OLDER DRIVERS STRATEGIES DURING VEHICLE TRANSFER

EXPLORING STRATEGIES USED BY OLDER DRIVERS DURING INGRESS AND EGRESS AND THEIR VARYING PHYSICAL MOBILITY

By DALE LEUNG B.H.Sc.

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AUTHOR:	Dale Leung, B.H.Sc. (University of Ottawa)
SUPERVISOR:	Brenda Vrkljan, PhD
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ABSTRACT

Background

Approximately 37,000 older adults are injured annually when entering (ingress) and exiting (egress) a motor vehicle. Previous studies examining driver ingress and egress movement patterns have focused on foot placement. Drivers typically use either a one-foot or two-foot strategy to enter and exit a vehicle; both of which are further divided into specific sub-strategies. To date, however, research has yet to comprehensively examine the specific ingress and egress movement patterns (foot, hand) of older drivers in relation to objective measures of physical mobility and other self-reported factors (e.g., history of falls, use of a mobility aid).

Purpose: The overall purpose of the present study was to examine the strategies used by older adults with regard to both foot placement and hand contact location as they enter (ingress) and exit (egress) a vehicle. The research questions were as follows:

1) What are the ingress and egress strategies principally foot placement and hand contact locations that older drivers use?
2) How do these strategies vary according to objective measures of physical mobility and self-reported mobility? And;
3) What are the observable relationships between foot placement and hand contact location during ingress and egress?

Method: A cross-sectional study was used to identify and, in turn, examine the participants' ingress and egress strategies in relation to their physical mobility and other characteristics. Purposeful sampling techniques were used for participant recruitment. A total of 33 participants were recruited, of which 32 completed the study. All participants had a valid driver's license and they completed the following: 1) demographic (self-report) questionnaires; 2) clinical measures of physical mobility (i.e. Timed Up and Go, Berg Balance Scale, One Legged Stance test, Rapid Pace Walk test). A physical mobility index was also developed using these clinical measures. Each participant completed vehicle ingress and egress on the same vehicle. Videos of the ingress and egress tasks were recorded using a Microsoft Kinect camera. These videos were analyzed by a single observer (DL) on five occasions. Using a descriptive approach, the mean and standard deviation (*SD*) of the clinical measures was then plotted. From the videos, the patterns of foot strategies and hand contact locations were identified for each ingress and egress transfer. The participants' ingress and egress strategies were described according to their level of physical mobility and self-reported history of falls, as well as use of a mobility aid.

Results: The mean age of the 32 participants was 71.84 years (*SD* = 6.97); 19 of whom were female. During both ingress and egress, older drivers were more likely to use one-foot strategies, which are considered less stable. Participants who used one-foot ingress and egress strategies had better overall physical mobility (according to their mean index scores). The armrest location was used by the majority of older drivers for both ingress and egress, and is used most often during one-foot strategies. Participants who used multiple hand contact locations during ingress/egress had lower physical mobility than participants who used a single hand contact location or made no contact with the vehicle

Conclusion: By evaluating human-vehicle interaction with regard to vehicle ingress and egress, the results from this study can inform educational materials targeting this population when it comes to strategies that can keep them safe during this transfer. As well, data from this study can be considered when determining design changes to the automobile that can prevent injuries to older drivers.

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LIST OF ABBREVIATIONS

Abbreviation	**Definition**
(AR)	Armrest
(BBS)	Berg Balance Scale
(BP)	B-pillar
(Candrive)	Canadian Driving Research Initiative for Vehicular Safety in the Elderly - Canadian Institutes for Health Research (CIHR) older driver cohort (5-year) study
(CEAL)	Challenging Environment Assessment Lab
(iDAPT)	Intelligent Design for Adaptation, Participation and Technology
(OCAD)	Ontario College of Art and Design
(OLS)	One-legged Stance
(OT)	Occupational Therapist
(RPW)	Rapid Pace Walk
(SD)	Standard Deviation
(SW)	Steering Wheel
(TRI)	Toronto Rehabilitation Institute
(TUG)	Timed Up and Go
(WF)	Window Frame
(WHO)	World Health Organization

GLOSSARY OF KEY TERMS

Key Terms	**Definition**
Balance[1]	An individual's ability to control his/her body position relative to his/her base of support (i.e. standing, or maintaining their position while moving without falling).
Base of Support[1]	The two-dimensional area or point of contact between the individual and the supporting surface (e.g., floor/ground, the car seat, steering wheel).
Centre of Gravity [1]	Point or location in space in which the entire weight (gravitational force) of an object (or individual) are concentrated.
Egress	The act of exiting a vehicle.
Egress Strategy	Orientation of an individual's body, including torso and feet, during egress.
Ingress	The act of entering a vehicle.
Ingress Strategy	Orientation of an individual's body, including torso and feet, during ingress.
Mobility[3]	The ability to freely and easily move from one place/position to another (i.e. walking using assistive device, transportation) within one's home or community environments. Mobility can involve five key categories - cognitive, psychosocial, physical, environmental, and financial.

Movement[2]	The act of moving one's joints to change place or position. Control of movement systems can also involve sensory systems (i.e., visual, haptic, acoustic, proprioceptive).
Motion[2]	Action or process of a change in position where points on a body or object moves either in a circular or in a linear fashion on a fixed central line or axis. In the case of human motion, parts of the body (i.e. limbs) moving or changing posture.
Physical Mobility[2]	A state in which an individual can perform a certain level of movement with ease.
Strength (Muscular)[1]	The ability to withstand a certain amount of stress (force) or load on a muscle or muscles.
Stability[2]	The extent of being able to withstand a certain amount of stress or capacity of an object to return to equilibrium or to its original position after displacement (i.e. maintain a level of balance).

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DECLARATION OF ACADEMIC ACHIEVEMENT

This thesis is the primary work of Master of Science candidate, Dale Leung. Dale was involved with creating the databases and analyzing the raw video data that was collected by a team of student Occupational Therapists and other graduate students from Kinesiology and Engineering, as part of a project funded by the Labarge Optimal Aging Initiative at McMaster University. Data within this thesis was collected during the summer of 2014 and were then analyzed during the 2015-2016 academic year. As the primary author, Dale's contributions include: literature review, organization and analyses of the collected data that have been disseminated in this thesis. Dale was also part of the student Occupational Therapy team that worked in collaboration with the Ontario College of Art and Design (OCAD) on a project that explored how this data could inform design considerations to facilitate safe entry and exit from the vehicle by older drivers.

Important contributors to this thesis include: Dr. Brenda Vrkljan, the thesis supervisor who funded this study, developed the study design, and assisted with interpretation of the results, and edited all submitted documents; Dr. Robert Fleisig, and Dr. Joy MacDermid who provided important considerations with respect to the focus of the video analyses on physical mobility; Tara Kajaks, Alexander Crizzle, Scott Coffin, and Ellyse Shacklady who collected the data; Alexandra Mueller who also helped with creating an outline, developing and refining research questions, as well as editing parts of the thesis; and student Occupational Therapists (Stacie Perlmutter & Olivia Fischer) who were part of the collaboration with OCAD.

CHAPTER 1

INTRODUCTION

1.1 The Importance of Driving in Later Life

Driving is the most common form of transportation in North America and has been identified as critical for older adults (≥ 65 years) to maintain their independence and well-being (Edwards et al., 2009; Statistics Canada, 2012). Access to an automobile in later life provides the means to remain socially connected to family, friends, and the community (Berkman, Glass, Brissette, & Seeman, 2000). As of 2009, 3.25 million, or three quarters of all older adults (65+) in Canada, had a driver's licence (Turcotte, 2012). Moreover, it is expected that the number of older drivers will continue to increase, as persons in this age group are the fastest growing segment of the Canadian population (Turcotte, 2012). While there is still a difference between the number of male and female older drivers, particularly among persons ≥85years (i.e., among men ≥85years, 67% had a driver's license in 2009, whereas among women ≥85years, only 26% had a driver's license), it is expected that this difference may dissipate, as nearly as many women as men, 45 to 64 years have a driver's licence (Turcotte, 2012). Since similar trends are noted in terms of the growing number of older drivers in Europe, Asia, and other countries (Rosenbloom, 2001), understanding the needs of this age group when it comes to driving is important, particularly given the increasing number of health-related changes and other factors that can impact their safety behind the wheel.

1.2 Health-Related Changes and Driving in Older Adulthood

Driving is a complex task, which requires the integration of visual, cognitive, and motor skills to achieve optimal performance. With age, older adults are more likely to experience medical conditions with resulting impairments that can affect behind-the-wheel behavior

(Meuser et al., 2016). Drivers ≥ 70 years have one of the highest crash and associated injury risks per distance driven, which has been attributed, in part, to the increased prevalence of such impairments (National Centre for Injury Prevention and Control, 2014).

The Canadian Medical Association as well as the American Medical Association have both released documents that detail how various health conditions can affect medical fitness to drive (Meuser et al., 2016). Examples of such conditions range from vision and hearing loss to cardiovascular diseases, such as stroke, as well as neurodegenerative (e.g., dementia) and psychiatric disorders (e.g., schizophrenia). While some of these conditions are more prevalent with age, their functional implications can vary widely. Hence, making a determination of medical fitness to drive should be according to function, rather than age or diagnoses alone (Dickerson et al., 2007).

