LET’S GET PHYSICAL: THE DUAL-TASK COSTS OF MULTIPLE MOTOR RESPONSES

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ABSTRACT

Dual-task costs occur when attention is divided among two or more concurrent tasks. Most dual-task studies involve paradigms where participants complete two, concurrent cognitive tasks; in these studies, performance on one or both tasks are slower and/or less accurate. The goal of this study was to examine whether dual-task costs would exist when participants completed a cognitive task while walking and whether those costs would be greater when the cognitive task required a motor-based response or when the task was more difficult. Twenty-two college students completed four blocks of a visual search task while walking. The difficult and the manual blocks were associated with the greatest accuracy costs, but performance was slower in both the difficult and the verbal modality blocks. These findings indicate that dual-task costs do occur, even when one of the tasks is walking, and that costs are greatest when the concurrent task is especially difficult.

DEDICATION

This thesis is dedicated to my mama, sister, grandmother, and best friend Emily for all of their unwavering support during these past two years. I cannot begin to thank you for all you have taught me and the love you have shown.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Attention resources are limited; at any given moment one must selectively focus on certain stimuli from the environment while avoiding, ignoring, or inhibiting all other stimuli. Because of the limitations on this cognitive resource, anytime that attention must be divided among multiple stimuli or tasks, performance on one or several of those tasks suffers (Treisman, 1964). For example, when texting while walking, it is common for a person to slow their walking pace to compensate for the fact that at least some of that person's attention is being diverted to the texting task. Similarly, some attention may also be diverted to monitoring the environment for obstacles while focusing on finding the perfect emoji. These declines are known as performance costs or dual-task costs, and they are defined as an increase in response time and/or a decrease in accuracy on one or both tasks that are being completed at the same time (Shumway-Cook & Woollacott, 2000). A commonly used approach to measuring these performance costs due to divided attention is with a dual-task paradigm.

A dual-task paradigm is an approach that requires participants to complete two or more tasks concurrently. These paradigms use either multiple tasks within the same stimulus modality (e.g., two auditory tasks) or multiple tasks that use different stimulus modalities (Treisman, 1964). Studies that use different stimulus modalities may require participants to listen to a series of letters and respond when the letter is a vowel (an auditory task) while also watching a series of images on computer screen and responding when an animal appears (a visual task).

Alternatively, participants could be asked to attend to an auditory task while also walking, which is the approach that Kelly, Janke, and Shumway-Cook's (2010) utilized.

In one of the first dual-task studies, Treisman (1964) found that stimuli that were selected and attended were processed more deeply and remembered better than information that was not selected and therefore received fewer attentional resources. Dual-task studies have since demonstrated that when attention is divided among multiple tasks, our ability to utilize information from those tasks (i.e., learned information from the tasks) is reduced and there is almost always a dual-task performance cost (Treisman, 1992).

Theories of Dual-Task Performance

One of the earliest theories of attention, Broadbent's filter theory, was also known as the structural bottleneck theory (Broadbent, 1957). Broadbent's theory was built upon the idea that incoming sensory information (e.g. from the eyes) is processed in parallel with other incoming sensory information (e.g. from the ears). However, immediately after initial sensory processing, that information is 'filtered' such that only sensory information that is allocated attention receives any further processing. As such, only information that passes through the filter is recognized and remembered. For example, if reading a book and also listening to music, only the attended information will be processed and remembered, perhaps the lyrics from the music and not the words from the book, or vice versa. Broadbent further postulated that the attended information is under cognitive control (even if unconscious control). Therefore, an individual is able to "filter" only certain information into conscious cognition.

A competing theory, one that argued for simultaneous processing was posited by Deutsch and Deutsch (1963). Their capacity theory of attention stated that that incoming sensory information was not filtered in early stages as Broadbent suggested, but instead all incoming stimuli is attended equally and at the same time. Their theory specifically stressed that while an individual may be able to weight the importance of particular stimuli (and therefore the amount of attention allocated to that stimuli) all incoming information is attended and processed (Deutsch, Deutsch, Lindsay, & Treisman, 1967). However, Treisman and Geffen (1967) challenged the Deutches' theory when they asked their participants to listen to, and report on, separate messages through each ear. Treisman and Geffen's participants were unable to accomplish the task, thus indicating that information must not be processed concurrently.

In her subsequent research, Treisman (1969) contributed substantially to the literature on attention processing. Her structural theory specifically indicates that while all incoming sensory information is allocated some attention resources, individuals can choose to attenuate (allocate minimal resources to) some stimuli while prioritizing others. Furthermore, in dual-task situations, her findings demonstrated that an individual can flip the task prioritization back and forth between tasks from moment to moment. For example, when attempting to attend to both a video game and a podcast, I must switch my attention back and forth between the stimuli. At any moment, I can choose to prioritize the video game, thus ignoring the podcast, but Treisman (1969) also suggested that it is impossible to completely block the concurrent stimuli from awareness.

Wickens (1980) addresses the specific implications that capacity theories of attention (Deutch & Deutch, 1963) and structural theories of attention (Treisman, 1969) have when explaining dual-task costs. With capacity theories being based on the premise that attention can be divided among stimuli continuously and in parallel (Kahneman, 1973) and that the amount of attention resources allocated to stimuli is determined by the task demands, more attention should be directed toward more challenging tasks (i.e., tasks that are novel, dangerous, or require more focused attention), while less attention should be directed to simpler tasks. Therefore, dual-task costs should be rare and only present when the demands of the concurrent tasks exceed the attention resources available at a given time.

The capacity theory has been tested in dual-task paradigms by manipulating the difficulty of concurrent tasks being performed. According to the theory, if a difficult and a simple task are completed concurrently, the difficult task should demand more of the available attention resources and should be associated with fewer declines in performance and any dual-task costs should be associated with the simpler task because it drew fewer resources overall. However, there is little experimental evidence to support this theory (Navon & Gopher, 1980).

The structural theory of attention suggests that concurrent tasks must compete for attention and that attention is allocated serially based on how tasks are prioritized (Keele, 1973; Treisman, 1969). In other words, attention continually switches back and forth while dual-tasking such that only pieces of each task are being processed at particular points in time. Therefore, dual-task costs are predicted by how efficiently the brain is able to prioritize and switch between multiple task demands. In a single task, attention does not need to rapidly shift so no performance costs are present; however, in a dual-task situation, attention must rapidly shift between tasks and each shift has an associated cost.

