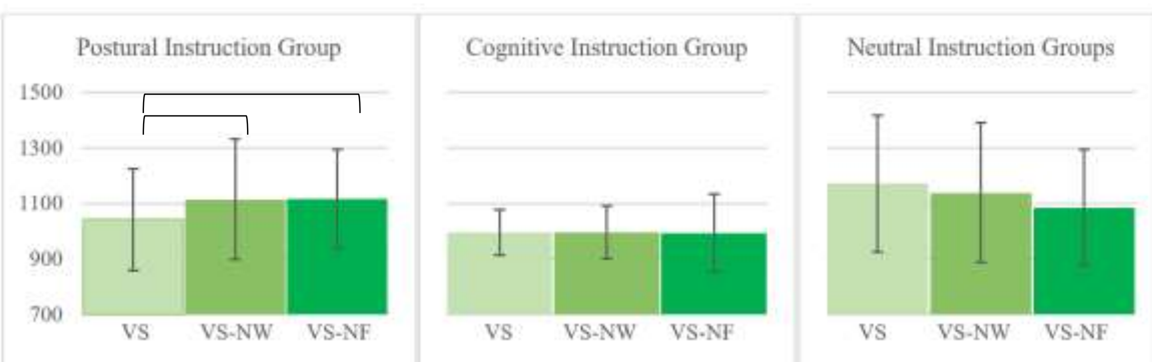

Figure 4: Average Stroop Test Reaction Time Bar Graphs. Each instruction group is represented separately under their respective titles. Brackets dictate statistical significance. Error bars represent standard deviation.

single task and dual task on a compliant surface (increase of 72.6 msec (95% CI, 19.6 to 125.6). The two other instruction groups, cognitive instruction group (F(58.401, 61368.317)=0.008, p=0.962) and neutral instruction group (F(26748.031, 56502.804)=2.840, p=0.115) did not exhibit a dual task effect on reaction time. Figure 4 dictates the Stroop test reaction time across the 3 analyzed conditions for each instruction group. Statistical significance for the dual task effect is dictated by the brackets on the postural instruction group graph.

Postural Assessment

The three metrics for posture were Force Plate Medial Lateral sway (FPML), Force Plate Anterior Posterior sway (FPAP), and Accelerometer Anterior Posterior sway (AAP). FPML and FPAP were measured in cm from COP displacement. AAP was measured in degrees from COP displacement. For the postural analysis, the four conditions that were analyses were narrow stance on firm surface alone (NW; i.e. a single task condition), narrow stance on compliant surface alone (NF; i.e. a single task condition), and the two dual task conditions of Stroop with narrow stance on firm surface

Table 3: Descriptive Results from the Postural Conditions – force plate medial lateral sway, force plate posterior lateral sway, and accelerometer anterior posterior sway mean and standard deviation by instruction groups and conditions.

	Postural Instruction Group		
Condition	FPML (cm)	FPAP (cm)	AAP (degrees)
NW	1.25 ± 0.47	2.93 ± 1.43	4.76 ± 5.54
NF	1.57 ± 0.44	1.99 ± 0.79	2.88 ± 1.66
VS-NW	1.19 ± 0.60	3.03 ± 1.15	7.85 ± 9.53
VS-NF	2.12 ± 0.95	1.54 ± 0.38	8.91 ± 8.50

	Cognitive Instruction Group		
Condition	FPML (cm)	FPAP (cm)	AAP (degrees)
NW	1.13 ± 0.34	2.59 ± 1.40	7.89 ± 4.72
NF	2.07 ± 1.02	2.16 ± 0.92	7.35 ± 6.72
VS-NW	1.19 ± 0.60	3.43 ± 1.53	12.39 ± 11.75
VS-NF	2.12 ± 0.81	2.11 ± 0.81	7.77 ± 6.39

	Neutral Instruction Group		
Condition	FPML (cm)	FPAP (cm)	AAP (degrees)
NW	1.13 ± 0.32	1.98 ± 0.93	7.26 ± 10.37
NF	1.78 ± 0.40	1.92 ± 0.38	3.89 ± 3.21
VS-NW	0.95 ± 0.36	2.21 ± 1.23	9.72 ± 13.16
VS-NF	1.84 ± 0.50.	1.60 ± 0.52	10.34 ± 13.52

(VS-NW) and Stroop with narrow stance on compliant surface (VS-NF). The mean and standard deviation for each analyzed condition across the three instruction groups are shown in Table 3.