Concerns for public safety and efforts to restrict older drivers must be carefully considered given the impact of license forfeiture on mobility and independence (Dickerson et al., 2007). Loss of licensure, whether voluntary or otherwise, can have devastating health and social consequences, particularly for older adults (Chihuri et al, 2016). In a recent systematic review that examined these consequences, Chihuri et al. (2016) found that driving cessation was associated with a decline in health in this age group, including physical, social, and cognitive functioning. In fact, they found driving cessation doubled the risk of depressive symptoms in later life.

Efforts targeting older driver safety have focused primarily on drivers. A screening battery for physicians and other health care professionals to identify unsafe drivers is under development (Marshall et al., 2013). Such initiatives, while important, neglect the vehicle environment, which can also influence behaviour. For example, improving vehicle design has much potential with regard to improving performance, but must be developed with the end user in mind. Drivers and passengers ≥ 65 years are set to become the largest single demographic of automobile users in the next decade (Eby & Molnar, 2013). For the automotive industry, the aging population represents a major shift from younger consumers and related designs to cross-generational designs that take into account both age and ability (Coughlin, 2009). Older adults have been suggested in previous studies as the ideal group to test the development of automotive designs due, in part, to their extensive driving experience and health and age-related changes that can affect their safety when using a car (Herriots, 2005; Meyer, 2009; Owsley, McGwin, & Seder, 2011). Among older drivers, including those with certain health issues (e.g., arthritis) (Vrkljan et al., 2010), problems with accessibility (e.g., getting in/out of vehicle, storage/trunk space) (Herriots, 2005), visibility (e.g., mirrors, instrumentation displays, exterior of vehicle) (Owsley, McGwin, & Seder, 2011), and adjustability (e.g., steering, seat) have been identified.

1.3 Falls and Serious Injuries Incurred during Vehicle Transfer in Older Adulthood

In a retrospective analysis from data between 2001 and 2003, a U.S. study found that approximately 37,000 seniors are injured annually getting into (ingress) and out of a vehicle (egress) (Dellinger, Boyd, & Heileyesus, 2008). In this study, individuals ≥ 65 years who were injured when entering or exiting a vehicle had a hospitalization rate 10 times higher than their younger counterparts. Moreover, they noted that females were more likely to be injured and that such injuries were more likely to occur when entering rather than exiting a vehicle, although serious injuries and falls were reported in both circumstances. Over 40% of the injuries from getting into and out of the vehicle were actually caused by falls. While it is not clear whether persons who were injured in this way were in fact drivers or passengers, the magnitude warrants further investigation, as falls can have serious implications for this population. Over one-third of the older adults admitted to a hospital for a fall-related injury are discharged to a long-term care facility (Scott, Wagar, & Elliott, 2011). The total cost of a fall involving serious injury is estimated to be $44,000 CAD (Zecevic et al., 2012). Preventing such falls and injuries from happening is critical. However, to do so, it is important to first have a comprehensive understanding of the biomechanics involved as well as how problems with physical mobility in older adulthood can affect the ingress and egress strategies.

1.4 Vehicle Ingress (Entry) and Egress (Exit)

Ingress is the first interaction that drivers will have with an automobile whereas egress is the last interaction that occurs as they leave a vehicle (Ait El Menceur et al., 2006). According to Ait El Mencuer et al. (2008), an ingress 'strategy' is the method used by an individual to enter the vehicle, whereas an egress 'strategy' is the method used for exiting the vehicle. These strategies accounted for both the foot placement and body orientation (torso) of the individuals. Ingress and egress strategies are first categorized into one-foot and two-foot strategies, then depending on the body orientation of the individuals, specific sub-strategies have been identified (Ait El Menceur et al., 2006; Ait El Menceur, Pudlo, Gorce, Thévenon, & Lepoutre, 2008; Ait El Menceur, Pudlo, Gorce, & Lepoutre, 2009; Chateauroux & Wang, 2010). These strategies are described in detail in the sections that follow.

1.5 Vehicle Landmarks and Vehicle Orientation during Ingress and Egress

When a driver has entered the vehicle or is preparing to exit, he or she is doing so from a 'ready-to-drive position'. In this position, the individual is sitting upright in the driver's seat, with his or her hands on the steering wheel and both elbows slightly flexed. Both of the driver's feet are inside the vehicle cabin planted on the floor, allowing the driver to reach both the brake and accelerator pedals (Ait El Menceur et al., 2006). The driver's head is facing the front of the vehicle, with the back of his or her head resting against the headrest of the vehicle seat.

Using a Cartesian coordinate system (see Figure 1-1), the driver's vertical motion is described on the y-axis (i.e., up and down). Both the vehicle and driver are forward facing or positioned parallel to one another along the x-axis. Motion along the z-axis represent lateral motion into and out of the vehicle cabin. Abduction and adduction refer to motions along the z-axis (while driver is facing forward on the x-axis). If the driver is facing perpendicular to the vehicle, he or she is moving along the z-axis. Hence, driver can be positioned in two ways during ingress and egress along the z-axis: 1) the driver's front torso faces the interior of the vehicle or 2) the driver's front torso faces away from the vehicle. As shown in Figure 1-1, vehicle landmarks are used to describe the position of the driver during ingress and egress.

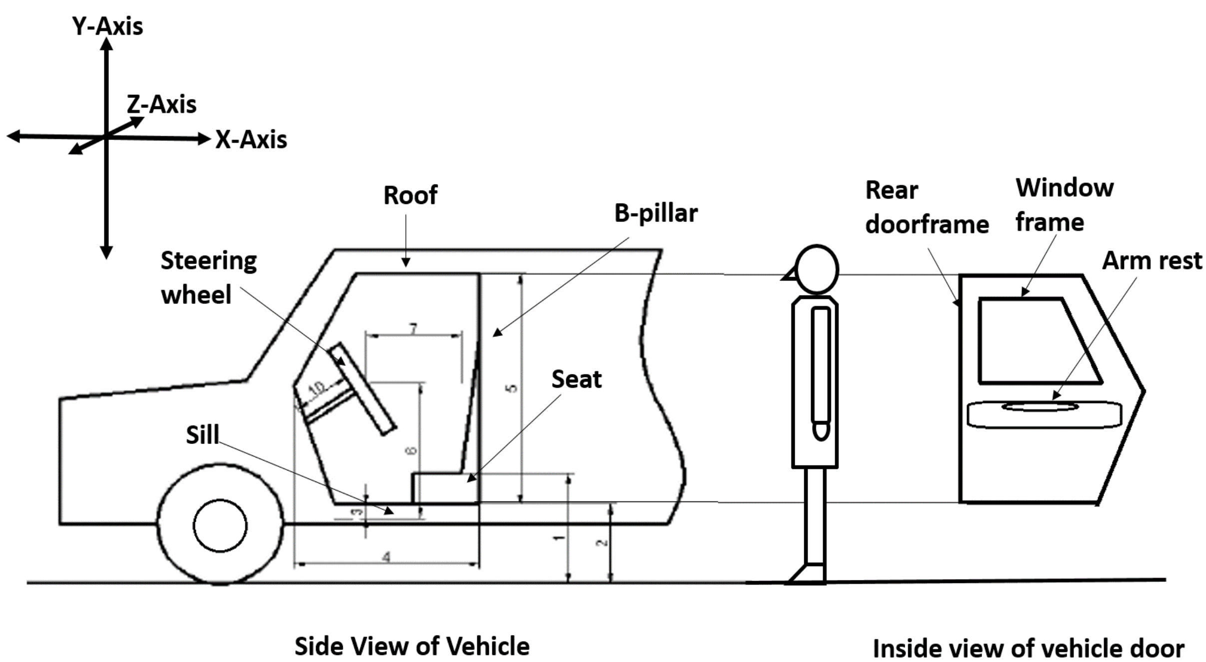

Figure 1-1. This diagram illustrates a side view of the vehicle cabin, including an inside view of a vehicle door, and a side view of the driver facing forward on the x-axis. This diagram includes the labelled landmarks of the vehicle and the Cartesian coordinate system (x, y, and z-axes)

1.6 Types of Vehicle Ingress Strategies

According to Ait El Menceur et al. (2006), the series of motions required to enter a vehicle can be categorized into three phases: 1) door opening, 2) ingress movement adaptation, and 3) seat positioning. The last two phases vary depending on whether drivers use a 'one- foot' or 'two-foot' ingress strategy, as each type of strategy requires a unique set of movements. The door opening phase is consistent for all ingress strategies. During the movement adaptation phase, a driver uses either a one-foot placement or two-foot placement strategy.

1.6.1 One-foot versus two-foot ingress strategies. When entering a vehicle, Ait El Menceur et al. (2008) reported drivers typically use either one-foot or two-foot strategies, which are further sub-divided into specific strategies. There are five ingress strategies: 3 one-foot ingress strategies [1) lateral sliding, 2) backward motion, and 3) forward motion (see Figure 1-2)], and 2 two-foot ingress strategies [1) trunk forward and 2) trunk backward (see Figure 1-3)].

