VIRTUAL STREET-CROSSING PERFORMANCE IN PERSONS WITH MULTIPLE SCLEROSIS: IMPLICATIONS FOR PEDESTRIAN SAFETY

BY

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THESIS

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ABSTRACT

The ability to cross the street successfully requires physical and cognitive proficiency. Multiple sclerosis (MS), a progressive neurological disease affecting the central nervous system, leads to impairments in physical and cognitive functioning, and thus might impact the ability to safely navigate a roadway environment. The purpose of this investigation was to examine the feasibility and safety of assessing street crossing performance in people with MS, and to identify differences in street crossing performance between people with MS and non-MS controls. We further examined the relationship between street crossing performance and fitness and functional outcomes within the MS sample. Participants completed 40 trials of a virtual street crossing task of walking on a manual treadmill through an immersive, 3-dimensional roadway environment. There were 2 crossing conditions (i.e., no distraction, talking on a phone); participants performed 20 trials of each. For all trials participants were instructed that the goal was to cross the street successfully. Street crossing performance was assessed as trial duration, success rate, and collision rate. Outcome measures of functional movement and fitness were walking speed, walking endurance, cognition, aerobic capacity, and muscular strength. Overall, assessing street crossing performance in people with MS was feasible and safe as there was a 93% completion rate, with no reported adverse events in the MS sample. Participants with MS took longer to cross the street than controls (p < .05). In the MS sample, walking speed correlated with trial duration, success rate and collision rate ($r = .52-.58$, $p_{all} < .05$). Walking endurance correlated with trial duration, success rate and collision rate ($r = .55-.59$, $p_{all} < .05$). Aerobic capacity correlated with success rate and collision rate ($r = .42$, $p_{all} = .03$). Regression analyses revealed that walking speed and endurance were independent predictors of street crossing performance for trial duration ($p_{all} < .01$). Street crossing performance is impaired in persons with MS compared to controls. Walking ability and aerobic capacity appear to be the most important variables for street crossing. Rehabilitation interventions might target these variables for improving real world street crossing performance and pedestrian.
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CHAPTER 1
Introduction and Background

Recently researchers are seeking to understand how people perform activities of daily living and other real-world tasks within the context of a laboratory setting. This is because previously, laboratory tests used to predict real-world behaviors did not necessarily adequately mimic the real-world task or the skills necessary to perform it. Thus, researchers have turned to virtual reality environments to better simulate the environment of real-world tasks, such as crossing the street. In order to successfully mimic real-world street crossing, the virtual reality environment involves a manual treadmill that is synchronized to computer display panels. Through this synchronization system, a three-dimensional image is projected in front of a participants, and as they walk forward on the treadmill, the three-dimensional environment moves and changes as well. This allows researchers to assess street crossing behavior in a safe, controlled environment which resembles the real-world task in close proximity.

Examining these behaviors in clinical populations has been of increasing interest due to the importance being able to adequately perform these behaviors has on a person’s ability to maintain autonomy and be an independent community member. It is therefore important to be able to accurately assess these behaviors in clinical populations to predict their ability to maintain autonomy. In the case of street crossing, this behavior is also related to an inherent risk as the task involves having to avoid moving vehicles and other pedestrians. This safety aspect of street crossing makes it of even more importance to study as a person’s ability to cross the street safely likely relates to their risk of pedestrian injury or fatality. Statistics on street crossing safety indicate that each year there are thousands of pedestrian injuries and fatalities (1). It is reasonable to suggest that clinical populations, such as people with multiple sclerosis (MS), may be at
increased risk of these traffic accidents as the disease is associated with the disease that lead to cognitive and physical impairment. The declines in cognition and ambulatory ability are substantial, as roughly 50% and 40-60% of people with MS suffer from these declines, respectively (2–5).

The street crossing task requires both cognitive and physical demands: the cognitive demands center on decision making and information processing which are necessary to determine if, and when, it is safe to cross the street based on sensory input from approaching vehicles and time gaps; the physical domain incorporates walking speed, walking endurance, and gait characteristics to influence the ability to ambulate across the street safely. Therefore, examination of street crossing behavior in a laboratory setting could potentially offer insight as to the related factors for successful street crossing performance in MS. It would also provide information relevant to which components influence street crossing performance the most, or in other words are the greatest determinants of success in the real-world task. Thus, through virtual reality street crossing it is possible to determine what affects the impairments associated with MS may have on street crossing performance, which ultimately provides insight into this population’s level of pedestrian safety.

1.1 References


CHAPTER 2

Review of Literature

2.1 Multiple Sclerosis

Today in the United States approximately one in 1000 people are affected by multiple sclerosis (MS). Currently, there are 400,000 people living with medically-diagnosed MS in the United States, a majority being young and middle-aged women as the ratio of diagnosed men to women is approximately 1:3 (6,7). Additionally, people are most often diagnosed with MS in their mid-30s as the average age of onset of the disease is 30-33 years, and the average age of diagnosis is 37 years of age (8). MS is a degenerative disease of the central nervous system that results in inflammatory demyelination of axons, axonal loss, and neurodegeneration (9). In this disease, demyelination of axons causes the interruption of communication between the neurons and their targets, such as muscle. This demyelination scars the myelin sheath, meaning that the action potential cannot be smoothly transmitted down the axon. The demyelination is the result of an abnormal immune-mediated response by the body which attacks the myelin of nerve cells (10,11). This causes a delay in the signal reaching its target, and, in some cases, the complete loss of signal transmission as the axon is rendered dysfunctional. Over time, repetitive lesions and demyelination can lead to neural degeneration. Though the immune-mediated response by the body plays a role in the demyelination of the myelin sheath, the underlying cause of the disease is still unknown and undergoing investigation (11).

No one case of MS is identical to another as the disease can manifest itself in a variety of ways and symptoms. There are four types of MS commonly characterized: primary progressive (PPMS), secondary progressive (SPMS), relapse-remitting (RRMS), and progressive-relapsing
The most common of these four types is the relapse-remitting disease course, which accounts for roughly 85% of the people initially diagnosed with MS (13). RRMS is characterized by short periods of relapses or exacerbations, where symptoms present themselves. In between periods of relapses, people with RRMS go through partial or complete recovery periods, otherwise known as remissions, where obvious progression of the disease is absent. People with RRMS can progress to SPMS, and, in this stage, there are generally no more relapses, though there is still a steady progression of the disease (i.e., impairments associated with present symptoms worsen). PPMS is similar to SPMS in that it is a steady worsening of disability; however, the distinguishing differences between the two types of the disease are that PPMS is characterized by a steady decline from the onset of the disease and there are usually no relapses. It is less common than RRMS as roughly 15% of people diagnosed with MS are diagnosed with PPMS. The final type of MS is PRMS, which is the least common of the disease courses. There is a steady worsening of neurologic function in combination with the presence of relapses or exacerbations and absence of remissions (14).

As mentioned earlier, there is high variability in the extent to which the disease impacts an individual. For this reason, a standardized exam is used to assess disability level of an individual with MS. This neurological exam is the Expanded Disability Status Scale (EDSS). The scale ranges from 0 to 10.0. Several important markers of disability occur at 3.0, 6.0, and 6.5. At an EDSS of 3.0, people with MS start to experience interference with their gait patterns and ambulatory ability; at an EDSS of 6.0, people with MS need unilateral support to walk; at an EDSS of 6.5, bilateral support is necessary for locomotion. Beyond this level of disability, at an EDSS of 7.0-8.0 some individuals are restricted to wheelchair use (15). It has been documented
that about half (roughly 50%) of people diagnosed with MS will eventually reach and EDSS of 6.0 and need at least unilateral support in order to ambulate (14,16).

As the disease progresses, people with MS suffer from various impairments. These impairments affect a variety of areas including physical, functional, and cognitive components. One impairment associated with MS is a decline in ambulatory ability, negatively affecting components such as mobility, walking speed, walking endurance, and balance. It has been reported that within 15 years of onset of the disease, roughly half of people with MS require at least unilateral assistance in order to walk (17). In fact, a majority of studies have found that about 40-60% of people with MS have walking impairment of some sort (2). This walking impairment results in impaired walking speed (i.e. T25FW) and walking endurance (i.e., 6MW) in people with MS compared to controls. When examining ambulation and gait there are several other parameters that are taken into account, including other temporal-spatial parameters such as cadence, stride length and percentage of double limb support. People with MS have been found to have slower walking speed (i.e., T25FW) (p < .001), shorter stride length (p < .001), and greater percentage of time spent in double limb support during the gait cycle (p < .001) (18). This confirms previous findings that walking speed was significantly slower in people with MS (19). Additionally, walking endurance is impaired in people with MS (and to an even greater extent as a function of disability status) as this population walks shorter distances on the 6MWT (20–23). With regards to gait patterns, people with MS have longer double leg stance percentage at a fixed walking speed compared with controls (19), and people with MS have shorter stride lengths compared to controls (20). It has also been demonstrated that these impairments in temporal-spatial parameters of gait are more pronounced with increasing disability level (i.e., higher pyramidal composite score on the EDSS) (18). Balance is also a vital component of
mobility and balance is impaired in people with MS when compared to controls. Using the Functional Reach Test (FRT) to assess balance, people with MS performed significantly worse compared with controls (p = .002). It has been suggested that some of the degree of impairment in gait (i.e., walking speed, stride length, percentage in double limb support) parameters are consequences of instability. This is reflected in the data demonstrating significantly reduced balance ability in people with MS compared with controls (18,24). It has been documented that people with MS have increased postural sway which is simultaneously associated with slower walking and overall limb movement (24). Importantly these attributes are associated with increased risk of falls in this population. Increased risk of falling is associated with reduced balance (i.e., ambulatory device needed for walking and increased postural sway), decreased walking endurance, and increased disability (25). This is important because being at risk of falls can affect the self-efficacy and self-confidence of a person with MS, which ultimately can impact their desire to continue to try to walk or be independently mobile within the community.

In addition to walking ability, another impairment associated with MS is a decline in fitness. Fitness, as will be discussed here, will encompass both muscular strength and cardiorespiratory fitness. Muscular strength of both the upper (e.g., handgrip strength, shoulder strength) and lower extremities (e.g. quadriceps and hamstring strength) has been found to be significantly reduced in people with MS (22). On leg extension tests, which is an assessment of quadriceps strength, Guerra et al 2014 determined people with MS had significantly weaker quadriceps muscles (p < .005). Similarly, people with MS were found to have significantly weaker handgrip strength compared to controls (p < .05). VO2peak has been found to be impaired in people with MS compared to controls (21). It has been found that this reduction in aerobic capacity is a significant and moderate reduction compared to controls (21). This reduction in
aerobic capacity is often associated with a reported decline in physical activity amongst people with varying levels of disability, and these fitness declines are associated with increasing disability (22). Overall, fitness as it applies to muscular strength and cardiorespiratory fitness is markedly reduced in people with MS which has implications for being able to complete activities of daily living as well as the risk of developing other comorbid health conditions.

The impairments associated with MS extend beyond physical domains; impairments also affect a person’s cognitive ability. Up to 40-70% of people with MS have some extent of cognitive dysfunction (26–28). Cognitive impairment, even in the absence of physical disability, can result in cessation of employment or a person’s ability to interact with others. This can have a dramatic impact on a person’s quality of life. Also, some studies have suggested a relationship between cognitive impairment and depression (29). Using correlational analysis from a study of 100 people with moderate MS, which examined perceived cognitive impairment, quality of life, and depression, depression was moderately correlated to quality of life ($r = .5$, $p < .001$) and depression was moderately correlated to perceived cognitive impairment (i.e., attention/concentration, retrospective memory, prospective memory, and planning/organization) ($p_{all} < .001$) (29). Using regression analysis, it was determined that cognitive impairment was further a predictor of quality of life, independent of depression. This is important because it suggests that perception of cognitive impairment can impact general health, social functioning, and emotional quality of life (29). Cognition is a broad domain and encompasses many processes. Cognitive processes such as information processing speed, recall, and memory are some of the common impairments associated with MS (27,28). Two tests that measure information-processing speed, the Symbol Digit Modality Test (SDMT) and the Paced Auditory Serial Addition Test (PASAT), were found to be the most frequently impaired cognitive tests in a
study of cognitive impairment in 125 people with mild-to-moderate MS (26). This suggests that information processing may be the primary cognitive deficit associated with MS. In a cohort study, these two information processing tests also were found to deteriorate the fastest compared with memory tests (27). It is demonstrated from this cohort study that tasks demanding more information processing or faster information processing begin to decline quicker in people with MS than tasks which have a reduced reliance on information processing. Thus, impaired information processing speed is not only one of the most prevalent cognitive impairments in people with MS, but it appears that declines happen much quicker with regards to this cognitive task than other cognitive tasks. Overall, cognitive impairment is common in MS and is associated with declines in quality of life, independence, and in some cases depressive symptoms.