Figure 5 depicts the statistical significance between difficulty levels denoted with bracketing. This indicated that the compliant surface was a more difficult condition than the firm surface condition.

Statistical significance occurred for the FPMP measurement for all three instruction groups – postural instruction group ($F(4.901, 9.242)= 4.243$, $p=0.042$), cognitive instruction group ($F(8.444, 8.524)= 7.925$, $p= 0.004$), and neutral instruction group ($F(4.309, 1.325)=19.512$, $p=0.000$). Pairwise comparison analysis revealed statistical significant indicated two levels of postural task difficulty. There was no statistically significant dual task effect as there was no significant difference between the single task and dual task conditions of the same postural condition (i.e. comparing NW to VS-NW, or NF to VS-NF). The brackets in Figure 5 indicate the statistical significance pairwise comparisons.

Statistical significance did not occur for FPAP measurement for the postural instruction group ($F(14.286, 29.186)=3.916$, $p=0.05$), cognitive instruction group ($F(10.164, 33.347)= 2.438$, $p= 0.123$), or neutral instruction group ($F(1.339, 8.067)=0.996$, $p=0.397$). Although there was no statistical significance found, a trend of improved postural sway in the more difficult postural condition is observed, regardless of the single task or dual task condition.

There was also no statistical significance for the AAP measurement data for the postural instruction group ($F(208.451, 591.868)=2.818$, $p=0.095$), cognitive instruction group (F(151.7577, 793.996)= 1.529, p= 0.245), or neutral instruction group (F(179.594, 493.211)=2.185, p=0.180). However, for the postural instruction group and the neutral