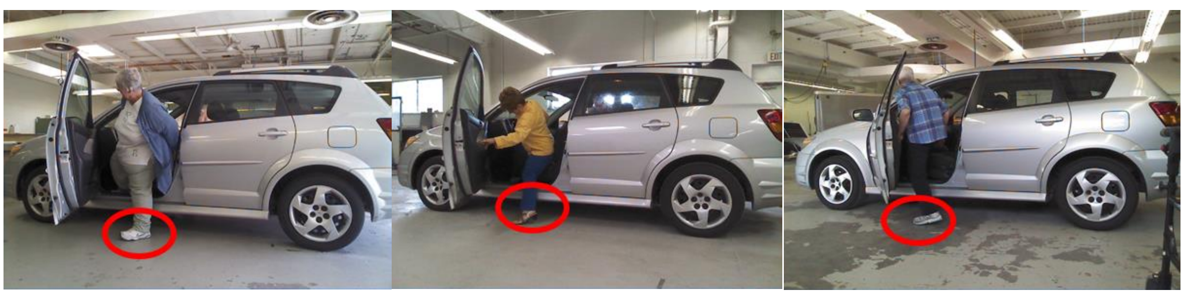

Figure 1-2. Still frames exemplifying the one-foot ingress sub-strategies: lateral sliding (on left), backward motion strategy (centre), and forward motion strategy (on right).

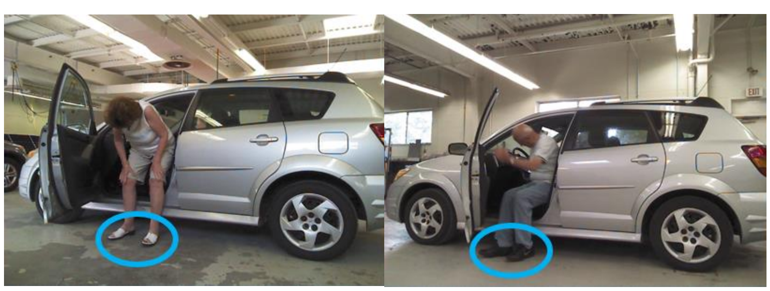

Figure 1-3. Still frames exemplifying the 2 two-foot ingress strategies: trunk forward strategy (on left) and trunk backward strategy (on right).

1.6.1.1 One-foot ingress strategies. *1) Lateral sliding strategy.* Prior to the ingress adaptation phase, the driver stands parallel to the vehicle; in other words, he or she is facing forward in the same direction as the vehicle (with his or her face oriented in the same direction of the vehicle hood). A driver begins this strategy by bending his or her torso forward (along the x-axis) and flexing laterally to the left (along the z-axis), while slightly flexing the left knee. Ait El Menceur et al. (2008) observed that the driver's head usually remains parallel to the vehicle (along the x-axis), and the right knee flexes upward (along the y-axis), as it is the first to enter the vehicle (adduct along the z-axis). The driver will also flex his or her neck and torso forward (along the x-axis) in order to avoid colliding with the roof. The driver then lowers his or her body (along the y axis), and leans towards the driver's seat while adducting and flexing his or her left leg into the vehicle (along the z-axis). Finally, the seat-positioning phase occurs, after which the driver will then close the door (as described in the General Vehicle Ingress Strategies section) (see Figure 1-4).

Figure 1-4. Still frame exemplifying a one-foot lateral sliding ingress strategy. The left frame illustrates the participant entering the cabin with her face parallel to the vehicle along the x-axis (i.e., looking forward at the vehicle hood while moving laterally along the z-axis into the vehicle cabin). The right frame illustrates the last stage of the ingress strategy where the participant flexes her hip and adducts her left leg inside the vehicle cabin.

2) Backward motion strategy. The initial standing orientation of the driver at the beginning of this strategy (movement adaptation phase) is the same as described in the lateral sliding strategy. According to Ait El Menceur et al. (2008), a driver who utilizes this strategy will begin by flexing his or her right knee and then abducting his or her right leg into the vehicle (moving along the z-axis). Meanwhile, the left leg remains outside the vehicle and the left knee should be slightly flexed. The neck of the driver remains flexed forward along the x-axis to avoid colliding with the roof. As shown in Figure 1-5, the torso of the driver remains almost perpendicular to the vehicle (along the z-axis), while the driver's head remains facing parallel to the same orientation of the vehicle. The driver then lowers his/her buttocks onto the seat while both knees remain flexed. At this point in the motion, the right leg is inside the cabin and the left leg is outside the vehicle. Once the driver is seated, he or she rotates his or her hips forward along the x-axis, flexes his or her left knee, while adducting (z-axis) and lifting (y-axis) his or her left leg into the vehicle. The seat-positioning phase subsequently occurs whereby the driver adopts a ready-to-drive posture, after which the door is then closed, as described previously.

Figure 1-5. Still frames exemplifying a one-foot backward motion ingress strategy. The left frame illustrates the participant entering the cabin with her back facing the vehicle cabin along the z-axis. The right frame shows the rotation of the body after the participant sat down as she brought her left leg inside the cabin.

3) Forward motion strategy. The initial standing orientation of the driver relative to the vehicle is the same as the aforementioned strategies. Ait El Menceur et al. (2008) reported that the driver begins this strategy by turning his or her head and torso so that they partially face the inside the vehicle cabin (toward the steering wheel along the z-axis). As the driver abducts his or her right leg into the vehicle, he or she flexes the left knee. The driver remains flexed forward at the hips (toward the steering wheel) as he or she moves his or her torso into the vehicle cabin under the roof along the z-axis. Drivers who use this strategy enter the vehicle in a single forward motion, leaning toward the steering wheel with their torso flexed and moving laterally to the right (along the z-axis). Once seated, the driver will align his or her torso and head in the same orientation as the vehicle hood (along the x-axis), while adducting his or her left leg inside the cabin before closing the door (see Figure 1-6).

Figure 1-6. Still frame exemplifying a one-foot forward motion ingress strategy. The left frame shows the participant entering the cabin as her torso faces the interior of the vehicle cabin along the z-axis. The right frame demonstrates the rotation of the body as she brings her left leg inside the cabin while positioned in the seat.

1.6.1.2 Two-foot ingress strategies. *1) Trunk forward strategy*. The initial orientation of the driver relative to the vehicle during the movement adaptation phase is the same as in the aforementioned strategies. The driver then positions his or her back to the vehicle cabin (along the z-axis), while both feet remain parallel to the orientation of the vehicle hood (along the x-axis). The driver then flexes both knees (both legs remain outside the vehicle), while his or her torso is lowered into the vehicle seat (along the y-axis) (Ait El Menceur et al., 2008). During this motion, the driver's neck and torso are flexed forward toward the steering wheel along the x-axis and lean laterally (on the z-axis) to avoid colliding with the roof of the vehicle. Once his or her head enters the vehicle cabin, the individual leans backward into the driver's seat along the z-axis. Afterwards, the driver rotates his or her lower body along the y-axis again, while first lifting the right leg into the vehicle, followed by the left leg. The driver enters the seat positioning phase once both feet are planted on the vehicle floor and then shuts the vehicle door (see Figure 1-7).

Figure 1-7. Still frames exhibit a two-foot trunk forward motion ingress strategy. The left frame illustrates the participant entering the cabin with both feet planted on the ground parallel to the vehicle. The right frame shows the participant bringing his left leg into the cabin once seated.

2) Trunk backward strategy. Unlike the aforementioned strategies, during the door opening phase, the standing orientation of the driver begins with the torso positioned perpendicular to the vehicle (along the z-axis direction, facing away from the vehicle cabin) (Ait El Menceur et al., 2008). The driver begins this strategy by flexing both knees and gradually lowering his or her body (along the y-axis) until he or she is positioned in the driver's seat.

During this action, the driver's neck and torso are flexed forward along the z-axis to avoid colliding with the roof. Instead of remaining in a parallel position, as described in the earlier strategies (facing the same direction as the vehicle along the x-axis), the feet and torso of the driver remain oriented away from the driver's seat (along the z-axis, facing away from the vehicle cabin). Once seated, the driver rotates his or her body (along the z-axis) while on the seat as he or she lifts both legs into the vehicle. As with the trunk forward strategy, the driver brings his or her right leg inside the vehicle (i.e., left leg first). The driver shifts his or herself into a ready-to-drive posture during the seat positioning phase, then closes the door (See Figure 1-8).

Figure 1-8. Still frames depict a two-foot trunk backward motion ingress strategy. The left frame illustrates the participant entering the cabin with both feet planted on the ground, perpendicular to the vehicle along the z-axis. The right frame illustrates the participant bringing both legs inside the cabin while rotating her torso as she moves into driving position.

1.7 Types of Vehicle Egress Strategies

According to Chateauroux and Wang (2010), egress can be categorized into three phases. The first phase begins after the driver has opened the vehicle door and then he or she proceeds to shift one or both feet from inside the cabin to outside the vehicle. Increased hip flexion is performed during this phase to allow the driver's feet to pass over the car sill (along the z-axis). The driver's torso and head also rotate outward in preparation for exiting the vehicle. During the second phase, the driver flexes his or her neck and leans his or her body out of the vehicle passing through the vehicle doorframe along the z-axis. Chateauroux and Wang (2006) noted drivers will shift their weight to the left foot during this phase when using either a one-foot egress strategy or both feet when using a two-foot egress strategy. During a one-foot strategy, the driver's right foot is placed outside the vehicle while he or she maintains his or her balance on the left foot. This shifting of weight from one foot to the other is only observed during a one-foot egress strategy, as both legs are already placed outside the vehicle during a two-foot egress strategy. During the final phase of egress, drivers will move to an upright standing position, after which the door is closed thereby signalling their exit from the vehicle

1.7.1 One-foot versus two-foot egress strategies. Prior studies (Ait El Menceur et al., 2008; Chateauroux &Wang, 2010) have identified that drivers will use either a one-foot or two-foot strategy when exiting a vehicle. Ait El Menceur et al. indicated there are a total of 3 egress strategies: 2 one-foot strategies (head forward and parallel to the vehicle) and 1 two-foot strategy.