2.2 Pedestrian Safety

In 2012 in the United States there were 4,743 pedestrian fatalities and 76,000 pedestrian injuries reported as the result of traffic crashes (26). Upon further examination of the 2012 Motor Vehicle Crash Data from Fatality Analysis Reporting System (FARS) and General Estimates System (GES) it appears that the majority of these pedestrian fatalities occur in people, ages 25-64 years. Pedestrian injuries were also most prevalent in people, ages 25-54 years. These alarming statistics have inspired investigation into causes of these traffic crashes that result in pedestrian injury and fatality. This investigation has included the examination of factors that may impair a person’s ability to navigate the roadway safely, which put a person at risk of injury or fatality if unable to successfully cross the street. In a traffic accident one of two parties may be at fault – the driver or the pedestrian, or in some cases both. The National Highway Traffic Safety
Association published data in their 2012 report about the related factors in traffic crashes that resulted in pedestrian fatality. Twenty-six percent have the pedestrian fatalities were related to failure of the vehicle to yield right away. While this statistic has implications for driver responsibility, some of the related factors data reveal pedestrian responsibility. Just over 16% (i.e., nearly 800) of the pedestrian fatalities reported in 2012 were related to improper crossing of the roadway or intersection. For example, this may include crossing at the wrong time or failure to cross within the cross-walk. Meanwhile inattentiveness (i.e., distraction such as talking, eating, etc.) and physical impairment were related to 2.2% and 1.8% of pedestrian fatalities respectively. Though this is a seemingly small percentage, these numbers are important to note as roughly 100 pedestrians were killed related to either inattentiveness, physical impairment, or both. Additionally these numbers do not include the number of pedestrian injuries to which these factors may also relate. Pedestrian safety is a real-world issue that affects all people, men and women, healthy and diseased. However, it is important to understand that some populations, particularly clinical populations such as people with MS, may have increased risk of injury or fatality in street crossing scenarios due to impairments associated with the disease that influence the factors related to pedestrian fatalities previously mentioned.

As previously described, people with MS have both physical impairment and cognitive impairment. It has been addressed that a majority of people with MS have physical impairment associated with slower ambulation, mobility, gait impairment, reduced balance, etc. This type of impairment was related with nearly 100 pedestrian fatalities and an unknown number of pedestrian injuries, making it cause for concern for identifying if a person with MS is capable to navigating a roadway safely. Impaired information processing may influence a person’s ability to analyze the roadway environment and evaluate whether it is safe to cross. This potentially could
contribute to people with MS entering the intersection at “unsafe” times or situations, leading to potential risk of injury or death. The same holds true with impaired cognition as it relates to attention or concentration as this impairment could worsen the impact of inattentiveness or distraction. Increased cognitive load, as is the case with added distractions such as talking or eating, may result in missing cues of oncoming traffic or traffic signals, leading to unsafe crossings.

A relatively novel approach to examining roadway navigation is in a laboratory setting using a simulated street crossing environment. This approach allows researchers to study the behavior in a safe, controlled setting without the risk of injury associated with the real-world task. This laboratory setting also allows researchers to examine the related factors documented by the National Highway Traffic Safety Association in their 2012 report, including those such as inattentiveness (i.e., distraction), physical capacity, portable devices (i.e., listening to music on an iPod), and decision making as they relate to street crossing performance.

2.3 Virtual Reality

Researchers interested in examining real-world behaviors, particularly those that are associated with risk of injury, turn to virtual reality laboratory environments as a means of creating a realistic simulation of the actual task. This allows researchers to examine the behavior without a real risk of injury to the participants. These environments also allow for greater control over external conditions. For example, researchers can manipulate the environment for distractions, ambient noise, scenery, etc. Several real-world tasks that have been studied in virtual reality laboratory environments are flight, surgery, driving, and street-crossing. Each of these tasks has a unique virtual reality environment and set-up.
Research in the realm of flight simulation is some of the earliest work regarding virtual reality simulation of real-world tasks. Studies involving flight simulation are dated back to the 1940s and 1950s. Much of the utilization for flight simulation is based on the premise of fuel conservation and cost reduction while training the skills required for aviation. Additionally, research in the area of flight simulation is concerned with the idea of skill transfer or transfer of learning. The virtual reality is created using computer software which uses modern graphics and aerodynamics software to create a realistic simulation of a single-engine aircraft. This computer software is synchronized to model flight sticks and pedals for an interactive experience (27). Results using flight simulation have found positive transfer of learning from the simulation models to training on the actual aircraft (27); this supports the idea that a virtual reality environment can be used to adequately simulate real-world apparatuses, skills, and environments.

In addition to flight simulation, a revolutionary approach to preparing for surgical procedures has been the inclusion of surgery simulation using virtual reality. In the case of surgical simulation using virtual reality, skill generalization and skill transfer commonly serve as the goal of performing the task. Minimally invasive surgical virtual reality trainers prepare surgeons by teaching professionals the fundamental psychomotor skills necessary to perform safe medical procedures (28). There are also virtual reality tasks that use manikins within the simulators to mimic actual procedures to a high degree. The close replication to the actual surgery allows for direct skill transfer to occur once the surgeon is in the operating room. In the virtual reality environments, surgical tools are synchronized to a computer monitor and desktop PC to show translation of physical movement throughout the task. The movement of the laparoscopic pens is updated near real time on the monitors as most systems have a frame rate of
15 frames per second (28). Several studies have found that both types of skill training (i.e., skill generalization training and skill transfer training) have resulted in better performance in the operating room, including quicker surgery times and better outcomes (29). This lends itself to the validity of using virtual reality as a means of closely simulating a real-world task.

The same could also be said for driving simulation as well. Driving is a task that involves both perception as well as interpreting sensory information from visual cues. Simulators are capable of providing most of these visual cues, however some real-world cues cannot be replicated due to the set-up of the virtual reality simulator. Most driving simulators lack head tracking devices that would allow for the interpretation of motion parallax (30). The motion parallax takes into consideration a person’s movements as they relate to objects in the environment, which helps to create depth cues. Despite this, landscape images and visual cues are presented to participants using a synchronization to computer software that renders 3-dimensional images onto a screen in front of the participants. Set-up of these studies varies depending on the outcome measures of interest. For example, in some cases partial simulation is appropriate (i.e., training, dashboard ergonomics, alertness) while in others, perceptual cues being rendered into the software program are necessary for improved validity in the study (i.e., when studying driver behavior (30). One area of interest using driving simulation is assessing participants’ perception reaction time as it applies to the sudden appearance of pedestrians, other cars, changing lights, etc. This is of particular interest when assessing aging populations who have potentially diminished reaction time due to age-related changes in processing speed and cognitive declines. As expected, studies have found that older adult drivers have significantly slower perceptual reaction time compared with young drivers using driving simulators and the sudden appearance of critical events (31). Other driving behavior such as velocity, collisions, and
lane position are also common outcome measures of studies using driving simulators. As with the other forms of virtual reality simulation, most of these protocols are comprised of a training period, or “practice trials” period so that the participant can get acclimated to the environment and the novelty of the experiment does not confound the results. This is an important step in virtual reality, because although the designs of the experiments are meant to mimic real-world tasks and behaviors, viewing the environment in a 3-dimensional projection while completing the task can feel different from the real-world task, especially initially. Additionally, though virtual reality is a cost-effective and safe manner to assess these behaviors, there are side effects for some people experiencing virtual reality – one of those being motion sickness. Thus, it is important that when incorporating virtual reality simulation to imitate a real-world task, participants are given time to get acclimated to the environment.

Much like flight, surgery, and driving simulation, street crossing simulation is used because it is a safe method for assessing a real-world behavior. It has also been found that these simulations are a valid tool for mimicking the real-world task itself. Assessing street crossing performance has several distinct set-ups, each with advantages and disadvantages. One set-up utilized is a “shout” technique. In this set-up, no physical movement is required to cross the street. Participants begin the task by standing adjacent to the actual street. They are asked to watch for traffic and indicate with their words when they deem it safe to cross (32). One benefit of the “shout” technique is that the participants are completing the task in a real-world setting (i.e., traffic and ambient noise is the same). Participants are also assessing traffic flow from the same place on the sidewalk as they would in a real-crossing scenario. Two disadvantages are that this task does not allow for feedback regarding movement based outcomes such as ambulation or crossing speed and they do not actually cross the street. A second set-up utilized is the “two-
“two-step” technique. This task mimics the “shout” technique in that participants will be assessing actual traffic from a road-side position. However, in the “two-step” technique participants start about two steps back from the curb. It is from that location that participants must judge when it is safe to cross. When they deem it safe, they take two steps forward towards the road to indicate this judgment (32). A benefit of the “two-step” technique is again that it is performed in a real-world setting with traffic and ambient noise. It also allows researchers to analyze initial motor movement following decision-making. However, this technique still lacks the ability to assess crossing parameters such as walking speed, crossing duration, head turns, etc. A third technique is crossing in the virtual reality environment, where participants do not walk across the full street, but indicate when they would deem it safe to do so. A simulated curb is constructed immediately in front of a three panel display that projects a virtual street with bidirectional traffic. To simulate real-world scenarios, ambient and traffic noise are projected to the participant via speakers. When participants would deem it safe to cross, they simply step off the curb on to a pressure plate that would record this movement. The unique benefit of this set-up is that once the participant steps off the curb, the scenario is changed from first-person to third-person and the participant is able to watch themselves, in cartoon form, carry out the rest of the events of crossing the street. The walking speed of the cartoon is matched to the speed that the participant achieved in a preliminary testing measure. It is through the cartoon visual of the street crossing task that the simulator is able to provide the participant with feedback regarding the safety of the crossing behavior (32). A fourth technique is street crossing in a virtual reality environment using a manual treadmill. This set-up addresses the disadvantage of the first two techniques because it allows for the assessment of what is occurring during crossing of the street. Also, it allows the participant to walk at a self-selected pace. In this set-up, the manual treadmill
is placed in front of a three-panel display that projects a three-dimensional image of a virtual road with bidirectional traffic. The three-dimensional image is created using virtual reality goggles that are synchronized to the display and worn by participants at all times. Flywheel magnets surrounding the treadmill are also synchronized to the goggles and PC that are able to track head movements and motion on the treadmill and record this data (33). The details of this set-up are more extensively described in the later chapters of this document. One disadvantage of this set-up is that most commonly, ambient and traffic noise is not projected to the participant during these trials, so it lacks the real-word environmental setting. A significant advantage of this manner of simulation is being able to assess physical movement throughout the street crossing task.

Several populations have been examined previously using virtual street crossing simulation. These populations include children, college-aged students, older adults, and clinical populations (e.g., people with Parkinson’s disease). Twelve studies will be outlined in the following paragraphs and describe the results found in each of these populations.

Children

Much of the work surrounding street crossing behavior in children examines the effect of other variables (i.e., fitness or distraction) on the manipulation of performance. In an early study conducted by Schwebel, Gaines & Severson (2008), the validity of using a virtual reality environment to assess street crossing behavior in children was examined (32). Children were ages 7-9 and the sample was comprised of 102 children of various ethnicities. The children performed 7 trials of the “shout” technique and “two-step” crossing technique and 8 street crossing trials within the virtual reality environment. Variables of interest included: (1) temporal
gap (i.e., the time between the successful completion of crossing of the participant and the arrival of the next car; (2) wait time (i.e., the amount of time participants were on the side of the street waiting to cross divided by the number of cars that passed in that time); (3) start delay (i.e., time it takes for a participant to begin crossing after a car passes the cross walk); (4) errors (i.e., collisions); (5) close calls (i.e., temporal gap less than 1 second). The results revealed that the youngest children (age 7) recorded more hits, had longer wait time, and greater start delay compared to adults (p < .05). Additionally start delay was greater in three groups of children (ages 7, 8 and 9) compared with adults (p < .05). These data suggest that younger age children may be impaired in street crossing performance compared with adults or even older children.