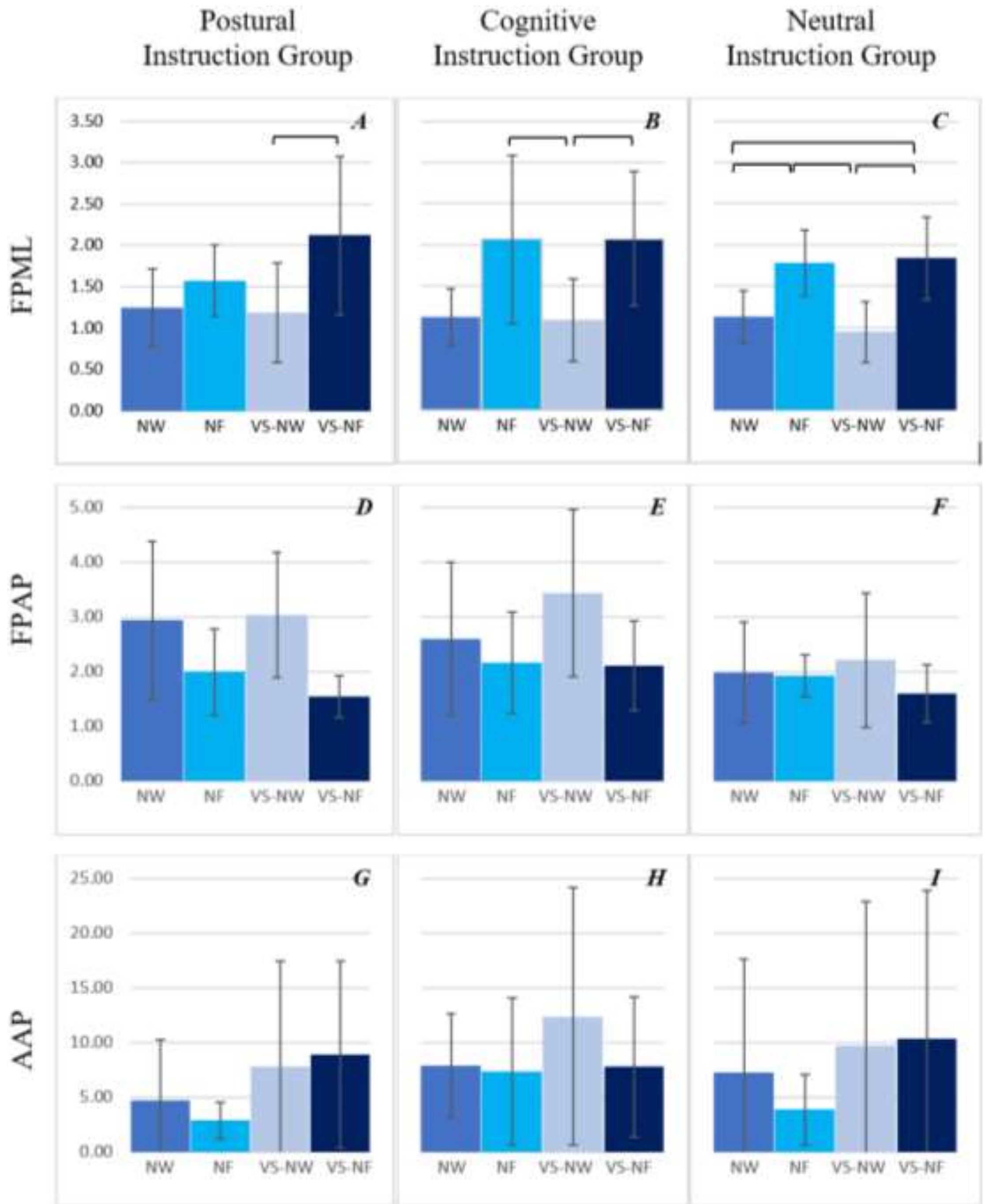

Figure 5: Postural Task Average Sway Bar Graphs Across the Four Conditions for Each Instruction Group. The graphs are displayed in rows and columns, with the same instruction group located in each column, and the postural task metric located in each row. Each column and row are headed by the instruction group title and metric respectively for easy reference. Error bars represent standard deviation.

group, there does appear to be a trend of increased sway for the dual task conditions compared to the single task conditions (Figure 5G and 5I).

Overall, analysis of dual task effect for postural conditions were not significant (P> 0.05) therefore additional analysis was not performed. Posture was not statistically significantly altered between single task and dual task conditions.

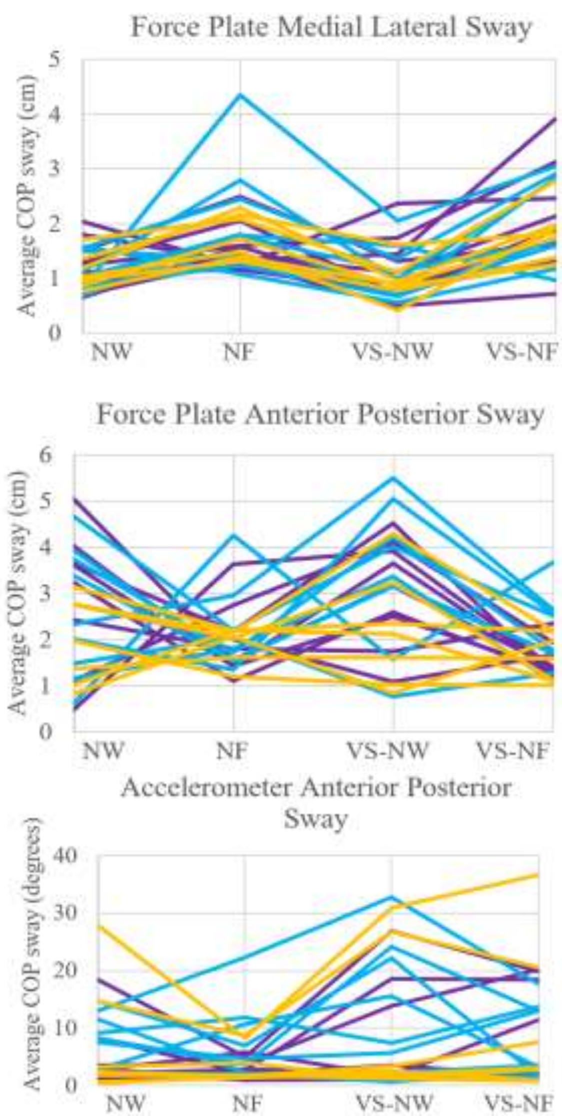

Figure 6: Individual's Sway Across Postural Conditions Scatterplot. Each line plots a participant's average COP sway and how the sway varies across the 4 postural conditions. Key: Purple = postural instruction group; Blue = cognitive instruction group; Yellow = neutral instruction group