Figure 1-9. Still frames exemplifying the one-foot egress strategies: head forward egress strategy (on left), parallel to the vehicle egress strategy (centre), and two-foot egress strategy (on right).

1.7.1.1 One-foot egress strategies. 1) *Head forward egress strategy*. According to Ait El Menceur et al. (2008), drivers who use this one-foot egress strategy begin by rotating their torsos (along the y-axis) from facing forward (at the steering wheel direction) to facing outwards of the vehicle, meaning the driver's head and torso move to a perpendicular position in relation to the vehicle. The driver then abducts his or her left leg out of the vehicle (along the z- axis) by flexing his or her knees and hips, and then plants the left foot on the ground. Concurrently, the neck and torso of the driver are flexed forward (still facing perpendicular away from vehicle cabin in the direction of z-axis) to avoid colliding with the roof. Subsequently, the driver transfers his or her weight to the left foot, which is placed on the ground outside the vehicle cabin, while shifting from a sitting to a standing position. Once the driver is able to maintain his or her balance on the left foot, he or she will then bring the right leg out of the cabin to come to a full standing upright position. The egress process ends when the driver is out of the vehicle and has closed the driver's side door (see Figure 1-10).

Figure 1-10. Still frames exemplifying the one-foot head forward egress strategy. The left frame illustrates the participant exiting the cabin while facing perpendicular (along the z-axis) to the orientation of the vehicle. The right frame illustrates egress, as the participant brings her right leg out of the cabin while standing on her left leg.

2) Parallel to the vehicle strategy. As described by Ait El Menceur et al. (2008), a driver using this strategy will begin by abducting his or her left leg (along the z-axis) from the vehicle cabin and planting his or her left foot on the ground. Unlike the previous egress strategy, however, Ait El Menceur et al. noted that drivers remain facing forward (along the x-axis) with their torso facing the steering wheel. Meanwhile, the driver's neck and torso flex laterally (in the direction on the z-axis) to avoid his or her head from hitting the doorframe. The driver then shifts his or her weight to the left leg, while the right leg moves along the z-axis to outside the vehicle cabin. The entire motion is performed facing parallel to the vehicle (along the x-axis). After both feet are positioned on the ground, the driver ends the egress strategy by closing the door in an upright standing posture (see Figure 1-11).

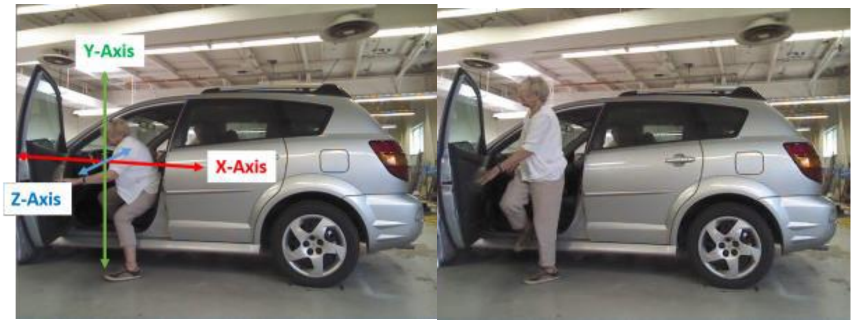

Figure 1-11. Still frames exemplifying the one-foot parallel egress strategy. The left frame illustrates the participant exiting the cabin while facing the front of the vehicle. The right frame illustrates the participant bringing her right leg out while standing on her left leg and facing the front of the vehicle.

1.7.1.2 Two-foot egress strategy. There has only been one two-foot egress strategy identified in the literature. According Ait El Menceur et al. (2008), this two-foot strategy begins when the driver places both feet outside the vehicle cabin, while flexing his or her hips (along the z-axis) and rotating his or her body whereby the feet are lifted along the y-axis, as they pass over the door sill. As the torso rotates, the driver's neck and torso are flexed forward facing outward from the vehicle cabin (along the z-axis) to avoid colliding with the doorframe. Once both feet are placed on the ground, the driver then performs a sit-to-stand motion, while transferring his or her weight forward. Once the driver moves vertically along the y-axis into an upright standing position, this egress strategy ends when the driver closes the door (see Figure 1-12).

Figure 1-12. Still frames exemplifying the two-foot egress strategy. The left frame illustrates the participant rotating his body and stepping out with both legs out of the vehicle cabin. The right frame illustrates the driver standing up on both legs while exiting the vehicle.

1.8 Hand Contact with the Vehicle during Ingress and Egress

In addition to the above named strategies, a drivers' hands also come into contact with the vehicle during ingress and egress. A systematic review of research on ingress and egress suggested that points of contact of hands should be tracked in relation to foot placement strategies (Crizzle, Vrkljan, Kajaks, Gish, Fleisig, 2014). Ait El Menceur et al. (2008, 2009) noted that strategic placement of the hands on various aspects of the vehicle (e.g., steering wheel, armrest) can improve the fluidity of egress. In their study of vehicle ingress and egress, Chateauroux and Wang (2010) identified three hand contact locations with the vehicle: 1) steering wheel; 2) seat; 3) door. It should be noted that they did not specify exactly where the participants came in contact with the vehicle in these three locations. While both Ait El Menceur et al (2008) and Chateauroux and Wang (2010) identified that drivers in their respective studies used the armrest on the vehicle door during vehicle ingress and egress, they did not describe the exact location participants touched their hands during ingress and egress. They did, however, suggest the importance of tracking hand contact on the vehicle in association with foot placement strategies given its potential role in maintaining one's balance.

1.9 Gaps in the Literature: Older Drivers, Physical Mobility, and Ingress/Egress.

A systematic review (Crizzle et al., 2014) that examined studies of ingress and egress of drivers (excluding commercial drivers) found much variability in terms of the demographics of the studied samples, including age and gender. Moreover, there were differences identified strategies used by certain populations. For example, some researchers have identified that two-foot egress strategies are used more often than one-foot strategies among older participants (Chateauroux & Wang, 2010), whereas other studies did not find this same result (Ait El Menceur et al., 2006; Ait El Menceur et al., 2008). Moreover, based on their systematic review, Crizzle et al. (2014) also identified that no studies had yet tracked exact hand placements with the vehicle in details during ingress and egress. Hand placement may provide an additional means of stability during ingress and egress. Many studies of ingress and egress have also used adjustable mock-ups of different vehicle models. These mock-ups have been stripped down to their core parts (i.e., driver's seat, steering wheel) for the purpose of doing human computer modelling of ingress and egress. As well, most of these studies have involved healthy (young) participants, with only a few including older participants (Causse et al., 2009; Causse, Wang, & Denninger, 2012; Choi & Lee, 2015; Coelho & Dahlman, 1999). A summary of these studies is outlined in Table 1. Because of the risk of injury during ingress and egress for older drivers, there is a need to better understand how changes in physical mobility as well as other factors might put older drivers at risk of injury when getting into and out of a car.

1.10 Research Questions

The purpose of this thesis was to examine how physical mobility as well as other self-reported factors that influence the foot placement and location of the hands during vehicle ingress and egress. This study addressed the following research questions:

1) What are the ingress and egress strategies (foot placement and hand contact locations) that older drivers use?;

2) How do these strategies vary according to age and gender and participants' level of physical mobility? And;

3) What are the observable patterns between foot placement strategy and hand contact locations during ingress and egress?

The strategies used during ingress and egress will be described according to the participants' age and gender. These strategies will then be described according to their physical mobility (i.e. as measured by a pooled index) and self-reported factors (i.e. use of a mobility aid, history of falls). The patterns between foot placement and hand contact locations will be examined according to the participants' self-reported factors and objective measures of mobility.

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Table 1-0.

Studies of Vehicle Ingress and Egress of Drivers (Excluding Commercial Drivers) in Alphabetical order

Author, year of publication, journal, sample characteristics (e.g., gender, age, etc)	Objective/Purpose	Experimental Design	Findings/Conclusions
Ait El Menceur et al. (2006) In Proceedings of *the European Annual Conference on Human Decision-Making and Manual Control*. *N* = 41(young; *n*=15; aged 19-31 vs. old: n=26; aged 66-84)	Presented the protocol and experimental set-up used to evaluate the older and younger healthy as well as disabled participants' comfort during vehicle ingress.	Ingress strategy were captured of participants entering a vehicle mock-up of 4 different models using motion analysis software. The different phases of motion were described in detail.	The three phases for ingress motion were identified: Door opening phase, ingress movement adaptation phase, and positioning on the sea phase. Healthy older and younger used the same 3 phases during ingress, with small modification in the movement adaptation phase.
Ait El Menceur et al. (2008) *International Journal of Industrial Ergonomics*. *38*(11-12), 1078-1087. *N* = 41(young; *n*=15; aged 19-31 vs. old: n=26; aged 66-84)	Detailed description of car ingress and egress motion by healthy as well as disabled younger and older participants.	Ingress and egress motions of participants entering and exiting a vehicle mock-up of 4 different models were captured using motion analysis software. Foot placements were described in detail using graphs and statistical analysis.	Five main ingress strategies were identified: One-foot lateral sliding, backward motion, forward motion, two-foot trunk forward and trunk backward strategy. Three main egress strategies were identified: One-foot head forward, parallel to the vehicle, and the two-foot egress strategy.
Ait El Menceur et al. (2009) *International Journal of Industrial Ergonomics, 39*(6), 966-980. *N* =	To quantify and classify the car ingress strategies by healthy as well as disabled	To quantify the complexity of the ingress motion (including body positions and dimensions	By providing a more detailed biomechanical analyses of the ingress motions, a 6th sub-