In 2009, a study by Stavrinos et al, using the same protocol as Schwebel et al (2008) sought to examine the effect of cell phone distraction on street crossing behavior in children (34). Pedestrian safety outcome measures included: (1) start delay; (2) safety time (i.e., same as temporal gap); (3) hits/close calls; (4) attention to traffic (i.e., the number of head turns before crossing divided by the time in seconds spent waiting to cross the street). Attentional capacity of the children was also measured. This study was comprised of children ages 10-11 and there were 77 in total who participated. The results revealed that the distraction component yielded larger safety time than the undistracted condition (p < .01). This riskier pattern held true for start delay, hits/close calls, and attention to traffic in the presence of a distraction (i.e., cell phone use) (all p < .05). Also, there was some evidence to support that children who had lower attentional capacity were more greatly impaired on street crossing performance (i.e., more hits and close calls, and reduced safety time) with the addition of the cell phone distraction. Thus, these results demonstrate that distraction conditions are associated with impaired street crossing performance in children.
Another study examining the effect of distraction in children on street crossing performance was conducted by Chaddock et al (2012). The study also took into account aerobic fitness with regards to performance (35). Thirteen high-fit and thirteen low-fit boys and girls participated in this study. The virtual environment used for this particular study was done in the CAVE environment at the University of Illinois. This environment is both immersive and interactive as participants walk on a manual treadmill, at a self-chosen pace, through a virtual environment. The virtual reality street was created using 3-panel displays synchronized to goggles worn by the participants. Outcome measures included: (1) crossing success rate; (2) trial duration; (3) initiation duration; (4) crossing duration; (5) initiation head turns; (6) crossing head turns; (7) pedestrian-vehicle distance at enter; (8) pedestrian-vehicle distance at exit; (9) time to contact at enter; (10) time to contact at exit; and (11) cardiorespiratory fitness (i.e., VO$_{2\text{peak}}$).

Results of this study confirmed previous findings that street crossing performance declined with the addition of a cell phone distraction condition. Success rates were lower (p = .004) in the cell phone distraction condition compared with the undistracted condition. Other street crossing outcomes were also impaired with the addition of the cell phone distraction including longer trial duration (p < .001), longer crossing duration (p = .015), more head turns (p = .05), and a shorter pedestrian-vehicle distance at exit (p = .002) in this distracted state. In terms of the effect of fitness, higher-fit children were found to be more successful at crossing the street (p = .035) with fewer head turns (p = .038) than lower-fit children regardless of distraction. Overall, this study determined that distraction impaired performance in children and higher fitness in children is associated with better street crossing performance.
College-aged students

The second population whose street crossing behavior has been studied in a laboratory setting is college-aged adults. This population was examined with the emphasis being on how distraction affects street crossing performance. In a study of 36 university students, a virtual reality, immersive environment was used to assess street crossing performance under a no-distraction, listening to music, or talking on a cell phone condition (33). Success rate was not significantly different between the no distraction condition and the listening to music condition, and was also not significantly different between the no distraction and the talking on the cell phone condition. Success rate was significantly lower in the talking on a cell phone condition compared with the listening to music condition, though (p < .01). It appeared that the trend of lower success rates with the addition of a distraction condition, could in part be explained by increased timeout rates (p < .005). Timeout rate was greatest in the talking on the cell phone condition. It was also found that students had longer overall trial durations when talking on a cell phone compared to listening to music (p < .001) or not distracted (p < .005). This result was the same for initiation and crossing times as there was longer initiation time and longer crossing time while talking on the cell phone compared with listening to music (p_{both} < .001) or not distracted (p_{both} < .001). These data suggest that distraction conditions, particularly talking on the phone, result in impairments in street crossing performance in young adults. An important finding of this study was that fatigue did not affect street crossing performance. By using a split-half analysis, researchers found that participants were as successful and faster at crossing the street in the second half of the trials, indicating that fatigue was not limiting participants’ performance. In a second study of 138 male and female, college-aged students of various ethnicities, the effect of distraction on street crossing performance was assessed. Schwebel et al (2012) examined the
street crossing performance of these individuals over the course of 12 trials, which were randomly selected to be one of four conditions (i.e., listening to music, talking on the phone, texting on the phone, no-distraction). *Look aways* was the term used to assess the amount of inattention on behalf of the participant as they crossed or in other words the amount of time the participant was not looking at the virtual road. Look aways were found to be significantly greater when texting ($p < .01$), listening to music ($p < .01$), and talking on the phone ($p < .05$) compared with not being distracted. Additionally, they found that listening to music and texting resulted in more collisions or hits than when undistracted ($p_{\text{both}} < .05$). Overall, the study determined that street crossing performance was impaired with the addition of distraction conditions, regardless of the distraction.

*Older adults*

Virtual reality street crossing has also been utilized in assessing the street crossing performance of elderly people in an attempt to examine the effect of distraction as well as compare their behavior to that of younger populations (36). An initial study by Dommes and Cavallo (2011) compared street crossing behavior between 20 young (ages 20-30 years), 21 younger-old (ages 61-71 years), and 19 older-old (ages 72-83 years) participants, with regards to unsafe decisions, missed opportunities, motion discrimination, time-to-arrival (TTA) estimation, processing speed and selective visual attention, inhibition, and walking speed on the task. There were fewer unsafe decisions (i.e., the participant was still in the road when the car passed the starting line, but did not get hit) in the young participants compared to the young-old and old-old participants ($p < .0001$). Also, older participants were more greatly affected by the speed of the approaching vehicle as unsafe decisions increased significantly as vehicle speed increased in
both of the older participants’ groups (p < .0001). There was no effect of age on missed opportunities. Young participants took less time to distinguish the angular velocities of the oncoming cars correctly compared to the younger-old and older-old participants (p < .01). Crossing time (i.e., a measure of walking speed) was greatest in the older participants’ groups compared with the young participants (p < .01). These results suggest that older participants are at greater risk of unsafe crossings (i.e., the potential of pedestrian injury from getting hit).

In a follow-up to the first comparison study between younger and older participants, the study conducted by Dommes et al (2012) assessed differences between younger and older adults as well as assessed street crossing performance changes in older adults following training (37). For this study, 20 elderly participants and 20 younger participants took part in the street crossing task. Both the younger and older participants completed initial testing of 75 trials at varying vehicle speeds (i.e., 30, 40, 50, 60, 70 km/hr). The older participants then went through a training stage which was two, 1.5-hour sessions. Participants were briefed on what information is necessary for deciding to cross the street and what constitutes safe crossing behavior. They then performed street crossing training where participants performed a series of trials that involved varying vehicle speeds and time gaps. During the training, experimenters provided feedback following each trial and discussed with the participant why behavior was unsafe. Following training, the older participants were tested again (i.e., one week post-training, and 6-months post-training). At baseline, older participants recorded smaller safety margins (i.e., the space between the pedestrian on the road and the vehicle on the road) (p < .001) than younger participants and thus had more unsafe decisions than younger participants (p < .0001). There was also a vehicle speed x age interaction, meaning that older adults had smaller safety margins and more unsafe decisions at high vehicle speeds than the younger participants (p < .05). Results indicated that the
training of the older adults was successful as safety margins increased and unsafe decisions decreased from initial testing to both 1-week post and 6-months post-testing (p < .05). An important finding of this study was that immediately following training, there was no longer a significant multivariate interaction between age and speed for any of the street crossing variables at high speeds. There was a significant age x vehicle speed interaction at low speeds as older adults had greater safety margins and fewer unsafe decisions compared with younger adults (p < .05). Importantly, at 6-months post training there were no significant differences between groups for any of the street crossing variables, indicating that the two groups performed about the same. When breaking down the trials by speed, older participants had smaller safety margins and fewer safe decisions, 6-months post-training compared to younger adults when the vehicles were at high speed (p < .05). The opposite was true at low speeds as 6-months post-training older adults had greater safety margins and a greater quantity of safe decisions than the younger participants at low speeds (p < .05). It appears that at baseline older participants perform more poorly than young participants with regards to safe street crossing. However, following training, at least some of this difference is attenuated.

A second follow-up to the initial comparison study of young and old participants was completed in 2014 by Dommes et al. In this third study, 18 young adults (ages 19-35 years), 28 younger-old adults (62-71 years), and 38 older-old adults (ages 72-85 years) participated in 2 blocks of 18 trials of simulated street crossing (38). This study focused on participants’ ability to determine if the time gap between vehicles was sufficient for safe street crossing. Both groups of older participants looked longer at the traffic (p < .001), had more collisions (p < .001), and took longer to cross (p < .001) than the younger participants. However, there were no significant differences between the older-old and younger-old participant groups for these outcome
measures. It was also found that crossing difficulty was greatest in the far lane of traffic as there was longer time spent looking at the traffic in this lane (p < .0001), more collisions (p < .001), participants took longer to cross (p < .001), and the safety margin was the least (p < .001) in the far lane compared to the near lane, regardless of group. Participants crossed two lanes of traffic in this study. The aforementioned data refers to the difficulty associated with crossing the second lane of traffic as participants made their way across the street. The same held true for the effect of vehicle speed as high vehicle speed resulted in greater difficulty crossing compared to low vehicle speed across all groups, though the effect on crossing time did not reach significance. There was an age by lane effect meaning that the older participant groups had worse performance in the far lane than the young participants as more collisions occurred in the far lane than near lane for these groups. There was also a significant difference between old-old and young-old groups as the older-old participants recorded more collisions in the far lane than the young-old. The older-old participants also had more collisions at high speeds than at low speeds and both older groups crossed more slowly at the higher vehicle speed than lower vehicle speed. Overall, age-related differences were most apparent in the far lane of traffic and at high speeds.

Other studies examining street crossing performance in older adults have been concerned with the dual-task effects on crossing behavior. Using the same laboratory set-up as their work on college students, Neider et al (2011) examined street crossing behavior in older adults with and without distraction (i.e., listening to music, and talking on the phone) conditions present (39). There were 18 highly functioning older adults who participated in the street crossing task of 60 trials in total, comprised of 20 trials of each condition. For comparison purposes, 18 undergraduate university students also completed the virtual street crossing task. Unique to the other age-comparison studies, this study found no significant main effect of age with regards to
success rate. There was, however, a significant age X intervehicle distance (i.e., the distance between approaching cars) effect indicating that older adults struggled more (i.e., lower success rate) with a lessened intervehicle distance compared to the young adults (p < .01). Success rate was also lower when a distraction condition was present (p < .05). An age by intervehicle distance effect was also present for collision rate and timeout rate indicating that older adults were affected to a greater extent (i.e., higher collision rates, p < .05, and more timeouts p < .01) than the young adults at the lower intervehicle distances. Timeout rates were greater in the older adults than the younger adults (p < .05). Timeout rates were also greater in the lesser intervehicle distance condition compared with the greater intervehicle distance condition (p < .01). There was an effect of distraction on timeout rates as well, indicating that there were more timeouts with the addition of a distraction condition (p < .05). When computing the analysis for the smaller intervehicle distance condition, it was found that older adults recorded more timeouts when talking on the phone compared to listening to music (p < .01) and compared to no-distract (p < .01), but there was no effect of distraction in the young adults. When computing the analysis for the greater intervehicle distance condition, there are no longer any significant effects on timeout rates (p > .09). The major findings for initiation duration was that older adults were affected to a greater extent by distraction (i.e., longer initiation time) than younger adults when talking on the phone (p < .05). Older adults were also more greatly affected by the lessened intervehicle distance compared to young adults as initiation time was longer in the short intervehicle distance condition (p < .05). In contrast to previous studies, this study found that older adults cross more quickly than younger adults (p < .005). Both groups crossed more slowly when talking on the phone (p < .01). In all, older adults are affected by a more challenging street
crossing task (i.e., cars at a closer interval or the addition of a distraction condition) than younger adults.

A study comparing three groups of participants (i.e., young adults, younger-old adults, and older-old adults) reveal significant effects of age and lane of traffic on crossing performance (40). For this study 16 young adults (ages 20-35 years), 17 younger-old adults (ages 60-67 years), and 18 older-old adults (ages 70-84 years) participated in the task, which was comprised of two testing sessions. The first session was a street crossing estimation task where participants were asked to judge whether the gaps between vehicles were sufficient for crossing the street at a normal pace. The second day of testing consisted of perceptual, cognitive, and physical tasks. Results indicated that the older-old adults made more decisions that would have led to a collision in real-life than both the younger-old adults and young adults (p < .05). Regardless of group, there were more collisions in the near lane compared with the far-lane in the experiment (p < .05). Unlike previous studies, no significant age X vehicle speed interaction was found (p = .23). When examining the conditions in the near lane alone, a significant age by lane X vehicle speed effect was present. This indicates that older-old adults had greater difficulty (i.e., made more decisions resulting in a collision) when traffic was in the near lane and the cars were traveling at a high speed (p < .05). Participants were asked to identify vehicle speed and there was an age group effect for this discrimination task as the older-old adults had significantly fewer correct identifications than the young-old and young groups (all p < .05). Correlational analysis revealed that age was moderately, and significantly, correlated with number of collisions (r = .36, p <.05), vehicle speed discrimination (r = -.59, p <.05), time-to-arrival estimation (r = .49, p < .05), and all of the cognitive and motor performance measures assessed in this study (all p < .05). Additionally collisions were significantly correlated to the perceptual, cognitive, and motor
performance measures (all p < .05), indicating that impaired perceptual, cognitive, and motor performance is associated with increased street crossing impairment. These results confirm previous findings that increased age is associated with increased risk of impaired street crossing performance (i.e., increased collisions and decreased success rate). It also is one of the first studies to assess the relationship between perceptual, cognitive, and motor performance scores to street crossing performance, with the results of this study suggesting a strong relationship between poor motor functionality, cognition, and perceptual ability scores being associated with poor street crossing performance.