Factors that Affect Dual-Task Costs

Within dual-task paradigms, the structural theory has been tested by manipulating whether attention is divided during encoding or not, whether the concurrent tasks require the same hemisphere of the brain, and whether the concurrent tasks involve the same stimulus modality. First, Wickens (1980) reported that when participants were asked to concurrently encode two types of information (e.g. visual and auditory) and at a later time recall that information, they experienced performance costs. However, when they were asked to immediately recall the encoded information (no delay) no dual-task costs were observed, presumably because no attention shifting was required.

Second, Kinsbourne and Hicks (1978) manipulated the concurrent tasks such that in one condition the tasks relied on processing from the same hemisphere of the brain while in another condition the tasks relied on different hemispheres. In the conditions where the same hemisphere was responsible for processing both tasks (e.g., singing and using the left hand) dual-task costs were observed present but not when the tasks did not compete for resources within the same hemisphere (e.g. when use of the left hand [controlled by the right hemisphere] and concurrent repetition of simple syllables ([controlled by the left hemisphere]). Finally, the stimulus and response modality of the concurrent tasks has been manipulated (McLeod, 1977). In conditions where both two tasks required the use of a motor response (e.g., playing video games while texting) performance costs were found, presumably because both tasks competed for the same attention resources and necessitated shifting.

In experiments that have assessed combinations of manipulating task difficulty, hemispheric specialization, and overlapping response modalities, task difficulty has a relatively small effect on performance (Shumway-Cook & Woollacott, 2000) but hemispheric specialization and overlapping response modality has had larger impacts on task performance (Ballesteros, Manga, & Coello, 1989; Chiang, Keng-Chen, Chen, Chao-Hsien, & Yun-An, 2014; McLeod, 1977). Indeed, Logan and Burkell (1986) discovered that when participants performed an auditory task while concurrently completing a visual task, their response time increased significantly. In addition, Mustonen, Berg, Kaistinen, Kawai, and Häkkinen (2013) found that in a dual-task paradigm where participants performed cognitive tasks (working memory and vigilance) while walking, their accuracy in steps decreased substantially.

Together these findings suggest that whenever the experiment conditions require that concurrent tasks complete for attention resources in some way, slower response times and/or decreases in accuracy are observed (Kelly et al., 2010; Pashler & Johnston, 1989; Shumway-Cook & Woollacott, 2000). In everyday life these dual-task costs can have real consequences. For example, if someone is attempting to divide their attention between listening to their partner and texting a friend, they may misunderstand or disregard their partner's request to take out the garbage and instead continue their text conversation (reduced accuracy) or perhaps respond to the partner's question about whether she'd like a glass of water only after a long delay.

Dual-Task Costs While Walking

Performance costs happen when concurrent tasks are especially challenging, but they are also present when we complete concurrent tasks that we do more automatically, such as walking, standing, and even sitting in a chair. Among relatively simple motor-based tasks, walking requires more attention than sitting or standing due to the increased balance needed to maintain posture and stability (McMahon, 1984). When walking at a comfortable pace, we naturally rotate our pelvis forward to center our mass over our base of support (i.e., the distance between our legs). In typical walking circumstances, these postural adjustments do not require a lot of attention (MacLellan & Patla, 2006), however when the body becomes challenged due to a competing cognitive demand or the presence of obstacles, the mechanics of maintaining balance while walking competes more for attention resources (Worden & Vallis, 2016).

The complexity of maintaining balance while walking has clear implications; dual-task costs are greater in paradigms that involve walking in comparison to sitting and standing (Lajoie, Teasdale, Bard & Fleury, 1993). Their participants performed an auditory cognitive task (e.g., Stroop working memory task) while walking, while standing, and while sitting. Their results were the first to document slower response times on the cognitive task when walking than while sitting or standing. In a more recent study, Kline, Poggensee, and Ferris (2014) conducted an experiment that involved completing a cognitive task while walking, but while their participants' performance on the cognitive task did not suffer the participants did have reduced step accuracy while walking. Similarly, when Worden and Vallis (2016) manipulated the difficulty of a walking task by requiring participants to walk through an obstacle course while completing a working memory task, they concluded that walking becomes more variable as the task becomes increasingly challenging, but they did not detect any performance costs in working memory.

A different pattern of results emerges when the base of support while walking is manipulated, and participants are concurrently completing a cognitive task. Under those, more challenging walking conditions, response times for the cognitive task were slower (Kelly et al., 2010), but only when participants were instructed to focus on the walking task component. Further, Mustonen and colleagues (2013) manipulated the difficulty of a working memory cognitive task while walking and determined that working memory accuracy suffered. Therefore, increasingly challenging cognitive and walking tasks may create more dual-tasks but further research is necessary to conclude that task difficulty accounts for the majority of variance related to cognitive performance costs.

Beyond the difficulty of the tasks, the actual type of task may also determine whether dual-task costs will emerge. While no dual-task costs were found when walking and completing a verbal working memory task (Grubaugh & Rhea, 2014), or spatial working memory task (Kline et al., 2014; Shumway-Cook & Woollacott, 2000), Mustonen et al. (2013) detected dual-task costs in a choice reaction time task that required a motor response. Similarly, Shaw et al. (2018) detected dual-task costs when participants completed a choice response time task that involved responding to targets manually while walking. Consequently, a pattern emerges when the dual-tasks both rely on motor/manual responses. Indeed, when assessing performance costs in younger adults, cognitive tasks that require a motor response while concurrently performing a walking task (Mustonen et al., 2013; Shaw et al., 2018) are associated with the slowest response times and worst accuracy.

Summary and Hypotheses of the Current Study

While there is a substantial body of literature that exists surrounding older adult dual-task costs while walking, these performance costs have been largely ignored in young and healthy adults. Currently, no conclusive evidence explains which conditions will create dual-task costs while walking. Previous research has examined the impact of manipulating the task type and the task difficulty, however, very few researchers have considered that response modality may hold a key in explaining the occurrence of dual-task costs in young and healthy adults.

The current study compares accuracy and response times on a cognitive task where task difficult is manipulated and where responses are verbal-based or motor-based (manually). This cognitive task is performed concurrently with a moderately challenging walking task. I hypothesized that accuracy on the cognitive task would be lowest when the task was (1a) more difficult and (1b) required a motor-based response, because the response modality of the cognitive task overlaps with the concurrent walking task. Further, I hypothesized that response times on the cognitive task would be slowest when the task was (2a) more difficult and (2b) required a motor-based response, because the response modality of the cognitive task overlaps with the concurrent walking task.