41(young; *n*=15; aged 19-31 vs. old: n=26; aged 66-84)	younger and older participants.	of the vehicles).	strategy was identified - Median Motion strategy. Their findings were described in their horizontal dendrograms, which illustrated the relevant angles of their subjects in their respective ingress strategies from a small car and a minivan.
Causse et al. (2009). *SAE International Journal of Passenger Cars - Mechanical Systems*, *2*(1), 1633-1640. *N*=2 (aged 30 & 25)	Test the feasibility of the full body dynamical analysis of car ingress and egress motion.	Ingress and egress motions were carried out by two subjects in two car configurations mock-up using motion analysis software. Each motion was analyzed and described in detail. Joint loads of the participants' motions were also assessed.	Confirmed the relevance of the proposed approach for analyzing car ingress and egress. Joint loads applied between the pelvis and the abdomen were also computed using relative RMS average for each force (in X, Y, and Z coordinate), which is 25, 27, and 34. The RMS average for each motion in X, Y, and Z coordinate were 18, 7, and 17.
Causse, Wang, & Denninger (2012). *Applied ergonomics*, *1*, 169–177. *N*=26 (woman; 24-36; men; 25-35)	To test the gap of acceptable roof height, how this gap is affected by the driver's stature and vehicle type.	Ingress and egress were carried out by subjects in 25 different configurations of car mock-up using motion analysis software. Roof height and motions were described in detail.	Identified the gap of acceptable roof height to be 45 mm; Concluded that roof height was not influenced by both vehicle type and by stature. Authors recommend further study of 1) disabled/older adults population 2) other car elements, such as sill width/height.

Chateauroux & Wang. (2010). *Applied Ergonomics, 42,* 169-77. *N*=25 (young; *n*=7; aged 20-35 vs. old: n=18; aged 63-82)	Detailed description of car egress motion by younger and older participants.	Participants were captured exiting a vehicle mock-up of 4 different models using motion analysis software. Each motion was described in detail.	Two main egress strategies identified: Left-leg first and two legs out strategy. Older participants were observed to use two-legs out strategy more often. Authors recommend further study of 1) hand contact locations and; 2) relationship between physical mobility using clinical measures and egress strategies.
Choi & Lee. (2015). *Sensors, 15*(6), 13568-13590. *N* = 12 (Aged 24 – 32)	To validate a new discomfort assessment method for truck ingress and egress based on human body movement.	Ingress and egress of participants entering and exiting a truck mock-up were evaluated based on a new quantitative and objective discomfort evaluation method on muscle maximum voluntary contraction (MVC) ratios calculated by biomechanical analysis.	Indicated a significant correlation between the objective and subjective discomfort of the participants performing truck ingress and egress, and could be described using a linear regression model. The relationship between the %MVC and subjective discomforts was strong ($R > 0.84$, $R2 > 71\%$) and significant ($p < 0.001$).
Coelho & Dahlman. (1999). *International Journal of Inductrial Ergonomics, 24*(2), 201-210. *N* = 4 (aged 20-40)	Evaluate side supports and the comfort level of the car seat (including characteristics during vehicle ingress and egress.	Comfort level and preference of the seat as well as ingress and egress characteristics were subjectively rated by researchers.	Results showed very low agreement among the subjects and researchers, and that video recordings captured in the study was not useful in terms of looking at support features of the driver's seat. Authors suggested: 1) reducing the

			number of body areas evaluated for comfort in future studies 2) distinguished the different types of lateral support of car seat in the questionnaires.
Giacomin & Quattrocolo. (1997). *Applied Ergonomics, 28*, 697-406. *N* = 36 (Aged 16 – 60)	Evaluate human comfort associated with vehicle ingress and egress, and to quantify the effects of the design parameters of the door frame and seats.	Ingress and egress motions of participants were captured entering and exiting a vehicle mock-up using motion measurement systems. A statistical analysis was performed on the data from the questionnaires.	Result findings indicate that subjective ratings of comfort levels from the questionnaires suggesting vehicle designs (i.e. roof, rail height) can influence the perceived discomfort during ingress/egress. Authors recommended further studies that evaluate the motions involved during vehicle ingress/egress.

CHAPTER 2

METHODOLOGY

This chapter will provide an overview of the methods involved with conducting this study beginning with study design, followed by the participant recruitment and procedures for data collection (i.e., tests of physical mobility and vehicle ingress and egress tasks). Finally, this chapter will conclude with an outline of the analyses that addressed the corresponding research questions (as outlined in section 3.4 in this chapter). This study was approved by the Hamilton Integrated Research Ethics Board for Human Subjects (HiREB). Data were collected by members of the Candrive research team (i.e., student occupational therapists collected the clinical measures data under the supervision of an occupational therapist). The author of this thesis (DL) was responsible for analyzing video recordings of the ingress/egress trials and developing the data files of the demographic data and clinical measures that were analyzed.

2.1 Study Design

An observational, cross-sectional study design was used where participants were asked to perform ingress/egress as they normally would in real life. The strategies of the participants entering (ingress) and exiting (egress) a vehicle were captured by video in the garage area of the research site. Each participant entered and exited the same vehicle, which was a 2007 Pontiac Vibe. The physical set-up of the testing environment of the garage where the vehicle was parked is illustrated in Figure 2-1.

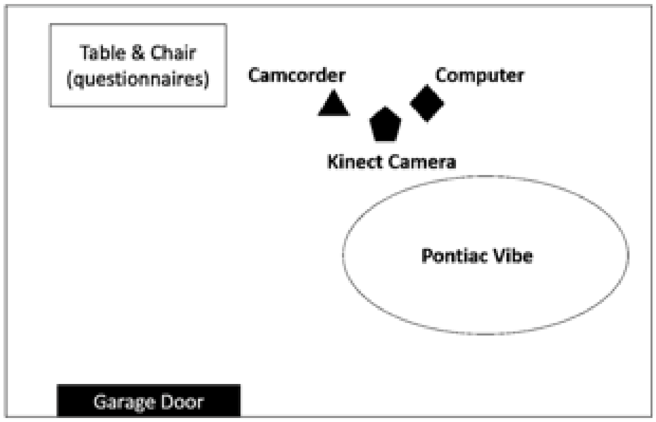

Figure 2-1. Schematic diagram (birds-eye view) of experimental set up of the parking garage with the locations of vehicles (oval shapes), table and chair (rectangle), laptop computer (diamond), the Sony camcorder (triangle), and the Microsoft Xbox Kinect camera (pentagon).

2.2 Participants

2.2.1 Recruitment. A purposeful sampling strategy (Palinkas et al., 2013) was used to recruit participants who had a range of physical abilities as well as impairments. Purposeful sampling is when a group of individuals are selected for the study based on the phenomenon of interest, which in this case reflected a range in terms of their physical abilities and were older drivers (Creswell & Plano Clark, 2009). Participants recruited from a purposeful sampling method were also available and willing to participate in the study (Bernard, 2002). In the present study, participants were recruited using the following three strategies: 1) a community presentation on the subject of older drivers that was held in conjunction with a University event organized for alumni and retirees; 2) announcements at a local gym that included exercise and aquatic programs focused on older adults; and, 3) a notification that was distributed by email about the project through the McMaster University's Retirees Association.

2.2.2 Telephone Screening. Prospective participants were contacted by telephone by two research assistants who asked a series of questions in order to get a sense of the participants' physical mobility (e.g., "do you use an assistive device when walking?"; "do you experience pain when getting into and out of a car?"). During the telephone interview, some participants indicated they had contacted the research team because they had experienced problems with entering and exiting a vehicle due to pain and other mobility problems. This information was important during the screening process in order to ensure that participants had varying levels of physical mobility. Participants were excluded from the study at this stage if they were undergoing surgical procedures in the near future or had medical conditions that impaired their ability to drive, such as uncontrolled seizures. All included participants needed to have a current, valid driver's licence and also drive regularly (at least once a week) to participate in the research study, so as to ensure that our sample consisted of older drivers who would experience vehicle ingress and egress on a regular basis.

Eligible participants provided verbal consent over the phone and then provided their email or mailing address in order for them to receive the required documents (i.e. consent forms, study summary), after which an appointment was scheduled for in-person data collection. Standardized measures assessed participants' respective level of physical mobility or other medical issues.

2.3 Participant Questionnaires

Upon arrival to the research site, a member of the research team reviewed the procedures involved in the study again with the participant, at which time the written consent form to participate in the study was also obtained (Appendix A). Participants then completed the following: 1) demographic (self-report) questionnaires; 2) measures of physical mobility and function, and 3) vehicle ingress and egress tasks. All participants completed all the measures involved with evaluating physical mobility before moving on to another part of the study, such as the demographic questionnaires or the vehicle ingress and egress task.

2.3.1 Demographic Questionnaires. Demographic information was collected from each participant (see Appendix B). Information collected from these questionnaires included: age, gender, marital status, living arrangement, education, and employment status. Participants also provided the following information on the questionnaires:

Health and Mobility (Self-Report). The same questionnaires also included items about their general health and self-reported mobility-related concerns (e.g., "do you sometimes have problems with your balance", "have you had any unexpected falls in the past year?", and "do you use a mobility aid (such as a cane or a walker)?").