Another study that was interested in examining the impact of distraction conditions on street crossing performance was completed by Nagamatsu et al (2011). This particular study was also interested in comparing street crossing performance of “at-risk” with “not-at-risk” seniors, which was a measure of physiological falls risk (41). There were 33 seniors who participated in the task of 60 trials (i.e., 20 trials of no-distraction, 20 trials of talking on the phone, and 20 trials of listening to music). This study produced a main effect of condition, indicating that both groups of participants performed worse (i.e., lower success rates, p = .002, and high collision rates, p = .05) in the talking on the phone condition compared with the no-distraction condition. There was also a group effect which revealed that those “at-risk” had lower success rates (p = .05) than those “not-at-risk”. Further analysis showed a significant group by condition effect for success rate as those “at-risk” had less successful trials than those “not-at-risk” in the phone condition (p = .009). “At-risk” seniors also crossed the street significantly slower than those “not-at-risk” (p = .04). There was a significant group by condition effect for the phone condition, indicating that “at-risk” seniors were significantly slower in the phone condition compared to “not-at-risk” seniors (p = .005). Thus, these results suggest that seniors who are at risk for falls
are impaired to a greater extent with the addition of talking on the phone than seniors who are not at risk for falls. Additionally, a distraction of talking on the phone, regardless of fall risk, impairs street crossing performance (i.e., lower success rates and higher collision rates).

Parkinson’s disease

Though assessing street crossing performance in clinical populations is still a relatively novel idea, it has been studied in pedestrians with Parkinson’s disease. In 2013, Lin et al undertook the first study of its kind addressing street crossing performance in people with Parkinson’s disease (42). The study included 81 participants with Parkinson’s disease and 50 healthy controls that were age, gender, and education matched. Participants did not physically move during the trials to cross the street, but rather pressed a button to identify if they were deciding to cross, based on the time gap allotted between vehicles on any given trial. There was a significant group effect as participants with Parkinson’s disease crossed significantly slower than the controls (p < .01). Additionally, by segmenting the clinical population by disease severity, those with increased disease severity (i.e., Hoehn and Yahr Stage 3-4) crossed significantly slower than those with lower disease severity (i.e., Hoehn and Yahr Stage 1-2) (p < .01). There was a vehicle speed effect for remaining time (i.e., difference between the time gap and the response time) regardless of group. As the cars traveled faster, remaining time was longer for both groups (p < .01). Using safety margin as the parameter, participants with Parkinson’s disease were at increased risk of engaging in an unsafe crossing behavior than the controls (p = .01). Additionally, regression analysis revealed low cognitive test scores to be a significant predictor for unsafe road crossing in all participants (p ≤ .02). This regression analysis, indicated that there was a strong relationship between poor cognitive scores and poor street crossing
performance. The results of this study also indicate that greater disease severity is associated with impaired street performance with regards to increased unsafe crossing decisions and slower crossing.

2.4 Purpose

MS is a disease that involves inflammatory demyelination and neurodegeneration within the central nervous system that results in debilitating impairments. These impairments involve both physical and cognitive domains and affect processes such as walking speed, walking endurance, cardiorespiratory fitness, mobility and gait patterns, balance, memory, and information processing speed. According to the National Traffic Highway Safety Association there are thousands of traffic incidents each year which result in pedestrian death or injury. These fatalities and injuries have been found to be, at least in part, related to distractions, inattentiveness, and walking ability. People with MS are affected by these factors and thus, are at risk of pedestrian injury or unsafe behavior as it relates to street crossing. For this reason, it is important to examine street crossing performance in people with MS compared to healthy controls, as well as to identify the underlying factors that may influence street crossing behavior in persons with MS. Based on studies examining street crossing in older adult populations, impaired cognitive performance and walking ability (i.e., slower walking speed) has a negative effect on street crossing performance (i.e., more unsafe crossings, slower crossing and more collisions, impaired performance with the addition of distraction, etc.). Similarly, there may be implications of physical and cognitive impairments associated with MS on street crossing performance. By examining street crossing behavior in a virtual street crossing environment,
people with MS are assessed in a safe setting, eliminating the risk of injury. This information can be used to improve pedestrian safety status within this population.

The overall purpose of this thesis was to examine street crossing behavior in people with MS. More specifically, this investigation sought to: 1) establish if assessing street crossing performance using a virtual reality environment was feasible in people with MS, since this has not been done previously; 2) examine street crossing performance under normal and distracted conditions in people with MS as well as matched healthy controls; and 3) examine which variables (i.e., walking speed, walking endurance, cardiorespiratory fitness, muscular strength, and cognition) are most important in determining successful street crossing performance in people with MS. Based on previous virtual street crossing experiments conducted with older adults, it was hypothesized that: 1) virtual street crossing trials would be feasible in people with MS and this would be indicated by a high completion rate within virtual street crossing trials and minimal adverse events; 2) people with MS would perform more poorly than matched healthy controls and that distraction conditions would impair performance in both groups, but to a greater extent in people with MS; 3) cognitive ability and physical outcomes, such as walking speed and walking endurance, would be the most important factors in determining street crossing performance in MS. Overall, the compilation of these studies will offer inside into the impact of MS on street crossing performance and this will provide direction for targeted rehabilitation programs centered on improving pedestrian safety in MS.

2.5 References


CHAPTER 3

Virtual Street-crossing Performance in Persons with Multiple Sclerosis: Feasibility and Task Performance Characteristics

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3.1 Introduction

Traffic crashes accounted for 76,000 pedestrian injuries and 4,743 pedestrian fatalities in 2012 in the US (1). This has prompted investigations of factors that impair one’s ability to safely navigate the roadway environment and increase risk for injury and fatality from traffic accidents. The study of factors that influence roadway navigation can be examined in the laboratory using a simulated street-crossing environment. The simulated environment provides a safe, controlled setting for understanding street-crossing behavior. Using this equipment, researchers have demonstrated impaired street-crossing performance in older compared to younger adults, (2) and with the addition of a distraction condition (i.e., crossing the street and listening to music) in both older adults and children (3,4).

The simulated street-crossing environment might be applicable for studying navigation of roadways in persons with multiple sclerosis (MS). MS is a neurological disease involving immune-mediated demyelination and transection of axons within the central nervous system. Common clinical manifestations of MS include impaired ambulation, balance, cognition, and fatigue. (5–9) Such impairments might impact the ability of persons with MS to navigate the roadway environment and, in turn, compromise their safety. Understanding street-crossing behavior in MS is important for maintaining community independence.

The primary outcome of this study was to determine the feasibility of virtual street-crossing in people with MS. The secondary goal of the study was to examine virtual street-crossing performance under normal and distracted conditions (i.e., crossing the street while talking on the phone) in persons with MS and matched healthy controls. Based on previous research involving virtual street-crossing in older adults, we hypothesized that: (1) it would be feasible (i.e., high task completion rate, no adverse events) for people with MS to complete a
virtual street-crossing task; (2) persons with MS would perform more poorly than controls on the street-crossing task; and (3) distraction conditions would negatively impact all participants’ performance, but would have a greater impact in persons with MS. The results from this study will provide novel and important information about the study of pedestrian safety in persons with MS.

3.2 Methods

Participants

Participants with MS were recruited through advertisements distributed from the North American Research Committee on Multiple Sclerosis registry and from a database of participants who had been involved with previous studies in our laboratory. Participants without MS were recruited through advertisements distributed through university-wide emails. Inclusion criteria for all participants were: 18-64 years; asymptomatic; capable of visiting our laboratory; minimal risk for engaging in physical activity; physician approval; and ability to walk on a self-propelled treadmill in the virtual environment. Additional inclusion criteria for people with MS were: physician-confirmed diagnosis of MS; Expanded Disability Status Scale (EDSS)<6.0; and not having a relapse within 30 days of testing. There were 128 people with MS initially contacted and 86 were screened for inclusion. Twenty-nine people with MS were enrolled and 27 completed the street-crossing task. There were 52 people without MS initially contacted, and 29 were screened for inclusion. Twenty controls were enrolled and 19 completed the street-crossing task.

Preparation
The virtual reality street-crossing task was performed in the Beckman Institute’s CAVE environment. The virtual environment was created in-house at the Illinois Simulator Laboratory using Python bindings for in-house C++middleware for cluster-based virtual reality (http://syzygy.isl.uiuc.edu/szg/index.html), with scenes rendered using PyOpenGL (http://pyopengl.sourceforge.net/). The set-up included a manual treadmill (Woodway Curve, Woodway USA, Waukesha, WI) in a completely immersive virtual environment. Eight magnets located around a flywheel on the manual treadmill allowed for the treadmill, connected through an Arduino microcontroller to the PC cluster, to control the speed at which the subject virtually crossed the street. The images were projected onto the panels from a synchronized PC cluster and the images were transformed into a 3-dimensional environment using synchronized goggles. The goggles were synchronized with the three-sided display panels, which each measured 303cm wide by 273cm high. As participants moved through the environment, head position was monitored using an Ascension Flock of Birds 6DOF electromagnetic tracker (Ascension Technology Corporation, Champlain Valley, VT). The manual treadmill allowed participants to walk at their desired speed in the forward direction only. Participants wore a gait belt around their waist that was secured to the treadmill by safety straps. Participants were instructed to hold onto the treadmill railings. Researchers were positioned on both sides of the treadmill to assist in the event that the participant lost their balance.

*Design*

A total of 40 street-crossing trials were attempted. The car spacing for each trial ranged from 75-90m and the car speed was set to 20mph. Parameters were based on previous experiences with older adults and pilot testing completed with two participants with MS. The
simulated road was a two-lane street; trials alternated between cars traveling in the same and opposite directions. The car spacing and car direction was randomly selected for each trial. The street-crossing task involved two conditions: (1) no distraction; and (2) talking on a phone. There were 2 blocks of 10 trials per condition. The condition order was selected at random. The no distraction condition involved participants attempting to cross the street without any distractions. The phone condition involved participants crossing the street while using a hands-free headset to communicate with one of the investigators. Questions posed by the investigators were open-ended in an effort to keep the conversation continuous and dominated by the participant.

**Outcomes**

**Disability:** Each participant underwent a neurological assessment for generating an EDSS score. The EDSS was performed by a Neurostatus-certified assessor and scores were used to characterize the disability level of the sample.

**Overground walking speed:** Participants performed the Timed 25-foot Walk (T25FW) test according to standardized instructions (10). This test was used to characterize the overground walking speed of the sample.

**Processing speed:** The Symbol Digit Modalities Test (SDMT)(11) was used to assess cognitive processing speed and characterize the cognitive ability of the sample. Participants were presented with an 8.5×11-inch sheet of paper with a key at the top of the page. The key consisted of a series of nine geometric symbols and each symbol was paired with a different digit from 1-9. Below the key was a series of empty boxes paired with symbols. Participants were given 90 seconds to orally identify correct digits that were associated with the empty boxes, according to the key pairing system at the top of the page. Participants were instructed to complete the boxes
in order and to not skip any boxes. Final scores included the total number of correct responses in 90 seconds.

Feasibility. We assessed this using the number of participants that were able to complete the task and the number of adverse events.

Street-crossing outcomes
Street-crossing outcomes were characterized for the trial overall, during initiation (i.e., preparing to cross the street) and crossing separately.

Overall outcomes. Trial duration: Trial duration was characterized as the total time, in seconds, taken to cross the street successfully. This included preparation and crossing durations.
Success rate: Success rate was calculated as the percentage of successful crossings out of the total number of crossings attempted.
Collision rate: Collision rate was calculated as the percentage of unsuccessful crossings, due to getting hit by a vehicle, out of the total number of street-crossings attempted.