CHAPTER II

METHODOLOGY

Participants

Twenty-two undergraduate students from the University of Tennessee at Chattanooga (UTC) participated in this study. Nineteen of the participants were female and the average age of participants was 20.82 years. Additionally, 18 participants were Caucasian, while two were African American, and two were biracial. All participants were ambulatory and had normal or corrected-to-normal vision. The participants were recruited using UTC's Sona recruitment tool and participants earned five Sona credits, which were applied to the psychology course of their choosing in the form of extra credit. Any participants who reported having previous or current heart problems, those diagnosed with multiple sclerosis, Parkinson's disease, and/or epilepsy were excluded from the study. Additionally, participants were excluded if they were currently on blood thinning or anti-convulsion medication. No participants were excluded due to any of the previously mentioned medical reasons.

The most frequently reported medications were different methods of birth control and anti-anxiety or anti-depressants. The most frequently occurring conditions within the sample were anxiety (57.1%), depression (42.9%), and concussion (14.3%) but none of these conditions were a basis for exclusion. All participants were right-handed and the 36-item Waterloo Handedness Questionnaire (Bryden, 1977) was used to objectively assess participant hand preference. On this questionnaire, right handers earn a positive score (maximum of 72) and left handers earn a negative score (maximum of -72). The average participant score was 54.10 and all participants scored in the positive (range: 36 to 72). However, two of the participants did not complete the questionnaire, so their data is not included in the average.

Materials and Procedure

Demographic Questionnaire

Upon providing informed consent, participants first completed a basic demographics questionnaire (Appendix B). The questionnaire consisted of five questions regarding participants' age, race, ethnicity, and sex. Additionally, the questionnaire asked about past or current diagnoses of neurocognitive conditions (e.g., multiple sclerosis, anxiety disorders, etc.), along with any current medications.

Walking Task

After completing the demographic questionnaire, participants proceeded with the main portion of the experiment where they walked on a KeyFitness 5500T treadmill. The treadmill has a large walking area, adjustable speed, and adjustable incline, however the treadmill remained in the 0% incline position throughout the study. Participants walked at a brisk speed that was customized to 90% of each participant's maximum walking speed.

Determining a participant's maximum walking speed involved a traditional staircase method (Shaw et al., 2018). Participants began walking at a pace of 2.5 mph and the experimenter increased the speed by .2 mph every thirty seconds. This incremental increase continued until the participant reached their maximum walking speed, which was the speed at which they reported that the pace was strenuous, or they were on the verge of needing to run. Finding this maximum walking pace took no longer than four minutes for each participant.

The participant's maximum walking speed was then decreased by 10% and held at this brisk walking pace for an additional thirty seconds to ensure the pace was moderate yet comfortable. Therefore, if Participant X found their maximum walking pace after one minute, their maximum walking pace would 2.9 mph and their preferred walking pace would be set to 2.6 mph (90% of the maximum pace). The preferred walking pace was used throughout the duration of all subsequent portions of the study (Table 1).

Table 1 Brisk Walking Paces for Individual Participants

Participant Number	Max. Walking Pace	90% Max. Walking Pace
1	4.1	3.7
2	3.6	3.3
3	3.4	3.1
4	3.2	2.9
5	4.0	3.6
6	2.9	2.6
7	3.9	3.5
8	3.1	2.8
9	4.3	3.9
10	3.4	3.1
11	3.9	3.5
12	3.6	3.3
13	3.4	3.1
14	3.1	2.8
15	2.9	2.6
16	4.0	3.6
17	5.0	4.5
18	3.4	3.1
19	3.4	3.1
20	3.9	3.5
21	3.6	3.3
22	3.4	3.1

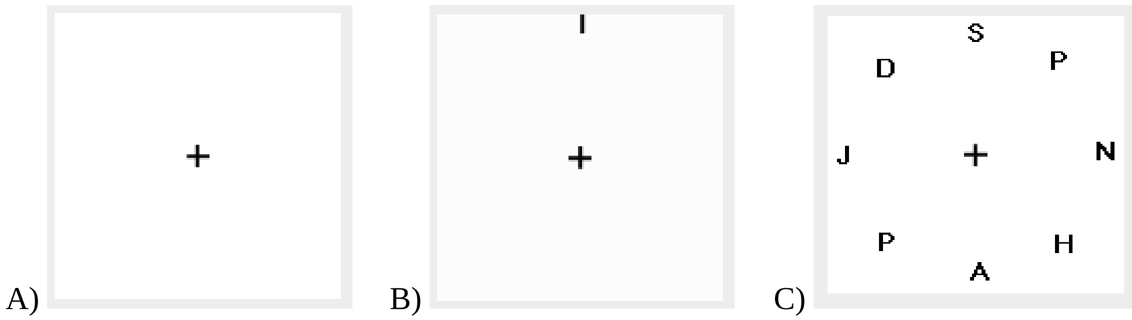
Note. The speeds are recorded in miles per hour (mph).

Visual Search Task

After establishing their brisk walking pace, participants began the concurrent visual search task. The concurrent task was modeled after Eriksen and Yeh’s (1985) task and participants’ response times and accuracy were measured. The visual search task featured two difficulty levels, easy and hard, and for each of these difficulty levels participants responded either manually or verbally. These manipulations resulted in a total of four blocks of trials.

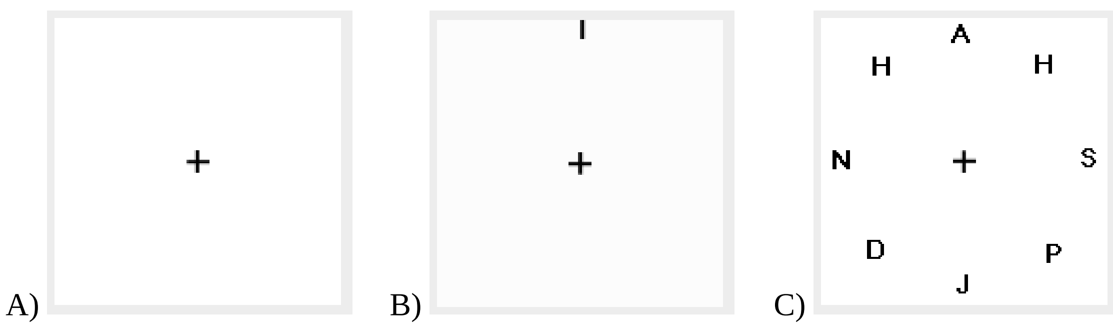
The task stimuli were images that were comprised of combinations of eight different letters (only one of which is the target letter) in a clock formation and these images were displayed on an LCD monitor on the wall in front of the treadmill. The participants were instructed that in each image a target – either an “S” or a “Y” - would be featured in the random array of letters and that their goal was to respond with which target letter they saw. Participants were instructed that only one of the targets would appear in each array and that there would always be a target in each image.