2.4 Standardized Measures of Physical Mobility

With the exception of the Berg Balance Scale, all measures were part of the Candrive cohort study of older drivers (see Appendix B). All participants underwent a functional battery of measures of their physical mobility that were administered in the following order: 1) the One-Legged Stance Test, 2) the Rapid Pace Walk Test, 3) Timed Up and Go Test, and, finally, 4) the Berg Balance Scale. Details of each test are described below.

2.4.1 The Timed Up and Go (TUG) test. The TUG test is a mobility test for evaluating lower extremity function (Herman, Giladi, & Hausdorff, 2011), which also takes into consideration of the person's static and dynamic balance. Static balance refers to the ability to stand still and be stable, whereas dynamic balance is described as the ability to maintain stability while undergoing a prescribed movement (Karimi & Solomonidis, 2011). The TUG test is a quick and simple performance test that has high inter-rater reliability among hospital in-patients (ICC = 0.99) (Podsiadlo & Richardson, 1991) and community-dwelling older adults (ICC = 0.98) (Shumway-Cook, Brauer, & Woollacott, 2000). It has also demonstrated high sensitivity and specificity (87%), meaning it was able to correctly identify fallers and non-fallers

(Shumway-Cook, Brauer, & Woollacott, 2000). The TUG cut-off time (13.50 seconds) was suggested in previous literature as a threshold for identifying persons with increased risk of falling (Herman, Giladi, & Hausdorff, 2011; Shumway-Cook, Brauer, & Woollacott, 2000).

2.4.2 The One-legged Stance (OLS) test. OLS or the Single Leg Stance test mostly examines the balance abilities of individuals and has high inter-rater reliability (ICC = 0.95), specifically for eyes open OLS test, and (ICC = 0.83) for eyes closed test (Springer, Marin, Cyhan, Roberts, & Gill, 2007). Older adults who are unable to perform this action for at least 5.0 seconds are identified as being at risk of falls (Beauchet et al., 2010; Vellas et al., 1997). In other words, the longer OLS performance time corresponds to better balance performance.

2.4.3 The Rapid Pace Walk (RPW) test. The RPW test is used to evaluate an individual’s lower limb functional ability, such as mobility and gait (Marottoli, Cooney, Wagner, Doucette, & Tinetti, 1994). It is a modified ‘rapid’ version of the Usual Pace Walk test. It has also been frequently used in driving studies and was recognized as a measure of note from the Physician’s Guide to Assessing and Counseling Older Drivers (Carr & Ott, 2010). A study found that the RPW had a moderate relative reliability (ICC = 0.61) among older drivers (Smith et al., 2013). A cut-off score of 7.5 seconds was also used in the guideline for assessing driver’s motor abilities (Staplin et al., 2003), and participants who scores lower than 7.5 are more at risk for mobility issues, including falls. RPW was also the only motor test included in a driving assessment model that examined driver’s motor performance (Stav, Justiss, McCarthy, Mann, & Lanford, 2008).

2.4.4 The Berg Balance Scale (BBS). The BBS is a comprehensive measure designed to assess the participant’s dynamic balance and fall risk (Berg et al., 1992). The task involves 14 simple every-day related activity tasks (see Appendix C). Each task is scored in a 5-point scale ranging from 0 to 4, with 4 being the normal performance and 0 being unable to perform the task. Therefore, higher BBS test scores are associated with better balance performance and lower scores with fall risk (i.e., the highest achievable BBS test score is 56 and the lowest score is 0. The BBS has been found to have excellent test-retest reliability (ICC = 0.91) and intra-rater reliability (ICC = 0.97) (Berg et al., 1992). According to a study reviewing the validity indexes of the BBS (Riddle & Stratford, 1999), a cutoff score of 45 for determining the fall risk of community-dwelling older adults was determined, with participants having a BBS of 45 and higher being classified as not at risk for falls, and participant with scores of less than 45 being at risk for falls. The sensitivity using the cutoff point of 45 from the study was 64% and the specificity was 90%.

2.5 Ingress and Egress Tasks.

Prior to initiating the current study, participants were all shown the vehicle and sat in the car in the *driver readiness* position and could adjust the seat accordingly. Participants then entered and exited the vehicle a total of five times respectively. After getting into and out of the vehicle three times, participants were permitted to take a break (approximately five minutes), after which they then completed the remaining two trials. Participants could also choose to skip the break and continue if they felt that they were able to do so. Participants were verbally instructed by the investigator "to enter and exit the vehicle as they normally would."

For *ingress*, the participants' motion begins from the *door opening* phase, as described in Chapter 1 (Figure 2-2). The driver's door on the vehicle was closed at the beginning of every ingress trial. Once the investigator pressed the record button, he or she then verbally informed participants that they could begin to enter the vehicle. The participant initiated ingress by first opening the driver's side door and then entering the vehicle until the vehicle door was closed behind them, thereby completing the *seat positioning* phase as outlined in Chapter 1 section 1.6 *General Vehicle Ingress Strategies.*

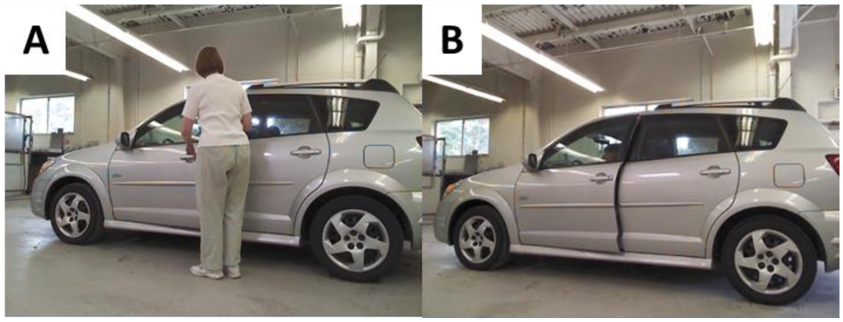

Figure 2-2. Still frames of the starting position of during ingress and egress. A (on left) shows the participant beginning vehicle ingress by opening the door during the *door opening* phase. B (on right) shows the participant beginning vehicle egress by opening the door during *door opening* phase.

For *egress*, the participants started the trial initially positioned in the driver's seat of the vehicle in the *driver readiness position* (see Chapter #1 section 1.7 *General Vehicle Egress Strategies*). The vehicle door was closed at the beginning of every egress trial. When the investigator pressed the record button on the laptop, he or she then verbally informed the participant to begin to exit the vehicle. Once the participant shut the vehicle door, they returned to the starting position from which they had begun the ingress trial.

2.5.1 Video-based Motion Capture System. A video-based motion capture system (Microsoft Kinect, WA, USA) was used to capture the motion of each participant entering and exiting the vehicle. A single Microsoft Xbox Kinect camera was used (Figure 2-2) to capture the participant's ingress and egress. The next section details the procedures with regard to how ingress and egress trials were conducted.

As illustrated in Figure 2-3, the Microsoft Xbox Kinect camera was in line with the rear tire of the vehicle. The height of the Microsoft Xbox Kinect camera from the floor was approximately 74.46 cm, and the distance from the vehicle to the camera position was approximately 233.01 cm. Location of equipment ensured consistency between vehicle and camera position across participants.

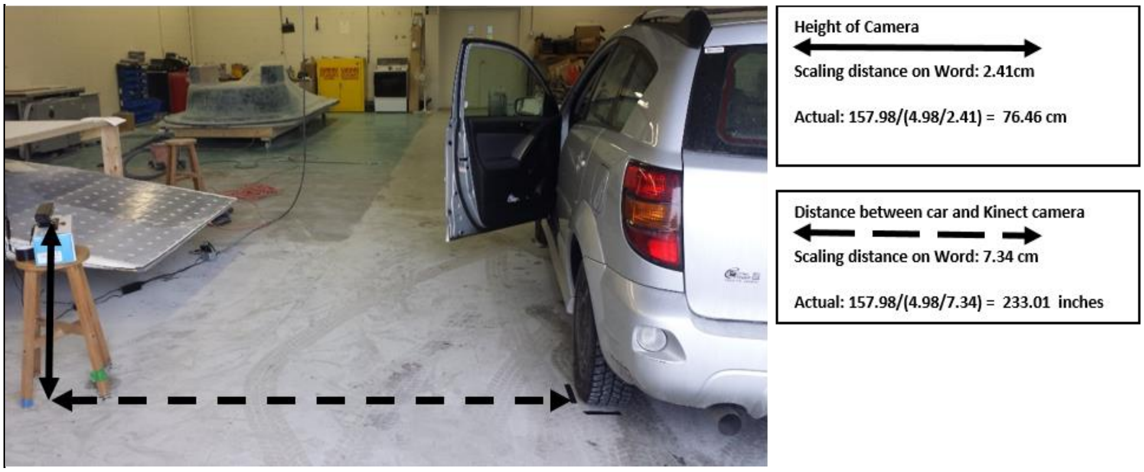

Figure 2-3. Positioning of Microsoft Xbox Kinect camera relative to the Pontiac Vibe. Note positioning of rear tire within the designated tape markings to ensure consistency across participants.

2.5.2 Data Processing. The generated video files were analyzed using version 1.8 of Microsoft Kinect Studio motion analysis software (Microsoft Kinect, WA, USA) on a Lenovo laptop, which was connected to the Microsoft Xbox Kinect camera. The video motion recordings of the participants performing vehicle ingress and egress were captured frame by frame at 640×480 resolution at 30 Hz level. This software has a feature that enables the video recording to be rotated in three-dimensions, meaning that each participant's ingress and egress can be analyzed from different viewpoints. There is also a zoom function. These software features ensured that both the motions with regard to foot placement and contact locations for the hands could be viewed, tracked, and identified accordingly.