Initiation outcomes. Preparatory duration: Preparatory duration was quantified as the amount of time, in seconds, from the initiation of the trial until the participant entered the street.
Preparatory head turns: Preparatory head turns were quantified as the number of times a participant turned their head from the initiation of the trial until the participant entered the street.
Car distance at enter: Car distance at enter was determined as the distance, in meters, that the participant was away from the nearest oncoming vehicle when the participant entered the street.
Crossing outcomes. Crossing duration: Crossing duration was determined as the amount of time, in seconds, from when the participant entered the street until when the participant exited the street.

Crossing head turns: Crossing head turns was quantified as the number of times a participant turned their head from the time that they entered the street until the time that they exited the street.

Car distance at exit: Car distance at exit was quantified as the distance, in meters, that the participant was away from the nearest oncoming vehicle when the participant exited the street.

Procedures

Participants were first briefed on the safety protocols and instructions for the street-crossing task. They were instructed that the goal of each trial was to walk across the street safely (i.e., without being hit by a car). Participants put on goggles and a gait belt, which allowed participants to be secured to the manual treadmill using safety straps. Practice trials were completed to allow participants to acclimatize to the manual treadmill and virtual environment. Participants then began the first block of 10 trials. To begin each block of trials, participants were given verbal instructions on which condition would be performed. Participants were instructed that each trial would begin once they crossed a yellow line. Once participants began walking they were able to wait on the sidewalk until they determined it was safe to cross. A successful trial was completed once the participant walked to the other side of the street. A complete trial was signaled with visual and auditory feedback as to whether or not the participant
crossed the street successfully. If the participant was hit by a car, the trial was terminated and this was signaled to the participant.

**Statistical Analysis**

Data were analyzed using SPSS Version 22.0 (SPSS Inc., Chicago, IL). Values in the text are presented as mean (SD), unless otherwise noted. Demographic and clinical characteristics of participants were summarized using descriptive statistics. Initial differences between groups on demographic and clinical characteristics were compared using independent samples *t*-tests and chi-square tests. We compared street-crossing performance using a series of mixed model ANOVAs with condition as the within-subjects factor and group as the between-subjects factor. Statistical significance was set at *p*<.05.

### 3.3 Results

**Participant characteristics**

Demographic and clinical characteristics of participants are presented in Table 1. Overall, participants with MS had mild-to-moderate disability (median EDSS=3.5 (IQR=1.5)). The majority of participants with MS were female (63.0%) and had a relapsing remitting disease course (92.6%). The mean disease duration was 10.7 years (7.8). There were no significant differences between controls and participants with MS for age (*t*=.69, *p*=.49), sex (*χ²*=2.48, *p*=.12), or SDMT performance (*t*=1.75, *p*=.29). There was a significant difference between controls and participants with MS for T25FW performance (*t*=3.05, *p*=.004), such that controls walked faster than those with MS.
Feasibility

There were 29 participants with MS and 20 controls that attempted the street-crossing task, of which 27 (93%) and 19 (95%), respectively, completed the entire task. The control participant that did not complete the task had to cease participation due to motion sickness. The two participants with MS that did not complete the task had moderate disability (EDSS score of 4.0 and 4.5) and were only able to complete half of the trials due to physical exhaustion. Overall, the MS group that completed the task consisted of 17 people with mild disability (EDSS range=1.5-3.5) and 10 people with moderate disability (EDSS range=4.0-5.5). There were no adverse events reported. This suggests that most individuals with mild-to-moderate MS were able to safely complete the simulated street-crossing task.

Street-crossing performance

Street-crossing performance in controls and participants with MS is presented in Table 2. There were no significant group by condition interactions on any outcomes. There was a significant effect of group on overall trial duration, initiation duration, crossing duration, and car distance at exit (all $p<.05$). This suggests that people with MS took longer to cross the street overall compared with controls. We further examined street-crossing performance controlling for group differences in overground walking speed based on T25FW. After entering T25FW speed as a covariate in the model, significant group effects persisted for trial duration ($F=5.75$, $p=.02$, $\eta^2=.12$), crossing duration ($F=11.48$, $p=.002$, $\eta^2=.22$), and car distance at exit ($F=13.45$, $p=.001$, $\eta^2=.24$). This suggests that walking speed alone does not explain the slower crossing times. There was a significant effect of distraction on overall trial duration, initiation duration, initiation head turns, crossing duration, and crossing head turns (all $p<.05$). This suggests that
people with and without MS both have impaired street-crossing performance when distractions are present.

3.4 Discussion

This study involved the first examination of street-crossing behavior in persons with MS. Three overarching conclusions were made from this investigation: (1) it is feasible and safe for people with MS to complete a virtual street-crossing task; (2) street-crossing performance, particularly duration, was impaired in persons with MS compared to healthy controls, indicating that people with MS cross the street more slowly, independent of walking performance; and (3) the effect of a distraction condition on crossing performance was not specific to persons with MS, such that distraction impaired performance in both groups. This has important implications for studying pedestrian safety among people with MS and might provide novel outcomes for interventions that target improving roadway navigation.

The primary aim of this investigation was to determine the feasibility of a simulated street-crossing task for persons with MS. Indeed, 95% and 93% of the control and MS samples, respectively, completed the task. EDSS scores of participants with MS ranged from 1.5-5.5, indicating that this task can be performed with participants with MS with substantial disability. Of note, none of the participants reported any adverse events during the street-crossing sessions. Overall, this suggests that simulated street-crossing is feasible and safe for individuals with mild-to-moderate MS. This virtual setting provides an environment for studying a real-world behavior; this has important implications for understanding and improving pedestrian safety in MS.
We examined differences in street-crossing performance between participants with MS and healthy controls. These analyses indicated that participants with MS cross the street more slowly than healthy controls, and this was reflected by a longer trial duration, initiation duration, crossing duration and shorter car distance at exit in the MS sample. Group differences occurred primarily with respect to variables affected by walking ability; therefore, it can be proposed that ambulatory ability might be most important for street-crossing in persons with mild-to-moderate MS. Over-ground walking speed (i.e., T25FW) did differ between persons with MS and healthy controls supporting impaired walking performance in the MS sample. However, group difference persisted after controlling for T25FW performance. This suggests that the differences in street-crossing performance between persons with MS and controls cannot be attributed purely to differences in walking dysfunction. Previous studies have reported that initiation variables (e.g., preparatory duration) and timeout rates were increased in older adults compared to young individuals (3). It has been suggested that these difference can be attributed to impairments in cognitive functioning (i.e., planning, attentional control, task-switching, encoding, and decision making) in older adults (3). In the present study, we observed a significant difference in initiation duration between controls and participants with MS, and this might be related to impairments in cognitive functioning, similar to that observed in older adults. There was an almost 7-point difference in SDMT score between participants with MS and controls, although this was not statistically significant. Perhaps cognitive functions other than processing speed were affected in the MS sample and these might be more important for street-crossing performance.

Our results suggest that impairments in street-crossing performance in persons with mild-to-moderate MS might reside to a greater extent in the physical (i.e., walking speed) rather than cognitive (i.e., decision making) aspects of street-crossing behavior, as most group differences
occurred with respect to variables involving walking ability. Though, it should be mentioned that walking speed was not the only factor affecting street-crossing ability. This concept should be investigated in future studies to determine other factors that impact street-crossing behavior and to identify the most important targets for improving street-crossing performance in MS. Our results suggest that individuals with MS require additional time to cross the street safely, and perhaps rehabilitation interventions that target walking would improve pedestrian safety in this population. Previous studies have demonstrated improvements in walking speed and endurance following aerobic (12–14) and resistance exercise training (14,15). This might be a reasonable approach for improving roadway navigation in persons with MS.

The addition of a distraction (i.e., talking on the phone) while crossing the street resulted in impaired performance. There was no group by condition effect, which suggests that the effect of distraction is not specific to individuals with MS. This confirms previous findings that talking on a phone while street-crossing results in more unsafe crossings, longer preparatory times, and slower crossing times in older adults,(3) and lower crossing success rates and longer preparatory times in college students (2). Examining the influence of distraction on street-crossing performance indicates that individuals with MS, and their age-matched healthy counterparts, should limit distractions while street-crossing. These findings alert pedestrians to the risk of added distractions while navigating the roadway.

3.5 Study Limitations

One of the strengths of this investigation is that it provides novel data on how people with MS perform on a real-world task of crossing the street. This was conducted using a unique simulated street-crossing environment. However, there are several limitations of this study. As
noted in previous studies using the virtual street-crossing design, a virtual environment does not contain the ambient noise associated with real-world street-crossing, such as traffic noise that may assist in crossing judgment. The study included primarily females, with mild-to-moderate, relapsing remitting MS and this limits the generalizability of our conclusions regarding feasibility and safety.

3.6 Conclusion

Overall, we determined that assessing street-crossing performance in people with MS is feasible. Also, we observed that street-crossing performance is impaired in people with MS compared to healthy controls, which is primarily reflected by slower street-crossing durations. The addition of a distraction impaired street-crossing performance and the effect was not specific to persons with MS. The results of this study are important because they offer insight into pedestrian safety. Considering traffic accidents account for thousands of pedestrian injuries and fatalities each year, understanding how MS impacts the ability to cross a street safely can provide important information for interventions and public policy regarding street-crossing regulations.

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Conflict of Interest

The authors declare that they have no conflict of interest.

 Suppliers
a. Woodway Curve, Woodway USA, W229 N591 Foster Ct, Waukesha, WI.

b. Ascension Technology Corporation, 107 Catamount Drive, Milton, VT.

c. Version 22.0, SPSS Inc., 203 South Wacker Drive, 11th fl, Chicago, IL.

3.7 References


CHAPTER 4

Predictors of Street Crossing Behavior in Persons with Multiple Sclerosis

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4.1 Introduction

There has been increasing interest in understanding how healthy and clinical populations perform real-world, everyday tasks such as crossing the street. Real-world tasks can be studied in the laboratory setting through the use of virtual reality environments. The virtual street crossing environment involves a manual treadmill that is synchronized with display panels that allows the virtual environment to change according to how the participant walks on the treadmill. The virtual reality environment provides a safe setting for understanding street crossing behavior by eliminating the risk of injury from collisions and falls. Examining simulated street crossing behavior can provide important information about the performance of a real-world task that has critical implications for safety and mobility within the community setting.

Understanding and evaluating street crossing behavior and its determinants might be particularly important for people with multiple sclerosis (MS) as the impairments commonly associated with MS could impact the ability to safely navigate the roadway environment. For instance, ambulatory impairment affects approximately 40-60% of people with MS (1–3) and ambulation is a vital component of the street crossing task. Cognitive impairment occurs in upwards of 50% of individuals with MS (4) and this might affect a person’s ability to process informational cues and make decisions as to if, and when, to cross the street safely. It has been reported that individuals with MS have lower levels of physical fitness (i.e., aerobic capacity and muscular strength) compared to controls without MS (5). Reduced physical capacity might limit street crossing performance in persons with MS and this might occur directly or indirectly through the influence of fitness on ambulatory performance. In fact, previous work has found high levels of cardiorespiratory fitness to be significantly associated with improved street crossing performance in children (6). Indeed, the ability to cross the street successfully requires
both physical and cognitive proficiency; therefore, it is critical to understand how MS impairments influence street crossing performance.

We have recently examined virtual street crossing behavior in people with MS and matched controls without MS. All participants performed 20 trials of two street-crossing conditions (i.e., no distraction while crossing or talking on a hands-free cell phone while crossing the street). Overall, participants with MS performed more poorly on the street crossing task than controls, as indicated by lower crossing success rates, increased collision rates, and slower trial and crossing durations. We did not observe differences in street crossing outcomes as they relate to cognition, and there were no significant differences found in cognition across groups, indicating that the impairments in street crossing outcomes in persons with MS must be related to another domain. This suggests that impairments in street crossing performance in persons with MS might resided to a greater extent in physical (i.e., walking speed) rather than cognitive (i.e., decision making) aspects of street-crossing behavior. We are now interested in understanding which factors, in particular, determine street crossing ability in people with MS. Such an examination will provide important information on the specific targets for rehabilitation interventions for improving real-world performance and pedestrian safety in persons with MS.