Each trial began with a fixation cross, which remained on the screen for a randomly determined period of time that ranged from 100 ms to 1000 ms (Shaw et al., 2018). Immediately following, a prime appeared for 150 ms. The prime was a simple, small line that was positioned just outside of either the top, right-most, bottom, or left-most letter locations. Within the easy blocks, the prime predicted the target letter location (either “S” or “Y”) 100% of the time (see Figure 1). However, in the hard condition, the prime predicted the target letter location only 40% of the time (see Figure 2).



Note: A) is the fixation cross (interstimulus interval; B) is the prime; and C) is the array of letters with the target "S" in being pointed to.

Figure 1 The Visual Search Task: Easy Condition



Note: A) is the fixation cross (interstimulus interval; B) is the prime; and C) is the array of letters with the target "S" not being pointed to.

Figure 2 The Visual Search Task: Hard Condition

All of the visual search stimuli were presented using SuperLab (Cedrus, 2020). SuperLab is a software tool that can be used to build experiments and display information (e.g., audio or visual) and participants' responses to that stimuli can be measured with excellent timing resolution. In each of the visual search conditions, the letter array was presented for 150 ms and was immediately followed by the fixation cross for the next trial.

In addition to manipulating the difficulty of the task, the response modality was also manipulated. In the verbal modality, participants were instructed to respond as quickly and accurately as possible by saying “S” or “Y” and in the manual modality participants were instructed to respond as quickly and accurately as possible by pressing the “S” or “Y” button on a response board (manual modality). Verbal responses were measured using a Cedrus SV-1 Smart Voice Key headset (see Figure 3), which can accurately detect participants’ verbal responses with precision to the millisecond. Manual responses were measured using a Cedrus RB-530 response pad, which was mounted to the right-side treadmill handle (see Figure 4). The response pad was mounted in a location that was comfortable for participants to reach while walking. Response times in both the verbal and manual modalities were measured to the millisecond and accuracy was calculated by dividing the total number of correct responses by the number of total possible responses.

Figure 3 Cedrus SV-1 Smart Voice Key Headset

Figure 4 Cedrus RB-530 Response Pad

The manipulation of difficulty and response modality resulted in four blocks of trials and every participant completed all four blocks: (a) Easy Manual response condition, (b) Hard Manual response condition, (c) Easy Verbal response condition, and (d) Hard Manual response condition. The block order was counterbalanced using a two-step randomization process. First, the response modalities were randomized and second, the task difficulty was randomized within the modality. Therefore, a participant was first randomly assigned to complete either the verbal or manual modality blocks, and then a nested counterbalancing of difficulty was completed. Each block contained eight practice trials and 40 test trials and took approximately three minutes to complete. Additionally, participants took a two-minute to five-minute break in between blocks as needed.

Debriefing Questionnaire

After completing the visual search task while walking, the participants completed an exploratory debriefing questionnaire (Appendix C). The items on this questionnaire focused on whether participants self-reported prioritizing their attention more heavily toward walking, toward the visual search task, or both tasks equally. Additionally, participants rated the amount of attention they allocated to each of the tasks on a Likert scale from 1-5 (1 being they paid no attention to the task and 5 being they paid all of their attention to the task). Previous research indicates that when participants are told to focus more heavily on one task over another, dual-task costs are diminished within the task that is prioritized (Kelly et al., 2010). For example, if a participant felt they were focusing more heavily on the walking task, then dual-task costs in the visual search task may be greater than for someone who focused more on the visual search task than the walking. Therefore, this exploratory questionnaire may serve future research in determining whether self-reported focus has an impact on the costs being observed.

CHAPTER III

RESULTS

Though 22 participants completed the study, only data from 21 of those participants was usable. One participant failed to adhere to the task rules and therefore the SuperLab data collection devices registered over 80% missing data. Of the data that was recorded for this participant, the individual means for response times and accuracy were well beyond two standard deviations from the group mean. Beyond that one participant, errors in data collection were relatively low. There were no errors for any participant in the manual modality blocks and on average the error rate for the verbal modality blocks was 16.9%.

To explore the impact of task difficulty and response modality on participants' response time and accuracy in the visual search task, two repeated measures analyses of variance (ANOVAs) were used. Both difficulty and response modality were treated as within-subjects factors and post-hoc Bonferroni tests were utilized where appropriate.

Accuracy

Consistent with the hypotheses, significant main effects of difficulty, F (1, 20) = 22.56, $p < .001$, $\eta^2 = .53$, and modality were found F (1, 20) = 4.58, $p = .045$, $\eta^2 = .19$, but there was no interaction between modality and difficulty, F (1, 20) = .06, $p = .813$, $\eta^2 = .003$ (see Figure 5). The data indicates that accuracy was highest in the easy verbal condition (*M* = 94.50%, *SE* = 1.95%). Accuracy was slightly lower when the easy trials required a manual response (*M* =

90.83%, *SE* = 1.87%). In the more difficult blocks, accuracy was lowest in the manual condition (*M* = 82.45%, *SE* = 1.58%) with the hard verbal trials being slightly higher (*M* = 86.47%, *SE* = 2.00%).