Figure 6 dictates each individuals sway across the 4 conditions and 3 measurements. FPML dictates a clear trend of increased sway for the more difficult postural conditions for all instructions groups. Trends of individual sway varied for the FPAP measurement, although most individuals performed similarly for the easy and hard postural tasks regardless of the cognitive task, ie individuals improved or performed worse on the more difficult postural task compare to the easier postural task, regardless of if they were doing the single or dual task trial. For the AAP measurement, many individuals had minimal sway across trials, dictated by the majority of individual sway lines overlapping on Figure 6 AAP. A handful of individuals had significantly more variability in sway across conditions for the AAP metric.

IV. Discussion

We defined a dual task effect as a change in one of the dependent variables (i.e. metric from either the Stroop test or a postural sway measure) between the single task and dual task conditions. Based on the posture first principle, we hypothesized that a dual task effect would be observed in this study cohort as a change in the Stroop task, while postural sway would be prioritized and would not change between single and dual task conditions. In addition, we speculated that instructions may shift the participants attention and alter the presence of any dual task effect.

Results showed that a dual task effect was elicited for the postural instruction group where we observed a significant slowing in the reaction time measurement in the dual task condition relative to the reaction time recorded in the Stroop single task condition. That is, participants that focused on postural stability saw a decrement to the cognitive task when asked to perform both the cognitive and postural tasks simultaneously. This confirmed the methodology was able to effectively elicit a dual task effect with a young healthy participant group and that instructions had an impact on the effect. A dual task effect did not occur for the other cognitive metric – accuracy. This is most likely due to the high accuracy scores which indicates a ceiling effect may have occurred.

A dual task effect also did not occur in any of our postural metrics. Similar to Yardley et al. (2001) the decrement was only observed in the cognitive task while the postural tasks metrics did not produce a dual task effect. One explanation is that participants always prioritize the postural condition to an extent (Yardley et al., 2001).

Another possible reason for the lack of dual task effect on the postural conditions may be the results of the postural tasks not being difficult enough. However, increased postural task difficulty can also result in a floor effect occurring, which occurred for the more difficult postural conditions in Yardley et al. (2001).

Our findings support the "posture first" theory which speculates when attentional capacity is exceeded, the postural task will be prioritized over the secondary task. Similar to our findings, Vuillerme and Nougier (2004) also saw a decrease in cognitive task reaction time when the dual task conditions were performed and saw an increase in the observed decrement for the more difficult dual task conditions. Unlike the standard definition of "posture first phenomenon" where the decrement is observed in the secondary task which is supported by both our results and Vuillerme and Nougier's (2004) results, Resch et al.'s (2011) data supported the posture first phenomenon in another way. Resch et al. (2011) concluded that the decrease in postural sway (i.e. improvement) during the dual task conditions supports the posture first theory as participants prioritized and improved their postural control for the more difficult conditions.

A dual task effect was only observed in the postural instruction group who were instructed to focus on their balance. In contrast, asking participants to focus on the cognitive task or providing neutral instructions resulted in no measurable dual task effect in this cohort. Similar to Burcal, Drabik & Wikstroma (2014), we found that providing explicit instructions was able to shift the participants' attentional demands. They observed an improvement in postural stability for the participants that were provided with explicit instructions, regardless of the focus location, as compared to the group without instructions. Contrary to Brucal, Drabik & Wikstroma's results, the dual task decrement we observed was in the cognitive metric. Regardless, both of our studies illustrated the importance of including the information regarding participant instructions in the research article methodology section, information that was omitted in 50% of the experimental studies we read (Andersson et al, 2003; Dault et al., 2001; Pellecchia, 2003; Resch et al., 2011; Yardley et al., 2001). It could be argued that explicit instructions may elicit a posture first phenomenon, as a dual task paradigm did not spontaneously occur in our neutral instruction group. Shumway-Cook et al. (1997) instructed participants to provide equal priority to both tasks and observed a decrement in the postural metrics contrary to their original hypothesis. They concluded that allocation of attentional resources may be influenced by instructions, task difficulty, and participant motivation and the posture first phenomenon, which may not be observed in a traditional research study, may still occur when instability leads to a "threat of injury". Comparison between dual task research studies and possible influence of instructions is limited due to the variability in methodology. Two studies, Pellecchia (2003) and Negahban et al. (2011) utilized similar methodology (counting backwards by 3 while standing on a compliant surface) although they tested young healthy participants vs patients with multiple sclerosis respectively. Pellecchia (2003) did not report what instructions were provided to their participants and observed an increase in sway variability for the more difficulty cognitive conditions. On the other hand, Negahban et al. (2011) indicated that participants were advised to provide equal attention towards both tasks and observed a decrease in postural sway for the dual task condition for the participants with multiple sclerosis, and no change in postural sway for the healthy control group. Differing instructions may be one reasons the results are inconsistent between these two studies; however, they also vary due to other methodology differences such as population of interest, eyes open vs closed, and the addition of other tasks.