2.6 Data Analysis

One researcher (DL) was responsible for observing all of the motion captured video recordings of the participants performing vehicle ingress and egress. Each participant's ingress and egress tasks were analyzed with regard to the following: 1) ingress motion; 2) egress motion; then 3) ingress - hand contact locations on the vehicle; and 4) egress – hand contact locations on the vehicle. A Microsoft excel form (See Appendix D for screenshot of the Excel form) was created to record and organize the observed strategies from the participants' recordings. In addition, since each participant performed ingress and egress five times, the researcher watched all five videos with each participant to ensure that consistent foot placement and hand contact locations were used throughout the five trials. The following section provides further detail with regard to how the videos were analyzed to identify the specific ingress and egress strategies as well as the corresponding hand contact locations.

2.6.1 Procedure for Identifying Ingress and Egress Strategies. For each video, the ingress portion was analyzed before the egress portion. As illustrated in Figure 2-4a, if participants used a two-foot strategy, they would first open the vehicle door and position their feet away outside of the vehicle cabin, and then sit down on the driver's seat before bringing their legs into the vehicle. Figure 2-4b shows a participant using a one-foot strategy, where the right foot is first placed inside of the vehicle while the participant balances on her left leg.

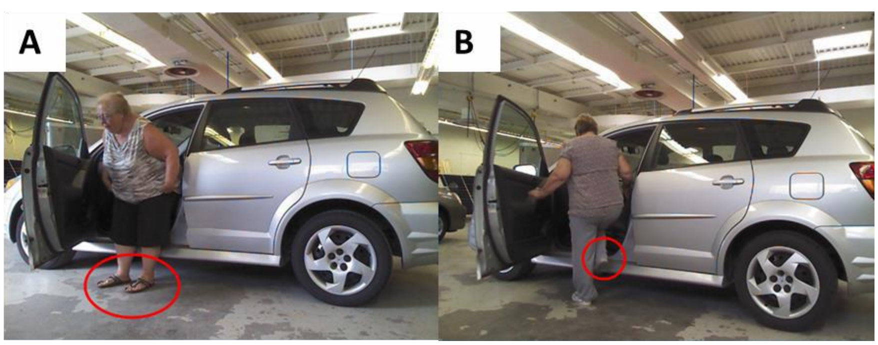

Figure 2-4. Still shots of participants using an ingress strategy. A (on left) shows the participant orienting her feet and torso in preparation to enter the vehicle (two-foot trunk backward ingress strategy), whereas B (on right) shows a participant enters the vehicle with her right leg first (one-foot forward motion ingress strategy).

Once it was determined whether a participant had used a one-foot or two-foot ingress strategy, the next step was to identify the specific sub-strategy that was being used. To make this determination, the position of the participant's head and torso were tracked in relation to the location of their feet. The ingress strategy for each trial was then identified accordingly as described by Ait el Menceur et al. (2005). For example, if the participant used a one-foot ingress strategy but entered the vehicle backwards, a one-foot backward motion strategy was identified. On the other hand, if the participant used a one-foot ingress strategy but entered the vehicle laterally (side-ways), a one-foot lateral sliding strategy was identified. A similar process was used for identifying corresponding egress strategy. For example, in Figure 2-5 a and b, the participants' body orientation and the position of their head and trunk are different. In A, the participant is using a *one-foot head forward* egress strategy, whereas in Figure 2-5b, the participant's head remains parallel to the vehicle (one-foot parallel-to-the-vehicle strategy).

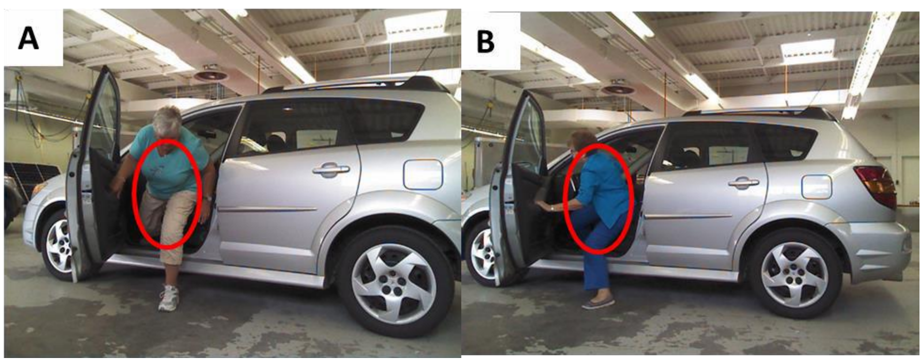

Figure 2.5. Still frames exemplifying one-foot egress strategies. A (on left) shows the participant using a one-foot head forward egress strategy. B (on right) shows the one-foot parallel-to-the-vehicle egress strategy.

Demographic information was entered into Microsoft Excel spreadsheet including age, gender, standardized measures of physical mobility, and self-reported responses with regard to use of mobility aid and history of falls (Appendix E). This data were linked with the other excel spreadsheets (ingress and egress strategies) as well as hand contact location and exported to IBM SPSS Statistics version 20.0 (IBM Corp, 2011). Descriptive statistics were then tabulated to summarize the data. For example using SPSS, the mean age and standard deviation (*SD)* of the participants who used *the one-foot lateral sliding* strategy during ingress was calculated. Graphs of the ingress/egress strategies according to age and physical mobility index by gender were plotted using Microsoft Excel.

Pooled index score. A pooled index of physical mobility score was calculated using the scores of all four measures of physical mobility (TUG, OLS, RPW, BBS). The index was created to provide a general overview of each participant's level of physical mobility relative to the rest of the sample, and will be described in the following chapter in details.

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CHAPTER 3

RESULTS

Sample Characteristics, Physical Mobility,

Ingress and Egress Strategies

Research questions:

1) What are the ingress and egress strategies (foot placement and hand contact locations) that older drivers use? And;

2) How do these strategies vary according to age and gender and participants level of physical mobility?

3) What are the observable patterns between foot placement strategy and hand contact locations during ingress and egress?

In Chapter 1: *Overview of Vehicle Ingress and Egress Strategies***,** a synopsis of the ingress and egress strategies identified in earlier studies was provided. Previous research studies classified participants' ingress and egress according to two types of strategies based on their foot placement: 'one-foot' or 'two-foot' strategy. These strategies were further classified into more specific sub-strategies. The results of the current study use the same approach, to describe first ingress, then egress according to age, gender, self-reported measures of mobility (i.e., use of a mobility aid, history of falling), and physical mobility characteristics, as measured by the pooled index. The hand contact locations for both ingress and egress were also described according to age, gender, self-reported measures of mobility and physical mobility characteristics.

3.1 Vehicle Ingress Strategies

Table 3-1 shows the vehicle ingress strategy observed among participants in terms of the number and percentage, according to gender. All five of the one-foot and two-foot ingress strategies, previously identified in the literature, were observed in the current sample (i.e., one-foot *lateral sliding, backward motion, forward motion*, and two-foot *trunk forward* and *trunk backward* strategies). All 32 participants used the same ingress strategy across all five trials. Twenty-three participants (72.88%) used the one-foot *lateral sliding* strategy and four participants (12.50%) used the two-foot *trunk backward* ingress strategy. Three participants (9.38%) utilized the one-foot *backward motion* strategy. One participant (3.13%) used the one-foot *forward motion* strategy and one participant (3.13%) used the two-foot *trunk forward* ingress strategy. In summary, the majority of the sample used a one-foot strategy during ingress, with the *lateral sliding* strategy being the most common.

Table 3-1.

Frequencies of Strategies during Ingress according to Gender

	One-foot *n* (%)			Two-foot *n* (%)		
Gender	Lateral sliding	Backward motion	Forward motion	Trunk forward	Trunk backward	Total *N* (%)
Female *n*	13	1	1	0	4	19
(%)	(40.63%)	(3.13%)	(3.13%)	(0.00%)	(12.50%)	(60%)
Male *n*	10	2	0	1	0	13
(%)	(31.25%)	(6.25%)	(0.00%)	(3.13%)	(0.00%)	(40%)
Total *N*	23	3	1	1	4	32
(%)	(71.88%)	(9.38%)	(3.13%)	(3.13%)	(12.50%)	(100%)

3.1.1 Ingress strategy based on age and gender. The mean age of participants was 71.84 years (*SD* = 6.97). Participants who used the one-foot *lateral sliding* strategy had a mean age of 71.87 (*SD* = 5.86). The mean age was 73.08 years (*SD* = 5.81) for females (*n* = 13) and

70.30 years (*SD* = 5.83) for males (*n* = 10). Participants (n=3) who used the one-foot *backward motion* strategy was 72.67 (*SD* = 12.50). One female (80 years old) was observed using the one-foot *forward motion* strategy and one male (80 years old) participant was observed using the two-foot *trunk forward* strategy. The two-foot *trunk backward* strategy was used by 4 women with a mean age of 67.00 years (*SD* = 8.33). In summary, the majority of the participants used one-foot strategies to enter the vehicle, with the lateral sliding strategy being the most common regardless of age or gender.