To that end, we undertook a secondary analysis of data examining virtual street crossing in persons with MS to understand the relationship between street crossing performance and MS impairments including walking speed, walking endurance, cognition, aerobic capacity, and muscular strength. The goal of this examination was to determine which variables are most important for successful street crossing in persons with MS.
4.2 Methods

Participants

Participants were recruited through advertisements distributed from the North American Research Committee on Multiple Sclerosis (NARCOMS) registry and from a database of participants who had been involved with previous studies in our laboratory. Information regarding participant recruitment and enrollment is detailed elsewhere (4). Inclusion criteria were: physician-confirmed diagnosis of MS; Expanded Disability Status Scale (EDSS) <8.0; no history of relapse within 30 days prior to testing; 18-64 years; minimal risk for engaging in physical activity; asymptomatic; capable of visiting our laboratory for testing on two occasions; and physician approval. Additional inclusion criteria for the street crossing task were ability to walk on a self-propelled treadmill and ability to undergo the virtual reality environment. Twenty-seven people with MS were enrolled to the study and completed the street crossing task.

Preparation

Beckman Institute’s CAVE environment, which was created at the Illinois Simulator Laboratory, served as the location for the virtual street crossing task. The creation of the virtual environment was completed using Python bindings for in-house C++ middleware for cluster-based virtual reality (http://syzygy.isl.uiuc.edu/szg/index.html), with scenes rendered using PyOpenGL (http://pyopengl.sourceforge.net/). The main component for the CAVE environment included a manual treadmill (Woodway Curve, Woodway USA, Waukesha, WI) which was placed within a completely immersive virtual environment. The manual treadmill allowed only forward movement and participants were able to control the speed at which they walked. The speed at which participants moved through the virtual street was controlled by eight magnets around a
flywheel on the manual treadmill which were connected through an Arduino microcontroller to the PC cluster. Depth perception was created through the use of goggles that were synchronized with the three-sided display panels. The computer image was projected through the goggles as a three-dimensional image on the display panels from a synchronized PC cluster. The panels measured 303cm wide by 273cm high. During each trial, head position was monitored and tracked using an Ascension Flock of Birds 6DOF electromagnetic tracker (Ascension Technology Corporation, Champlain Valley, VT). Participants wore a gait belt around their waist at all times throughout the street crossing task. The gait belt was secured to the treadmill using two safety straps, and participants were instructed to grasp the railings of the treadmill at all times. During each trial, one researcher was positioned on either side of the treadmill to spot the participant in the event that the participant lost their balance.

**Design**

Each participant attempted 40 street crossing trials which were arranged in 2 blocks of 10 trials performed for each condition (i.e., 20 total trials per condition). The two conditions included: (1) no distraction; and (2) talking on a hands-free cell phone. The condition order was selected at random. The no distraction condition involved participants attempting to cross the street without any distraction. The hands-free cell phone condition involved participants talking to an investigator by wearing a hands-free headset attached to a phone while attempting to cross the street. The conversation was intended to be participant-dominated in that investigators posed questions that were open-ended, allowing discussion to also be continuous. The car spacing and car direction for each was randomly selected. Cars were spaced at 75m or 90m and traveled at a constant speed of 20mph.
Outcomes

Disability: Each participant underwent a neurological assessment for generating an EDSS score. The EDSS was performed by a Neurostatus-certified assessor and scores were used to characterize the disability level of the sample. Based on this score, participants were grouped as either mild (EDSS = 1.0-3.5) or moderate (EDSS = 4.0-5.5) MS.

Walking speed: Walking speed was assessed using the Timed 25-foot Walk (T25FW) according to standardized instructions (7). Participants were instructed to walk as quickly and safely as possible over a 25-foot distance. Participants performed two walking trials and an average of the two trials in seconds was recorded.

Walking endurance: Walking endurance was assessed using the 6-minute walk test (6MWT) (7) according to standardized instructions. Participants were instructed to walk as fast and as far as possible for 6-minutes in a rectangular hallway. The distance traveled was measured by a member of the research team who followed 1-3 meters behind the participant with a measuring wheel (Stanley MS50, New Briton, CT).

Aerobic Fitness: Aerobic fitness was measured using an incremental exercise test on a recumbent stepper (Nustep T5XR, Nustep Inc., Ann Arbour, MI). Participants were first fitted to the recumbent stepper to adjust for leg and arm length. Participants were then briefed on the test procedures. Participants began the test with a one minute warm-up at 15 Watts. The resistance on the stepper increased continuously by 5-10 Watts each minute until the participant reached volitional fatigue. Expired gases were collected using a Hans Rudolph, two-way non-rebreathable valve and oxygen consumption was measured continuously using an open circuit spirometry system (TrueOne 2400, Parvo Medics, Sandy, UT). At the end of each minute during the test, participants were asked to provide a rating of perceived exertion (RPE) and heart rate.
was recorded using a heart rate monitor (Polar Electro Oym, Finland). VO\textsubscript{2peak} was determined as the highest recorded 20-second VO\textsubscript{2} value when at least one of the following three criteria were met: (1) RPE ≥ 17; (2) peak heart rate within 10 beats per minute of age-predicted maximum heart rate; or (3) respiratory exchange ratio ≥ 1.10.

**Muscular Strength:** Knee flexor (KF) and knee extensor (KE) peak torque were measured using an isokinetic dynamometer (Biodex System 3 Dynamometer, Biodex Medical Systems, Inc., Shirley, NY). Participants were positioned on the machine according to the manufacturer’s instructions, with the hip and knee flexed at 90° and 60°, respectively. Participants performed three, 5-second maximal knee extensions and one, 5-second maximal knee flexion, with a 5-second rest period between trials. The highest recorded value in Nm per limb was used as a measure of peak torque.

**Cognition:** The Symbol Digit Modality Test (SDMT) was used to assess cognitive ability. Participants were presented with an 8.5 × 11-inch sheet of paper. The top of the page contained a key consisting of a series of 9 geometric symbols, each paired with a different single digit. Below the key was a list of 110 symbols and the participant was instructed to provide the digit corresponding to the symbol according to the key pairing system. Participants were instructed to provide as many correct digits associated with each symbol as possible in 90 seconds. Answers were provided orally by participants and recorded by a researcher. The score on the SDMT was the total number of correct symbols provided in 90 seconds.
**Virtual Street crossing outcomes**

**Trial duration:** Trial duration was characterized as the total time, in seconds, taken to cross the street successfully. This included preparation and crossing durations.

**Success rate:** Success rate was calculated as the percentage of successful crossings out of the total number of street crossings attempted.

**Collision rate:** Collision rate was calculated as the percentage of unsuccessful crossings, due to getting hit by a vehicle, out of the total number of street crossings attempted.

**Procedures**

Prior to being acclimated to the virtual environment and manual treadmill, participants were briefed on safety procedures and test instructions. Participants were instructed that the goal of each trial was to cross the street safely, without being hit by a car. Once fitted with the goggles and gait belt, participants performed a series of practice trials. The condition for the first block of 10 trials (i.e., no distraction or phone condition) was randomly selected and participants were given verbal instructions. The participants were also informed that each trial would begin once they crossed a yellow line on the sidewalk. The participants then began the first block of 10 trials of the street crossing task. Participants were reminded that once they began walking they could wait on the sidewalk until they determined it was safe to cross the street and that they were only able to walk in the forward direction to walk to cross safely (i.e., no running was allowed). A successful trial was completed once the participant reached the sidewalk on the other side of the street. A completed trial was signaled with visual and auditory feedback as to whether or not the trial was successful.
**Statistical Analysis**

We used descriptive statistics to analyze demographic and clinical characteristics of the sample, which included t-tests and chi-square tests to identify group differences. Correlational analyses were conducted to examine the relationship between overall street crossing performance and functional and fitness outcomes. We performed multiple hierarchical linear regression analyses to examine predictors of street crossing performance (i.e., trial duration, success rate, and collision rate) in people with MS. The first set of regression analyses examined the contribution of walking speed and aerobic capacity to trial duration, success rate, or collision rate. Walking speed (T25FW) was entered in the first step of the model followed by aerobic capacity in the second step of the model. The regression analyses revealed the contributions of walking speed and aerobic capacity to trial duration, success rate, or collision rate independently. The second set of regression analyses examined the contribution of walking endurance and aerobic capacity to trial duration, success rate, or collision rate. Walking endurance (6MW) was entered in the first step of the model followed again by aerobic capacity in the second step. Statistical significance was set at $p<.05$.

**4.3 Results**

Overall, the majority of participants were female (63.0%) and were diagnosed with relapsing remitting MS (92.6%). Mean age was 49.19 (9.07) years. Median EDSS score was 3.5 (1.5) and mean disease duration was 10.7 (7.8) years.
Correlation analyses

Correlation coefficients are presented in Table 3. Correlational analyses revealed that trial duration ($r = .58, p = .002$), success rate ($r = .52, p = .007$), and collision rate ($r = -.52, p = .007$) were significantly correlated with T25FW. Significant correlations also existed for trial duration ($r = -.59, p = .002$), success rate ($r = .55, p = .004$), and collision rate ($r = -.55, p = .004$) with regards to 6MW. Success rate ($r = .42, p = .03$) and collision rate ($r = -.42, p = .03$) were also significantly correlated to VO$_{2peak}$. There were no significant correlations between street crossing variables and disability ($r = -.29-.35, p > .05$), cognition ($r = -.32-.24, p > .05$), KE strength ($r = -.15-.15, p > .05$), or KF strength ($r = -.42-.42, p > .05$). This suggests that street crossing performance is most strongly associated with walking speed and endurance, and cardiorespiratory fitness.

Regression analyses

We selected variables for regression based on the correlational analyses. We selected those variables which had the strongest correlations (i.e., walking speed, walking endurance, and aerobic capacity). The first set of regression analyses, presented in Table 4, determined that T25FW explained a significant ($F[1, 24] = 12.01, p = .002$) portion of variance ($R^2 = .33$) in trial duration in Step 1. The addition of VO$_2$ in Step 2 did not explain additional variance ($F[1, 24] = 2.51, p = .127, \Delta R^2 = .07$). 6MW performance explained a significant ($F[1, 24] = 12.75, p = .002$) portion of variance ($R^2 = .35$) in trial duration in Step 1 of the analysis. The addition of VO$_2$ in Step 2 did not explain further variance in trial duration ($F[1, 24] = 1.83, p = .19, \Delta R^2 = .05$).
In the second set of regression analyses shown in Table 5, T25FW explained a significant \((F[1, 24] = 8.75, p = .007)\) portion of the variance \((R^2 = .27)\) in crossing success rate in Step 1. The addition of VO\(_2\) in Step 2 did not explain further variance in success rate \((F[1, 24] = .225, p = .64, \Delta R^2 = .01)\). 6MW performance explained a significant portion of the variance \((R^2 = .30)\) in success rate \((F[1, 24] = 10.16, p = .004)\) in Step 1. The addition of VO\(_2\) in Step 2, did not explain additional variance in success rate \((F[1, 24] = .239, p = .63, \Delta R^2 = .01)\).

The regression analysis data for collision rate are presented in Table 6. T25FW explained a significant \((F[1, 24] = 8.75, p = .007)\) portion of the variance \((R^2 = .27)\) in crossing collision rate in Step 1. The addition of VO\(_2\) in Step 2 did not explain further variance in collision rate \((F[1, 24] = .225, p = .64, \Delta R^2 = .01)\). 6MW performance explained a significant portion of the variance \((R^2 = .30)\) in collision rate \((F[1, 24] = 10.16, p = .004)\) in Step 1. The addition of VO\(_2\) in Step 2, did not explain additional variance in collision rate \((F[1, 24] = .239, p = .63, \Delta R^2 = .01)\).

4.4 Discussion

We have previously identified impairments in virtual street crossing performance in persons with MS compared to healthy controls. The goal of this study was to identify which factors influence street crossing ability in persons with MS with the purpose of identifying targets for improving this behavior. This study involved the examination of functional and fitness variables (i.e., EDSS, T25FW, 6MW, SDMT, LE\(_{\text{peak}}\), LF\(_{\text{peak}}\), and VO\(_2\)\(_{\text{peak}}\)) in relation to street crossing performance (i.e., trial duration, success rate, and collision rate). Two notable conclusions were made from this investigation: (1) walking speed, walking endurance, and cardiorespiratory fitness were most strongly associated with street crossing performance; and (2)
walking speed and walking endurance were independent predictors of street crossing 
performance in persons with MS. These findings have important implications for improving 
street crossing ability in MS as it identifies walking speed and walking endurance as the primary 
targets for rehabilitation interventions.