As we observed a dual task effect only in the postural instruction group, as opposed to occurring in all three groups, this suggest that instructions may in fact results in a dual task effect occurring when a dual task effect would not have naturally occur. Instructions may exacerbate the posture first phenomenon. Zijlstra et al. (2008) equated the posture first theory to a “safety first theory.” Although there was increased medial lateral sway for the more difficult postural condition, the risk of fall or injury was minimal even for the difficult postural task. It is possible that with an increased risk of fall the “posture first phenomenon” would have been observed in the neutral or cognitive instruction group. This could be achieved with either a more difficult postural task, a different population with either cognitive or postural impairments, or even instructions given by the researcher that led the participant to believe there is a significant likelihood of falls.

Overall, the population was made up of young, healthy participants without cognitive or postural decrements. When the same study is performed in individuals with balance or cognitive disorders, it is likely there will be a greater dual task effect observed. In addition, a dual task effect might be observed in the postural task or accuracy of the cognitive tasks as well, due to the additional difficulties these individuals face.

A dual task study is essential as a fall risk assessment as it provides individuals with a better understanding on their risk of fall in a real-world scenario. Developing a dual task methodology with vision denied conditions (i.e. wearing goggles so that visual information that may be used for orientation and balance is not accessible) is essential for testing a vestibular population. This type of test can reveal residual impairments in balance that may not be evident in the standard balance assessment as it taxes the attentional capacity of an individual.

The versatile methodology allows for both the postural and/or the cognitive task to be increased or decreased in difficulty. Portability of equipment is essential to allow for low-cost equipment and the ability for testing in various locations, such as in nursing homes.

One limitation of our study may be that the small sample size limited the ability to reach statistical significance. If a larger participant group was used, statistical significance may occur in the postural metrics. Additionally, Stroop test difficulty may have resulted in a ceiling effect for the accuracy metric.

Future studies may want to increase difficulty of the postural and/or cognitive task based on the population of interest. Versatility of the methodology allows for the protocol to be adjusted for use across different population. Increasing Stroop test difficulty may result in an effect on accuracy when assessing young healthy participants. In addition, studies that involve participants with postural impairments may see a greater decrease in accuracy when posture is prioritized over the cognitive task. While our study was able to effectively elicit a dual task effect in young healthy adults, the exact same methodology will elicit a larger dual task effect in vestibular patients or an older population.

V. Conclusions

A dual task paradigm can provide valuable information regarding the effects of vestibular loss on functional balance as well as the extent balance requires attentional resources. This is important to understand as both postural changes and cognitive changes are frequently reported in patients with vestibular loss. Unfortunately, there is no standard dual task paradigm for studying this phenomenon in vestibular patients. The primary purpose of this study was to establish a methodology for a portable and versatile dual task study paradigm that could be eventually used in vestibular patients and that could be adjusted in terms of difficulty. Results showed that this paradigm effectively elicited a dual task effect, but that instructions mattered as the dual task was only observed in the group instructed to focus on their postural control. Future studies are needed to look at altering the difficulty of the secondary cognitive task, as there was some ceiling effect observed during the Stroop test, and to assess the dual task effect in populations where we expect to see greater imbalance such as aged individuals and those with vestibular disorders.

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