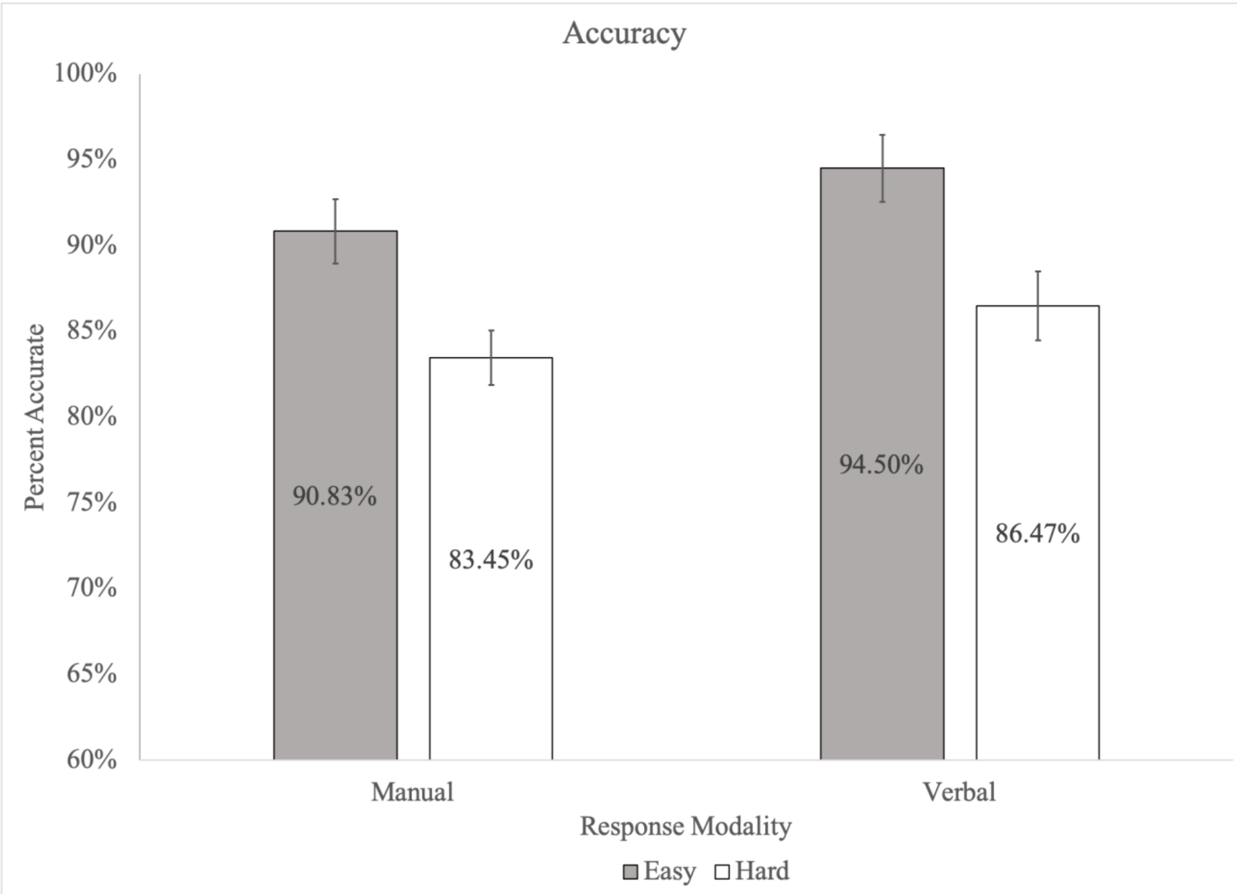


Figure 5 Mean Accuracy across the Blocks

Note. The error bars represent the standard error of the mean.

Response Time

Consistent with the hypotheses and the findings associated with accuracy, there was also a main effect of difficulty on response time, *F* (1, 20) = 15.96, *p* = .001, η^2 = .44. Specifically, it took participants significantly less time to respond in the easy blocks compared to hard blocks. In addition, there was also a main effect of modality on response time, F (1, 20) = 6.59, p = .018, η^2 = .25, in that response times were significantly faster in the manual modality blocks compared to the verbal modality blocks (see Figure 6). While main effects were detected for both modality and difficulty, there was no interaction between variables, F (1, 20) = 1.07, p = .314, η^2 = .05. The data indicates that response times were fastest in the easy manual condition (M = 514.03 ms, SE = 45.90 ms). Response times were slightly slower on the hard manual modality trials (M = 649.47 ms, SE = 69.80 ms). In the verbal modality blocks, response times were slowest in the hard condition (M = 897.52 ms, SE = 72.03 ms) with the easy verbal trials being considerably faster (M = 670.31 ms, SE = 46.84 ms).

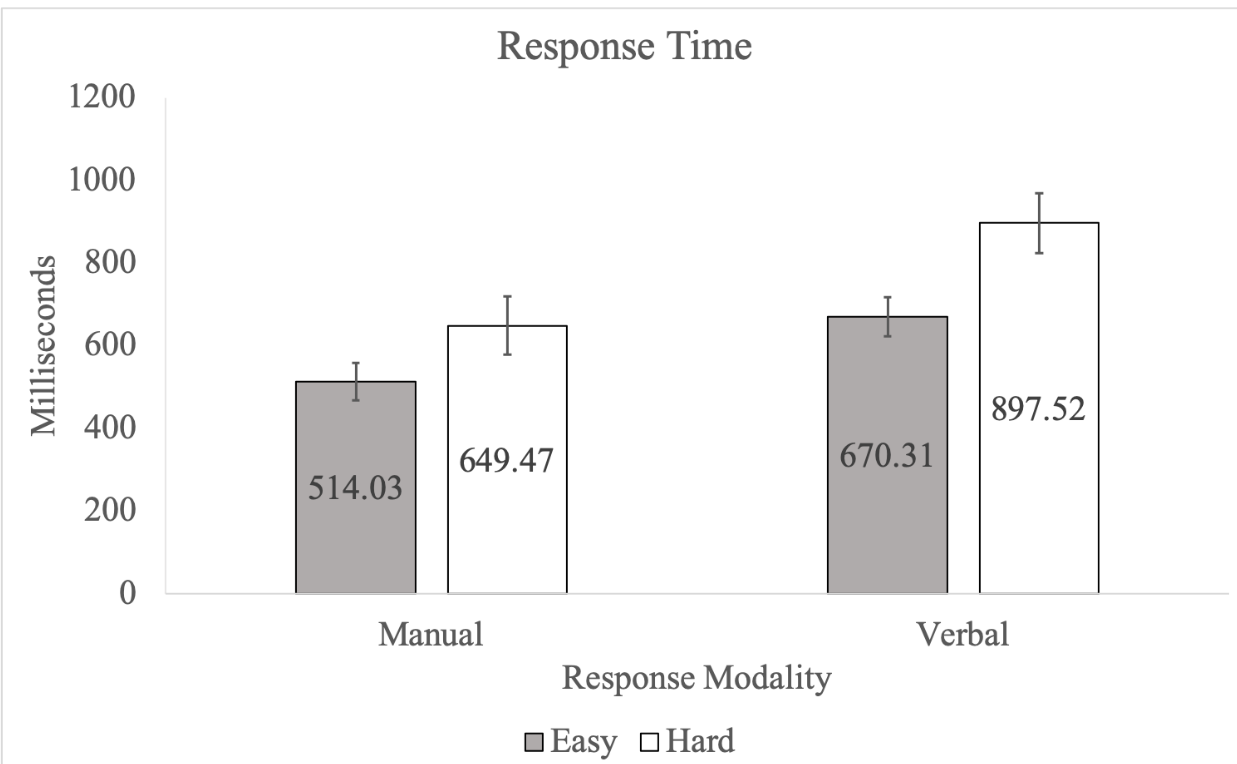


Figure 6 Mean Response Times across Experimental Blocks

Note. The error bars represent the standard error of the mean.