We observed significant, moderate correlations between T25FW, 6MW, and VO$_{2peak}$ and 
street crossing performance. Further, walking speed and endurance were independent predictors 
of street crossing behavior. This suggests that ambulatory ability is most important for successful 
roadway navigation in persons with MS. The association between ambulatory ability and street 
crossing performance is not surprising as it has been reported in other populations. For instance, 
significant, moderate correlations were reported between walking speed and street crossing 
decisions and collisions (all p < .05) in healthy individuals ranging from young (ages 20-35), 
younger-old (ages 60-70), and older-old (ages 70-85) individuals (8,9). Similarly, high levels of 
cardiorespiratory fitness in people with MS, which is associated with increased ambulatory 
ability, have been associated with increased success rate in simulated street crossing tasks in 
children (p = .009) (6). This is consistent with our current findings that aerobic fitness, as 
measured by VO$_{2peak}$, is significantly and moderately correlated with street crossing success rate 
In the present study, we observed small, non-significant associations between disability (i.e., 
EDSS), cognition (i.e., SDMT) and muscular strength (i.e., LE$_{peak}$, LF$_{peak}$) and street crossing 
performance. In contrast, previous studies comparing street crossing performance in old and 
young adults have attributed differences in performance, particularly longer decision making 
times and incorrect street crossing decisions, to differences in cognitive performance, although 
cognition was not directly measured in all studies (8–10). In studies by Dommes et al (2011 & 
2013), cognition was assessed as processing speed and visual attention threshold, and also took
into account perceptual ability (i.e., time-to-arrival and vehicle speed estimations). These studies determined that collision percentage was significantly and moderately correlated to cognitive ability (i.e., processing speed and visual attention) \((p < .05)\) (9). Additionally, unsafe street crossing decisions (i.e., decisions to cross which put the participant at risk of collision) were significantly and moderately correlated to both perceptual ability and cognitive ability (all \(p < .01\)) (8). Since cognitive decline is associated with both aging and MS (reference), it is surprising that we did not determine a significant association between cognitive processing speed and street crossing performance. The lack of a significant relationship between disability, cognition, or strength and street crossing performance may be the result of the characteristics of the participants enrolled to this study. Eligibility requirements involved the ability to power a manual treadmill in the virtual street crossing environment and therefore, we did not have a sample with more severe impairment. Overall, we determined that walking speed and walking endurance were most important for successful street crossing performance in persons with mild-to-moderate MS.

Understanding the key determinants of virtual street crossing performance is important for developing targeted rehabilitation programs to improve real-world street crossing, pedestrian safety, and community independence. Our data suggest that rehabilitation programs that target walking speed and walking endurance might be effective for improving street crossing ability in people with MS. One approach for improving mobility is through exercise training. Indeed, aerobic and resistance exercise training have been associated with improved walking speed and endurance. For instance, 8-10 weeks of leg cycle ergometry or arm ergometry training resulted in significant improvements in walking endurance (i.e., 6MW) in 42 people with moderate MS (EDSS range = 4.0-6.0) (11). Another study, consisting of 8 weeks of treadmill training (30
minutes, 3 times a week at 40-75% age-predicted maximal heart rate) in a sample of 31 women with mild-to-moderate MS demonstrated significant improvements in walking speed (i.e., 10-m walk) (p < .05) (12). Progressive resistance training has also resulted in improving walking speed and walking endurance in people with MS. A 10 week progressive resistance training program resulted in significant improvements in 10-m walk times, in 8 people with mild-to-moderate MS (p = .04). (13). Progressive resistance training of 12 weeks, twice weekly of five exercises targeting the major muscle groups of the lower body resulted in significant improvements in the 6-minute walk test as a component of functional capacity (p < .05) (14). Additionally, 10 weeks, twice weekly, consisting of three exercises for each major muscle groups of the upper and lower body resulted in a trend to increased walking endurance as measured by increased distance walked in the 2-minute walk test in people with mild-to-moderate MS (p = .055) (13). It will be important to determine if rehabilitation interventions that improve walking speed and endurance do indeed improve street crossing performance, and this concept can be evaluated in the simulated street crossing environment. Other rehabilitation interventions such as virtual reality training to improve street crossing performance in MS should also be explored.

While this study provides insight as to which variables have the greatest impact on street crossing behavior in people with MS, there are several limitations. First, there was a small sample size of people with MS. Additionally, we did not capture the high end of the disability spectrum of people with MS as all participants were required to walk on the manual treadmill. Other variables in addition to those examined might have impacted street crossing performance. For example, behavioral variables, geographic location of residence (i.e., urban vs rural), or previous street crossing experience might influence street crossing performance. In the case of
the latter, previous experience (i.e., pedestrian accidents) would likely decrease self-efficacy with regards to street crossing behavior and might negatively impact performance.

Overall, our data suggest that walking speed and walking endurance are the most important factors for successful street crossing in people with MS. For this reason, these variables should become targets of rehabilitation interventions for improving real-world roadway navigation in MS. This might be accomplished through exercise training or virtual reality training interventions. In the future, additional variables should be taken into consideration, such as previous experience with street crossing that might also impact street crossing performance in persons with MS.

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Conflict of Interest
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4.5 References


Yearly the National Highway Traffic Safety Administration compiles a report of all traffic accidents resulting in pedestrian fatalities and injuries. This information tells us that pedestrian safety is a major issue as there are thousands of pedestrian fatalities and injuries documented on a yearly basis. Pedestrian safety can be influenced by a variety of factors, including components such as attentional focus, presence of distractions, and walking ability. It is reasonable to expect that populations with impaired abilities may be at an increased risk of pedestrian injury or pedestrian fatality due to their inability to manage distractions or crossing scenarios effectively. People with MS represent one of these populations, as several impairments associated with MS directly impact factors that have been known to influence pedestrian safety. For example, people with MS have impaired walking ability as demonstrated by slower walking speed, diminished walking endurance, impaired balance ability, and increase prevalence of gait problems. In busy communities, where traffic is most likely heavy, crossing time may be limited. Thus, a person who is unable to cross in a shortened amount of time, such as those with MS, may be at increased risk of collision with a vehicle. Additional impairments associated with MS, including cognitive impairments, namely problems with information processing, attentional focus, memory, and executive function, relate to a person’s ability to make decisions regarding if, and when, it is safe to cross a street. This decision making process requires a person to perceive environmental cues, often times in the presence of other distractions (i.e., other people, talking, conversing on a cell phone, listening to music, etc.), and evaluate whether they are capable to cross in the given time gap. Thus, this decision making process which is predominantly based on information processing of environmental cues would be particularly
challenging for people with MS, leaving this population at increased risk of unsafe street crossings. Overall, considering the number of pedestrian fatalities and injuries, pedestrian safety is a primary concern especially among populations who may be at greater risk of unsafe street crossing behavior, such as people with MS. It is therefore important to evaluate street crossing behavior in people with MS. In addition, it is also important to identify factors that contribute to street crossing performance in order to identify targets for rehabilitation and street crossing training programs aimed at improving pedestrian safety in people with MS.

The purpose of this thesis was to evaluate street crossing performance in people with MS, which is a novel area of investigation. The purpose was to identify the feasibility and safety of assessing street crossing performance in people with MS, compare street crossing performance of people with MS to healthy controls, examine the effect of distraction on street crossing performance, and identify targets for rehabilitation. All participants who met our inclusion criteria, independently detailed in each of the studies above, completed a simulated street crossing task in a virtual environment. Importantly, disability level inclusion criteria required that participants be able to walk independently and power a manual treadmill. The street crossing task involved a no distraction and distraction (i.e., talking on the cell phone) condition. The inclusion of a dual-task scenario was based upon 1) the evidence that distraction is related to pedestrian fatalities and injuries (1); and 2) the inclusion of a distraction condition in previous virtual reality street crossing studies in children and older adult populations. We first examined the feasibility and safety of street crossing performance in people with MS, as well as differences in street crossing performance across both conditions between people with MS and matched controls. We then examined potential factors (i.e., functional and fitness variables) that influence
street crossing performance in people with MS, and furthermore, to what extent these variables serve as independent predictors of street crossing behavior in people with MS.

There were several takeaways from this investigation. First, it is feasible to assess street crossing behavior using a virtual reality environment in people with MS, as evidenced by a 93% completion rate in the MS sample. Second, street crossing performance is impaired in people with MS compared with matched, healthy controls, as evidenced by longer trial and crossing durations, and lower crossing success rates in people with MS. Additionally, slower street crossing times in participants with MS was independent of walking performance (i.e., walking speed and endurance). Third, the addition of a distraction condition impaired street crossing performance in both people with MS as well as healthy controls. Upon further investigation of the contribution of fitness and functional variables to street crossing performance, we concluded that walking speed, walking endurance, and cardiorespiratory fitness were strongly associated with street crossing performance. Furthermore, walking speed and walking endurance were independent predictors of street crossing performance in people with MS.

Collectively, these findings lead to the development of several implications for people with MS. These implications affect risk of injury, maintenance of independence, level of physical activity, need for a reduction of distractions, and heightened awareness and improvement of the independent predictors of street crossing behavior. First, these findings indicate that people with MS are at greater risk of pedestrian injury or fatality as the result of a traffic collision. In addition, risk of injury may pose greater challenges for people with MS due to the complications associated with the disease. For example, rehabilitation for people with MS following a pedestrian injury may be more challenging due to physical and cognitive deficits, loss of function, and fear or apprehension. Second, for people with MS, maintaining autonomy
and the ability to be an independent community member is of immense importance. However, if people with MS are unable to safely ambulate within the community, autonomy may be compromised. Therefore, impaired street crossing in people with MS leads to implications of dependence upon others to assist in safe locomotion throughout a community. Third, people with MS may limit their lifestyle physical activity if there is an increased risk of injury associated with the task, much like there is with street crossing. Fourth, these data suggests that people with MS should limit distractions when walking, and especially when attempting to cross streets within the community because distraction has been demonstrated to impair safe street crossing behavior. Finally, by establishing several independent predictors of street crossing performance we can focus on these specific variables through intervention strategies, and they can help predict a person’s risk of unsafe street crossing behavior.

To summarize, the results of these studies provide novel evidence that street crossing is impaired in people with MS, that distraction impairs street crossing performance in people with MS as well as controls, and that walking speed and walking endurance are independent predictors of this performance. Together, these results imply that people with MS may be at increased risk of pedestrian injury, though, the potential for rehabilitation programs that target walking speed and walking endurance may assist in reducing this risk.

Future Directions

Moving forward, there are several steps to take to expand upon the data in this investigation. Future work should center on two general focuses: 1) additional experiments in a virtual environment in people with MS to confirm and extend the present findings; and 2) intervention-based research to improve street crossing performance. With regards to additional
experiments in a virtual environment there are several aspects to consider. For one, experiments should test for the influence of additional variables on street crossing performance, not included in the current experiments. These variables may include the influence of behavioral factors, such as previous experience or self-efficacy on street crossing performance. In the current studies, walking speed and endurance were found to be independent predictors of street crossing performance, while aerobic capacity explained some of the variance in street crossing performance. Therefore, there are potentially other factors or variables that may explain the variance in street crossing performance across people with MS and between people with MS and healthy controls. Identifying other variables would help researchers establish protocols for targeted rehabilitation programs and street crossing training regimens. Future experiments should also control for additional demographic variables such as geographic residence of participants, as people living in rural compared to urban areas might have varied exposure to street crossing in real life. Additionally, it would be beneficial to assess street crossing performance in people with moderate-to-severe MS. In other words, future experiments should aim to examine the street crossing ability of people with MS who rely on unilateral (i.e., a cane) or bilateral (i.e., a walker) assistance to ambulate. It is likely that cognitive declines would be associated with physical impairments, such as walking ability. Thus, examining street crossing ability in people with more severe physical disability may also target people with more severe cognitive disability as well. Studies examining people with moderate to severe MS would better assist communities in creating cross walks and identifying the appropriate crossing time needed for clinical or disabled populations. Collectively, examining other variables that might influence performance, controlling for additional demographic variables, and examining street crossing behavior in more
disabled samples of people with MS are three of the next steps for future experiments in this area.