Impact of Practice on Response Times

While most participants are very familiar with responding to experimental tasks manually (i.e., pressing a button in response to a stimulus), very few have had any exposure to tasks that require a verbal response into a headset. Therefore, as participants worked through the verbal modality blocks, it is possible that they were learning how to best complete the task; this would be a learning experience that was unnecessary in the manual modality blocks. To account for the impact of repeated practice or exposure to the verbal and manual modality trials I conducted two linear regressions (verbal and manual), where response time was the dependent variable and trial number (1-80) was the independent variable. When conducting each analysis, I saved the unstandardized residuals, as those residuals are what remain of the variability in the dependent variable once the impact of trial number (exposure) is removed.

The regression analyses revealed that while trial number (exposure) significantly predicted response time in the manual blocks, $B = 1.78$, $SE = .49$, $t = 3.63$, $p < .001$, $r^2 = .01$, an even greater proportion of the variability in response time was predicted by trial number in the verbal modality blocks, $B = 3.31$, $SE = .78$, $t = 4.24$, $p < .001$, $r^2 = .01$. These regressions indicate that as participants got greater exposure to the task, their response times decreased, not because of the task difficulty or response modality manipulations, but simply due to increased practice with the stimuli and experiment conditions.

A product of the linear regressions was the unstandardized residuals, what remained of the variability in response times in the verbal and manual modalities once the impact of trial number (exposure) was removed. As an exploratory analysis, I performed a paired samples *t*-test to determine if there were any significant differences in response time between the manual modality and verbal modality blocks once practice effects were removed. The result of this test was not significant, the response times did not differ between blocks, t (20) = -.27, p = .793.

Debriefing Questionnaire

A final exploratory analysis involved whether self-reported dual-task prioritization impacted response time and/or accuracy. Participants rated their focus on each task (walking versus visual search) on a scale of 1-5 (1 being paid no attention and 5 being all attention focused). A paired samples *t*-test revealed that the amount of attention participants allocated to the walking task (M = 2.43, SE = .20) was significantly less than that allocated to the visual search task (M = 4.43, SE = .16), t (20) = -7.03, p < .001. In a separate item from the debriefing questionnaire, participants indicated whether they focused most on the walking, most on the visual search, or equally between the two concurrent tasks. A total of 15 participants (71.4%) reported that they allocated more attention to the visual search task, while five participants (23.8%) indicated they paid equal attention to both the walking and visual search task, and only one participant (4.8%) said they paid more attention to the walking task.

Those participants who self-reported prioritizing the visual search task (N = 15) were further examined to determine if task difficulty or response modality significantly impacted their response times and/or accuracy. The results of a repeated measures ANOVA confirmed the earlier reported finding (where all participants were included). Specifically, task difficulty significantly affected accuracy, F (1, 14) = 11.67, p = .004, η^2 = .46, such that accuracy was highest in the easy blocks, but within this group there was not a significant effect of modality, F (1, 14) = 1.19, p = .30, η^2 = .08. Further, there was no interaction between response modality and task difficulty, F (1, 14) = .37, p = .56, η^2 = .03. Together these results indicate that regardless of whether participants self-report focusing on the visual search task, accuracy is highest in the easy conditions.

Similarly, another repeated measures ANOVA examining response time as the dependent variable confirmed the earlier reported finding (where all participants were included) that there is a main effect of difficulty on response time, F (1, 14) = 11.74, p = .004, η^2 = .46, a main effect of modality on response time, F (1, 14) = 6.18, p = .03, η^2 = .31, and no interaction, F (1, 14) = 1.21, p = .29, η^2 = .08 (see Table 2). Together these results indicate that regardless of whether participants self-report focusing on the visual search task, response times are slowest in the hard conditions and also slowest in the verbal conditions.

Table 2 Means and Standard Error of the Means for Accuracy across Experimental Block

Block Name	Accuracy Mean	Accuracy Standard Error	Response Time Mean	Response Time Standard Error
Easy Manual	92.50%	2.07%	459.19	51.15
Hard Manual	84.67%	1.58%	593.61	82.59
Easy Verbal	93.71%	2.71%	640.46	55.16
Hard Verbal	87.78%	2.31%	900.64	98.86

Note. The response time is recorded in milliseconds.

CHAPTER IV

DISCUSSION

Though dual-task costs while walking have been consistently demonstrated in older adults and individuals with neurocognitive impairment, there has been inconsistency in the literature regarding whether dual-task costs are evident in healthy and young adults when they perform a cognitive task while concurrently walking. Past research has manipulated task type (e.g., verbal versus spatial working memory; (Grubaugh & Rhea, 2014; Kline et al., 2014) and the difficulty of the walking and/or cognitive task (Shaw et al., 2018) but the results have been mixed. However, a pattern does emerge such that concurrent tasks that demand the same response modality seemingly produce the greatest dual-task costs. Therefore, in this study I manipulated both task difficulty and response modality to test my hypotheses: that accuracy would be lowest when the visual search task was (1a) more difficult and (1b) required a motor-based response, and (2) response time would be slowest when the visual search task was (2a) more difficult and (2b) required a motor-based response.

Accuracy

In regard to accuracy on the visual search task, my hypotheses were supported in that participants were least accurate in the hard blocks of trials that required a manual response, slightly more accurate in the hard-verbal blocks and most accurate on the easy verbal blocks. Together this indicates that the dual-task cost of decreased accuracy was most prevalent in situations where the cognitive task was most difficult and also, when the demands of the cognitive task overlapped with the demands of the concurrent walking task.

It is important to note however, that contrary to my hypothesis, response modality had less of an influence on accuracy than task difficulty; task difficulty accounted for a substantially larger proportion of the variance in participant accuracy. Specifically, task difficulty accounted for 34% more variance than response modality. However, response modality still accounted for almost 20% of the variance in accuracy, indicating that response modality should be considered when conducting dual-task paradigm type studies in healthy and young adults.

The results regarding accuracy indicate that even in a healthy and young adult sample, the ways in which we respond to multiple tasks have an impact on the efficiency with which we complete a task. In other words, the results of this study suggest that while walking down the street and texting, (both activities generally use multiple motor responses) there will be a higher rate of errors in communication compared to when talking on the phone and walking. However, it is important to note that I did not measure walking performance so it is just as likely that one's walking pace or gait may suffer when simultaneously completing a cognitive task.

Response Times

My second hypothesis, regarding how dual-task conditions would impact response times, was partially supported. As expected, the data indicated that when the difficulty of the visual search task was higher, participants took significantly longer to respond. However, while task modality did explain approximately 25% of the variance in participant response time, the effect was in an unexpected direction. In direct contradiction with my hypothesis, participants were actually slowest at responding in the verbal condition and they were faster in the manual condition. Perhaps unsurprisingly, in the blocks where participants were slower to respond they also had higher accuracy. In other words, there appears to have been a speed-accuracy trade off and this pattern is consistently found in the literature (Fitts, 1966; Mustonen et al., 2013). Indeed, when looking at the data from this study, the trials in the verbal blocks had slower response times but were completed more accurately; whereas, the trials in the manual blocks had faster response times yet with less accuracy. Although the literature is evidence enough to explore this theory, I also conducted four linear regressions in which the accuracy for each block was the dependent variable, and the response time for each block was the independent variable. Only in the verbal Easy block did response time significantly predict accuracy, $B = -.02$, $SE = .008$, $t = -2.92$, $p = .009$, $r^2 = .31$, 95% CI [-.04, -.007]. This indicating that the speed with which the participants responded does in fact predict how accurately they performed on the cognitive task, at least within the Verbal Easy block.

It remains unexpected though that the speed-accuracy trade off was most substantial for the verbal blocks and not the manual blocks where there was most overlap in task demands with the concurrent walking task. It is possible that one explanation for this unexpected direction of the effect is related to the novelty of the verbal modality. While most participants were very familiar with responding to experimental tasks manually (i.e., pressing a button in response to a stimulus), very few have had any exposure to tasks that require a verbal response into a headset. Therefore, participants may have been more careful and slower in the verbal condition, not because of the task was particularly difficult or because the response modality caused excessive attention demands, but simply because it was unfamiliar. To account for this potential exposure explanation, I regressed trial number (exposure) onto response time on the verbal blocks and separately onto response time on the manual blocks and used the residuals from this regression to retest my hypothesis about the impact of modality on response time. The result of that analysis was consistent with the overall ANOVA; it did not provide support possibility that exposure to the verbal modality could explain the unexpected direction of the effect.

Allocated Attention

Within dual-task paradigms, where attention allocation is controlled by participants, it is important to determine where participants allocate most of their resources (Kelly et al., 2010; Siu, Chou, Mayr, van Donkelaar, & Woollacott, 2008). This is important because where one puts their focus has consequences for their performance. For example, if someone is playing video games while listening to their partner in the next room, they may perform worse on the video game if attention is more allocated to their partner. But, if that same person is allocating more of their attention towards the video games instead of their partner, they may not process or remember all of the information they are being told. While this phenomenon has been demonstrated in older adults (Siu et al., 2008), the results from young and healthy adults have been mixed (Kelly et al., 2010). Results in previous literature has indicated that when young and healthy adults are allocating attention to one simuli over another the stimuli that is not being attended is responded to more quickly but with less accuracy (Kelly et al., 2010). However, I cannot accurately replicate Kelly and colleagues' (2010) study without measuring dual-task costs within the walking task.

The results of my exploratory questionnaire revealed that only one participant reported focusing most of their attention on the walking task while 15 of the 21 participants reported focusing most of their attention on the visual search task. After restricting my sample to the 15 who focused most on the visual search task, I replicated the main effects of modality and difficulty on response times but there was only a main effect of difficulty on the accuracy of the visual search task. Perhaps with only 15 participants the ANOVA was underpowered, but it is also possible that the impact of modality was simply not significant because accuracy is not often impacted by the allocation of attention between concurrent tasks.

Overall, the results of this study suggest that manipulating response modality can induce dual-task costs and therefore it is an important factor to consider when examining dual-task costs in young and healthy adults. This finding supports structural (or filter) theories of attention as it indicates that completing task demands force attention to switch back and forth between concurrent tasks. Finally, the study addresses a gap in the dual-task walking literature by demonstrating that young and healthy adults do experience dual-task costs even when one of the concurrent tasks is seemingly automatic (i.e., walking).

Limitations

Due to the overlapping task demands, I had hypothesized that response modality would induce greater dual-task costs than task difficulty. However, the data showed that difficulty actually accounts for more variance in accuracy and response times than modality. In fact, contrary to the hypothesis, participants were actually slower in the verbal blocks, where the task demands did not overlap with the concurrent walking task. One potential explanation for this unexpected finding is that the walking task itself was not challenging enough. The speed at which the participants walked was 90% of their maximum walking pace but based on the results of the exploratory questionnaire, the walking task may not have demanded enough attention to have a substantial impact on accuracy and/or response time. It is possible that using self-report methods of maximal output was not the most appropriate method of determining a strenuous pace, and a more objective method (e.g., heart rate) should be used in the future.

It is also possible that forcing a strenuous pace was not an effective way to ensure that the walking task competed for participant attention. Other studies have manipulated the difficulty of walking by utilizing an obstacle course (Worden & Vallis, 2016) while other researchers have manipulated gait width (by narrowing the base of support) and pace (Kelly et al., 2010; Kline et al., 2014). Perhaps one or several of those manipulations would have been more effective at forcing performance costs. Of note however, is that when the walking task has been made particularly difficult the researchers were also collecting data on the participants' actual walking performance (e.g., step width and length changes, speed changes, etc.). Without the equipment or resources to measure those variables, I focused on the cognitive costs of dual-tasking but future research should consider measuring the performance costs to both concurrent tasks.