In addition to virtual reality experiments in this population, future directions for this area of research should include establishing training interventions either within a virtual reality environment or through exercise training protocols that target and improve street crossing performance. The goal of these interventions would be to manipulate and improve the variables (i.e., walking speed, walking endurance, and aerobic capacity) which appear to have the strongest relationship with street crossing performance. Virtual reality street crossing training has been successfully used in other populations (i.e., children and older adults) previously. Virtual reality street crossing training proved to be effective in preventing child pedestrian injuries by reducing the risk of collisions and close calls (2). Within the simulation training, participants would begin in a first person view of the road, but once they deemed it safe to cross the virtual street and stepped off the curb, the virtual setting transformed into a third person view. In this way, participants were able to watch the results of their street crossing decision from an external point of view. After this enactment, an avatar would discuss with the participant the safety of their decision, whether it resulted in a successful crossing, a collision, or a close-call (2). This is the same method of training used in virtual reality training for older adults (3). Through behavioral feedback, people within these training environments are able to address concerns over perception of safety and strategies for assessing what makes a roadway safe to cross (i.e., car spacing, approaching speed of the vehicles, adjustment of their own walking speed, etc.). Also, the idea of using virtual reality to train for a real-world scenario is not a novel one, as it has been used extensively in fields such as aviation, driving, and surgery. Virtual reality surgery allows surgeons to safely practice techniques used for operations, and it has been found that this task
translation or skill transfer is valid and reliable when performing the same task in a real-world setting (4). Similar findings have been reported in simulation training for flight and driving, whereby virtual skill practice involving interpreting environmental cues and practicing reaction time in response to critical events has proven effective in improving aviation and driving performance in a real-world setting (5,6). Thus, utilizing a virtual reality street crossing paradigm for training purposes may be beneficial in improving the sensory-motor function of people with MS. This type of training would provide people with MS with increased awareness for environmental cues to take into consideration when deciding whether or not it is safe to cross the street.

Another type of rehabilitation training that should be considered in the future is aerobic and resistance exercise training. The results of the current studies suggest that physical variables (i.e., walking speed and walking endurance) have the greatest impact on street crossing performance, and consequently, would impact risk of unsafe crossings (e.g., as walking speed increases, risk of unsafe crossings decreases). Further, MS is associated with progressive declines in ambulation and physical fitness measures. It is therefore imperative to preserve and improve these variables as much as possible to avoid the inherent increased risk of unsafe street crossing over time with the progression of the disease. From previous research, both aerobic and resistance exercise training have been found to improve walking speed and walking endurance in people with MS (7–10). Most exercise training studies that have improved walking speed and walking endurance have involved twice weekly of aerobic or resistance exercise for the duration of 8–12 weeks. Progressive resistance training programs have focused on major muscle groups of the upper and lower body (9). Many of the aerobic training programs for people with MS have involved treadmill or leg cycle ergometry as the predominant mode of exercise (8). There has yet
to be a study examining the direct effect of aerobic and/or resistance exercise training on street crossing performance. Such an investigation would provide novel data on the effect of exercise training on street crossing performance in people with MS.

Limitations

This investigation provides novel data regarding street crossing behavior and its predictors in people with MS; however, there are several limitations of this investigation. First, the sample size of people with MS was relatively small and there was little variation in disability level of the sample. Participants at the high end of the disability spectrum were not included, since all participants had to be able to power a manual treadmill. Also, participants were predominantly female with relapse-remitting MS; therefore, generalizing the feasibility, safety, and efficacy of the task to people with MS with other characteristics may be difficult. Additionally, using a virtual environment to assess street crossing behavior lacks the ambient noise (i.e., traffic noise) that would be present during the real-world task. Lastly, there may have been other variables (i.e., behavioral, geographic location of residence, or previous experience, self-efficacy, etc.), in addition to the fitness and functional variables examined, that may have been important for street crossing performance as well. Not assessing or controlling for these factors could confound our results.

Conclusions

Overall, pedestrian safety is a major issue in America as thousands of pedestrian injuries and fatalities are reported annually. People with MS are likely at a greater risk of these events as they suffer from several physical and cognitive impairments associated with the disease that may
influence their ability to cross the street safely. Despite these impairments, we determined that it is feasible and safe to assess street crossing performance in people with MS. We observed that people with MS perform more poorly (e.g. slower crossing durations) than controls on the street crossing task. It was determined that conversing on a cell phone while attempting to cross the street impairs performance, or results in more collisions, but this effect was not specific to people with MS. Through additional analysis we found that walking speed and walking endurance were the most important factors for determining successful street crossing in people with MS. The results of these studies provide information relative to potential fitness, rehabilitation, and virtual reality interventions targeting improved walking speed, endurance, and street crossing performance. These data also provide information relevant to making changes in public policy regarding street crossing regulations, such as time allotted for crossing at a crosswalk.

5.1 References


Table 1: Demographic and clinical characteristics of participants with MS and controls.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control (n=19)</th>
<th>MS (n=27)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>51.2 (10.7)</td>
<td>48.2 (9.1)</td>
</tr>
<tr>
<td>Sex, female/male</td>
<td>16/3</td>
<td>17/10</td>
</tr>
<tr>
<td>MS type, relapsing/progressive</td>
<td>N/A</td>
<td>26/1</td>
</tr>
<tr>
<td>Disease duration, years</td>
<td>N/A</td>
<td>10.7 (7.8)</td>
</tr>
<tr>
<td>EDSS, mdn (IQR)</td>
<td>N/A</td>
<td>3.5 (1.5)</td>
</tr>
<tr>
<td>T25FW, seconds*</td>
<td>3.7 (0.6)</td>
<td>4.5 (1.6)</td>
</tr>
<tr>
<td>SDMT</td>
<td>65.5 (12.6)</td>
<td>58.7 (13.2)</td>
</tr>
</tbody>
</table>

NOTE: EDSS: Expanded Disability Status Scale; T25FW: timed 25-foot walk test. *Significant difference between MS/Control. Values are mean (SD), unless otherwise indicated.
Table 2: Street-crossing performance in persons with MS and non-MS controls.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>No distraction</th>
<th>Phone</th>
<th>Group Effect</th>
<th>Condition Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>F</td>
<td>p</td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration, sec</td>
<td>Control</td>
<td>14.0 (0.9)</td>
<td>15.8 (1.1)</td>
<td>12.14</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>MS</td>
<td>18.0 (0.8)</td>
<td>20.4 (0.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Success rate, %</td>
<td>Control</td>
<td>97.1 (2.5)</td>
<td>96.3 (3.1)</td>
<td>1.76</td>
<td>.19</td>
</tr>
<tr>
<td></td>
<td>MS</td>
<td>92.8 (2.1)</td>
<td>91.3 (2.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collision rate, %</td>
<td>Control</td>
<td>2.9 (2.5)</td>
<td>3.7 (3.1)</td>
<td>1.76</td>
<td>.19</td>
</tr>
<tr>
<td></td>
<td>MS</td>
<td>7.2 (2.1)</td>
<td>8.7 (2.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initiation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration, sec</td>
<td>Control</td>
<td>5.4 (0.6)</td>
<td>6.8 (0.8)</td>
<td>5.22</td>
<td>.03</td>
</tr>
<tr>
<td></td>
<td>MS</td>
<td>7.4 (0.5)</td>
<td>8.7 (0.7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head turns</td>
<td>Control</td>
<td>3.1 (0.3)</td>
<td>3.6 (0.4)</td>
<td>.51</td>
<td>.48</td>
</tr>
<tr>
<td></td>
<td>MS</td>
<td>3.5 (0.3)</td>
<td>3.8 (0.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car distance at enter, m</td>
<td>Control</td>
<td>61.8 (0.8)</td>
<td>59.5 (1.6)</td>
<td>1.53</td>
<td>.22</td>
</tr>
<tr>
<td></td>
<td>MS</td>
<td>62.9 (0.7)</td>
<td>61.7 (1.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crossing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration, sec</td>
<td>Control</td>
<td>4.8 (0.2)</td>
<td>5.0 (0.2)</td>
<td>19.82</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>MS</td>
<td>6.0 (0.2)</td>
<td>6.4 (0.2)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3: Correlations between overall outcomes and functional/fitness variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>EDSS</th>
<th>T25FW</th>
<th>6MW</th>
<th>SDMT</th>
<th>LE&lt;sub&gt;peak&lt;/sub&gt;</th>
<th>LF&lt;sub&gt;peak&lt;/sub&gt;</th>
<th>VO&lt;sub&gt;2peak&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial duration</td>
<td>.35</td>
<td>.58*</td>
<td>-.59*</td>
<td>-.32</td>
<td>-.13</td>
<td>-.35</td>
<td>-.22</td>
</tr>
<tr>
<td>Success rate</td>
<td>-.29</td>
<td>.52*</td>
<td>.55*</td>
<td>.24</td>
<td>.15</td>
<td>.38</td>
<td>.42*</td>
</tr>
<tr>
<td>Collision rate</td>
<td>.29</td>
<td>-.52*</td>
<td>-.55*</td>
<td>-.24</td>
<td>-.15</td>
<td>-.38</td>
<td>-.42*</td>
</tr>
</tbody>
</table>

Mean (SD)

NOTE: EDSS: Expanded Disability Status Scale; T25FW: timed 25-foot walk test; 6MW: 6-minute walk test; SDMT: single digits modality test; LE<sub>peak</sub>: leg extension peak; LF<sub>peak</sub>: leg flexion peak; VO<sub>2peak</sub>: peak aerobic capacity. * Significant correlation (p < .05).
Table 4: Regression analyses for trial duration

A)

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T25FW</td>
<td>-2.03</td>
<td>.59</td>
<td>-.58*</td>
</tr>
<tr>
<td><strong>Step 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T25FW</td>
<td>-2.90</td>
<td>.79</td>
<td>-.83*</td>
</tr>
<tr>
<td>VO\textsubscript{2peak}</td>
<td>.22</td>
<td>.14</td>
<td>.36</td>
</tr>
</tbody>
</table>

NOTE: $R^2=.334$ for Step 1; $\Delta R^2 = .065$ for Step 2; *p<.05 with two-tailed test.

B)

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6MW</td>
<td>-.02</td>
<td>.01</td>
<td>-.59*</td>
</tr>
<tr>
<td><strong>Step 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6MW</td>
<td>-.03</td>
<td>.01</td>
<td>-.78*</td>
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<tr>
<td>VO\textsubscript{2peak}</td>
<td>.18</td>
<td>.13</td>
<td>.29</td>
</tr>
</tbody>
</table>

NOTE: $R^2=.347$ for Step 1; $\Delta R^2 = .048$ for Step 2; *p<.05 with two-tailed test.

6MW: 6-minute walk; T25FW: timed 25-foot walk; VO\textsubscript{2peak}: peak aerobic capacity
Table 5: Regression analyses for success rate

A)

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T25FW</td>
<td>5.23</td>
<td>1.77</td>
<td>.52*</td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T25FW</td>
<td>4.40</td>
<td>2.50</td>
<td>.44</td>
</tr>
<tr>
<td>VO\textsubscript{2peak}</td>
<td>.21</td>
<td>.45</td>
<td>.12</td>
</tr>
</tbody>
</table>

NOTE: $R^2 = .267$ for Step 1; $\Delta R^2 = .007$ for Step 2; *p<.05 with two-tailed test.

B)

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6MW</td>
<td>.06</td>
<td>.02</td>
<td>.55*</td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6MW</td>
<td>.05</td>
<td>.03</td>
<td>.47</td>
</tr>
<tr>
<td>VO\textsubscript{2peak}</td>
<td>.20</td>
<td>.41</td>
<td>.11</td>
</tr>
</tbody>
</table>

NOTE: $R^2 = .297$ for Step 1; $\Delta R^2 = .007$ for Step 2; *p<.05 with two-tailed test. 6MW: 6-minute walk; T25FW: timed 25-foot walk; VO\textsubscript{2peak}: peak aerobic capacity
Table 6: Regression analyses for collision rate

A)

<table>
<thead>
<tr>
<th>Variable</th>
<th>$B$</th>
<th>$SE_B$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T25FW</td>
<td>-5.23</td>
<td>1.77</td>
<td>-.52*</td>
</tr>
<tr>
<td><strong>Step 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T25FW</td>
<td>-4.40</td>
<td>2.50</td>
<td>-.44</td>
</tr>
<tr>
<td>VO$_{2peak}$</td>
<td>-.21</td>
<td>.45</td>
<td>-.12</td>
</tr>
</tbody>
</table>

NOTE: $R^2$ = .267 for Step 1; $\Delta R^2 = .007$ for Step 2; *p<.05 with two-tailed test.

B)

<table>
<thead>
<tr>
<th>Variable</th>
<th>$B$</th>
<th>$SE_B$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6MW</td>
<td>-.06</td>
<td>.2</td>
<td>-.55*</td>
</tr>
<tr>
<td><strong>Step 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6MW</td>
<td>-.05</td>
<td>.02</td>
<td>-.47</td>
</tr>
<tr>
<td>VO$_{2peak}$</td>
<td>-.20</td>
<td>.41</td>
<td>-.11</td>
</tr>
</tbody>
</table>

NOTE: $R^2$ = .297 for Step 1; $\Delta R^2 = .007$ for Step 2; *p<.05 with two-tailed test.
6MW: 6-minute walk; T25FW: timed 25-foot walk; VO$_{2peak}$: peak aerobic capacity