A further limitation of the current study is that I used two separate pieces of technology to record response times. While the Cedrus RB-530 response box performed consistently and reliably, the Cedrus SV-1 device had a tendency to not recognize voices, particularly when the vocal volume was low or the ambient noise was high. The overall error rate among both verbal blocks was 16.96%. Specifically, the average error rate for the Verbal Easy blocks was 16.55% and the average error rate for the Verbal Hard blocks was 17.38%. Furthermore, while the Cedrus SV-1 device records the timing of a verbal response, it does not record the actual content of the response. As such, the researchers manually recorded the "S" or "Y" response for each trial in the verbal blocks. Therefore, it seems that this device may have introduced possibility of error.

Conclusion

While there is a substantial body of literature that indicates that older adults and those with neurocognitive impairment suffer dual-task costs when completing a cognitive task while walking (Beauchet, Dubost, Aminian, Gonthier, & Kressig, 2005; Shumway-Cook & Woollacott, 2000), these performance costs have been largely unstudied in young and healthy adults. Indeed, the scant research that has been conducted has only examined the impact of the type of concurrent task and the difficulty of the walking environment.

This study addressed this gap in the literature by comparing accuracy and response times on a cognitive task where task difficulty was manipulated and where responses are verbal-based or motor-based (manually). While difficulty was still shown to be one of the top ways to produce dual-task costs, the influence of response modality cannot be understated. Researchers should be cognizant of the ways in which they are asking participants to respond to multiple stimuli. If researchers desire to induce as few dual-task costs as possible then the response modalities for the concurrent tasks should be independent.

Importantly, the study demonstrates that young and healthy adults do experience measurable dual-task costs, even when one of the concurrent tasks is largely automatic. Previous research has been mixed regarding which aspect of tasks need be manipulated in order to induce these costs. I have found that modality along with difficulty should be considered when designing dual-task paradigms for young and healthy adult participants. Indeed, when concurrent tasks demand the same or similar response modalities it appears that attention resources are strained, and the dual-task costs are measureable.

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APPENDIX A

IRB APPROVAL

THE UNIVERSITY OF TENNESSEE
CHATTANOOGA

Institutional Review Board
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TO: Taylor Hutson
Dr. Amanda Clark

IRB # 19-123

FROM: Lindsay Pardue, Director of Research Integrity
Dr. Amy Doolittle, IRB Committee Chair

DATE: 10/9/2019

SUBJECT: IRB #19-123: Let's Get Physical: The Dual-Task Costs of Multiple Motor Responses

Thank you for submitting your application for research involving human subjects to The University of Tennessee at Chattanooga Institutional Review Board. Your proposal was evaluated in light of the federal regulations that govern the protection of human subjects and approved via the expedited review procedure authorized by 45 CFR 46.110 and 21 CFR 56.110.

You must include the following approval statement on research materials seen by participants and used in research reports:

The Institutional Review Board of the University of Tennessee at Chattanooga (FWA00004149) has approved this research project #* 19-123*.

Please keep in mind that all research must be conducted according to the proposal submitted to the UTC IRB. If changes to the approved protocol occur, a revised protocol must be reviewed and approved by the IRB before implementation. For any proposed changes in your research protocol, please submit an Application for Changes, Annual Review, or Project Termination/Completion form to the UTC IRB. Please bear in mind that significant changes could result in having to develop a new application for submission and approval. Your protocol will be automatically closed at the end of the proposed research period unless a change request application is submitted. No research may take place under a closed or expired protocol.

A goal of the IRB is to prevent negative occurrences during any research study. However, despite our best intent, unforeseen circumstances or events may arise during the research. If an unexpected situation or adverse event happens during your investigation, please notify the UTC IRB as soon as possible. Once notified, we will ask for a complete explanation of the event and your response. Other actions also may be required depending on the nature of the event.

APPENDIX B

DEMOGRAPHIC QUESTIONNAIRE

1. What is your age (in years). ___________________________________

2. Please tell us about yourself by checking all that apply:

   a) Ethnicity:
      - ☐ Hispanic or Latino
      - ☐ Non-Hispanic or Non-Latino

   b) Race:
      - ☐ White/Caucasian
      - ☐ African American or Black
      - ☐ Alaska Native or American Indian
      - ☐ Arabic or Middle Eastern
      - ☐ Asian
      - ☐ Native Hawaiian or Pacific Islander
      - ☐ More than one race

   c) Gender:
      - ☐ Male
      - ☐ Female
      - ☐ Other (specify): ____________________________________

3. Are you currently taking any medications?
   - ☐ Yes - Please list: ____
   - ☐ No
   - ☐ Prefer not to answer.

4. Have you experienced any of the following medical conditions currently or in the past?
   - ☐ Multiple Sclerosis
   - ☐ Heart Attack
   - ☐ Concussion
   - ☐ Bipolar disorder
   - ☐ Mild Cognitive Impairment
   - ☐ Anxiety
   - ☐ Schizophrenia
   - ☐ Traumatic Brain Injury
   - ☐ Attention Deficit Hyperactivity Disorder

5. Have you ever been diagnosed with any other medical conditions or illnesses?
   - ☐ No
   - ☐ Yes - Please describe: __________________________
   - ☐ Prefer not to answer

APPENDIX C

EXPLORATORY DEBRIEF QUESTIONNAIRE

1. Which task do you feel you paid the most attention to?
   - ☐ Walking
   - ☐ Cognitive task
   - ☐ Both equally
   - ☐ Other (specify): ____________________

2. What strategies did you use to complete the tasks? (For example, did you just try to answer the cognitive questions without looking at your feet? Or did you go back and forth between looking at your feet and completing the cognitive task?)

   ____

   ____

Walking	1	2	3	4	5
Cognitive	1	2	3	4	5

3. On a scale from 1-5, how much attention do you believe you paid to each of the following tasks?

   Where the number **1** being “I did **not** pay any attention to this task” and **5** being “I paid **all** of my attention to this task.”

VITA

Taylor Nicole Hutson was born on January 5, 1996 to April Charlene Cameron and Christopher Todd Hutson in Cleveland, TN. She attended Cleveland State Community College for the first two years of her college career where she earned her Associate of Science in Psychology in 2016. She then earned her Bachelor of Science in Psychology from the University of Tennessee at Chattanooga in 2018. She continued her education in the University of Tennessee at Chattanooga’s Master of Science: Research Psychology program. Specifically, she worked in the Assessing Cognition Lab and the Sexism, Workplace, and Gender Lab during her time in the Master’s program. She will graduate in May 2020 with her Master of Science in Psychology after which she will pursue a Doctoral degree in cognitive psychology.