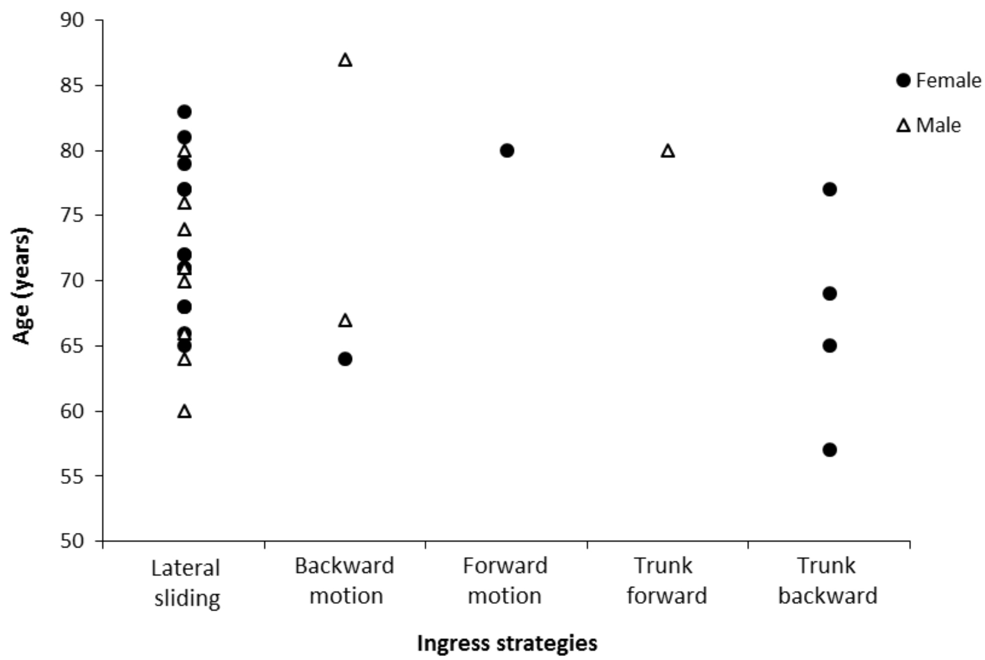

Figure 3-1. Ingress strategies according to age and gender.

3.2 Physical Mobility Measures and Ingress strategy

Descriptive results of the sample's physical mobility was measured using four standardized measures (BBS, TUG, OLS, & RPW) and the physical mobility index score.

3.2.1 Berg Balance Scale. The BBS test scores for the sample ranged between 30.00 to 60.00 with a mean BBS score of 50.00 (*SD* = 5.83). The mean BBS score for male participants was 49.31 (*SD* = 4.97) and the mean BBS score for female participants was 50.47 (*SD* = 6.43).

Using the BBS, a cut-off score of 45 points reported in the literature (Riddle & Stratford, 1999), 81.25% of the sample (*n* = 26) did not reflect problems with balance, as they scored over 45. Only 18.25% (*n* = 6) scored below 45, and would be considered at risk of falling.

3.2.2 Timed up and Go (TUG) Test. The TUG scores ranged from 6.00 to 18.00 seconds with a mean score of 10.65 seconds (*SD* = 2.38). The mean TUG for males was 10.18 (*SD* = 2.40) and for females was 10.97 (*SD* = 2.38). Using the cut-off score of 13.50 points (Shumway-Cook, Brauer, & Woollacott, 2000), approximately 10% (n=3) of the sample would be considered at risk for falls (≤ 13.50 seconds).

3.2.3 One-Legged Stance (OLS) Test. The OLS for the participants ranged from 0.00 seconds to 90.00 seconds, where 0.00 seconds reflected the inability to stand on one leg at all and 90.00 seconds is the longest possible time one could remain standing on one foot. The mean OLS for males was 4.63 seconds (*SD = 24.86)* and 4.43 seconds (*SD* = 24.42) for the left and right leg respectively. The OLS for females was 14.84 seconds (*SD* =13.58) and 15.69 seconds (*SD* = 15.18) for the left and right leg respectively. Results indicate that 47% (*n* = 15) of the total sample were below the cut-off of 5.00 seconds (Beauchet et al., 2010; Vellas et al., 1997) and would be considered at risk of falls.

3.2.4 Rapid Pace Walk (RPW) test. The scores for the RPW ranged between 4.00 to 15.00 seconds for completion. The time in seconds to perform this test was 7.23 (*SD* = 1.83) for men and 7.75 (*SD* = 2.22) for women. Previous studies have indicated that requiring more than 7.50 seconds to complete the RPW can signify a problem with physical mobility (Smith et al., 2013; Staplin et al., 2003). Using a cutoff of 7.50 seconds on the RPW indicates that over 47% (*n* =15) of the total sample would be considered as having problems with mobility (e.g., RPW ≥7.50 seconds).

3.3 Performance on Clinical Measures and Risk of Falls

The results indicate that there is variability in the results obtained from these measures (as shown in the Figure 3-2), where some participants who performed well on one test might not perform as well on another. For example, our sample appears to have good overall balance as indicated on the BBS. However, a higher percentage of the sample had problems with balance as indicated by their performance on the OLS (left and right leg).

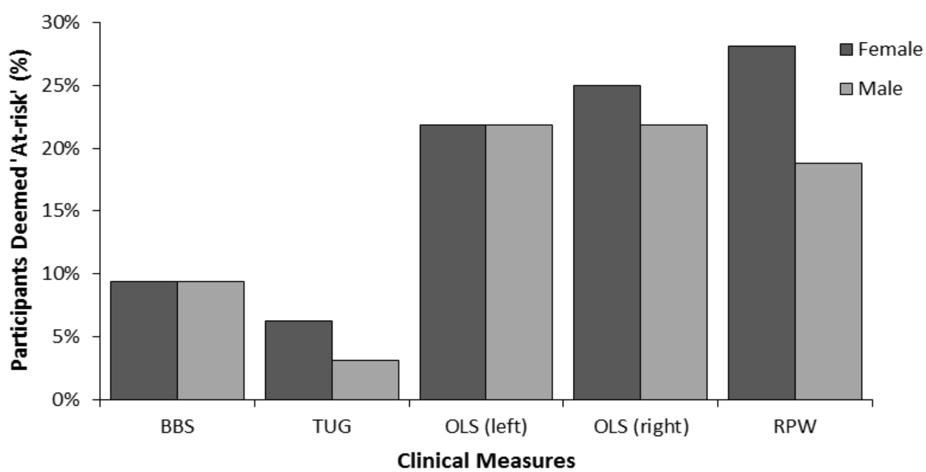

Figure 3-2. Percentage of participants who were deemed at risk of falls according to clinical measure and gender.

3.4 Pooled Index of Physical Mobility

Using the cut-off scores for falls and mobility problems for the four performance measures discussed above shows that there is a difference between the percentages of participants classified as having mobility problems and balance problems. Therefore, a single pooled index was created using the scores from all four measures, as they all represent slightly different but important aspects of mobility. Hence, the index reflected a consolidated measure of these aspects. However, each measure is scored on a different metric, which had to be considered in the creation of the index. For instance, the Berg Balance Scale (BBS) uses a total score that is based on performance of 14 items; each of which is scored out of 5-points, whereas the Timed

Up and Go (TUG) test, Rapid-Pace-Walk test, and One-Legged-Stance (OLS) test were measured in terms of time (seconds). In addition, these clinical measures have different cut-offs scores. Moreover, an important factor was how duration (time) was considered within the clinical measure as a dependent variable of interest (i.e., OLS, TUG, RPW), meaning a longer time by a participant when performing the OLS equates to better balance, whereas longer performance times on the TUG are reflective of problems with mobility. (Herman, Giladi, & Hausdorff, 2011; Shumway-Cook, Brauer, & Woollacott, 2000). Similarly, the greater a participant's score on the BBS, the better his or her balance (Riddle & Strateford, 1997). In order to provide a more general view of the participants' respective level of physical mobility, a pooled index was developed in order to consider the potential of clinically important factors. To calculate the pooled index score, a standardized score to normalize each measure was first created by subtracting the sample's mean score on that measure from the participant's score, then dividing the difference by the standard deviation of the sample.

$$\boldsymbol{Standardized\ score = \frac{x - \bar{x}}{\sigma}}$$

Where x is the participant's score, $\bar{x}$ is the sample's mean score, and σ is the standard deviation of the sample's mean. The participant's standardized scores were then summed for all four measures to create a **pooled** score for the physical mobility index. To standardize the measures with different orientation (i.e., TUG and RPW), the dataset of these measures was multiplied by a constant of -1.

$$\boldsymbol{Standardized\ score = -\left(\frac{x - \bar{x}}{\sigma}\right)}$$

3.4.1 Ingress Strategy according to Physical Mobility Index Score and Gender. The pooled index scores for males ranged from -5.77 to 10.98 with the mean of 0.18 (*SD* = 4.39), whereas females ranged from -10.98 to 4.47 with a mean score of -0.11 (*SD* = 3.63). Figure 3-3 shows the ingress strategies according to gender and physical mobility, as measured by the pooled index.

For persons who used the lateral sliding strategy, the mean index score was 1.15 (*SD* = 3.21). For males, the score was 0.86 (*SD* = 4.24) and for females it was 1.37 (*SD* = 2.28). The mean index scores (*n* = 3) for those who used the one-foot *backward motion* strategy was -4.58 (*SD* = 1.05) . All four participants who used the two-foot *trunk backwards* strategy were female, and the mean index score for these participants was -1.05 (*SD* = 2.16), with a range of -3.14 to 1.10. The participant who used the one-foot *forward motion* strategy had an index score of -10.98 and the participant who used the two-foot *trunk forward* strategy had an index score of 2.81. Hence, participants who used the **one-foot** *lateral sliding* strategy had higher mean index scores than those who used the **two-foot** *trunk backwards* strategy. However, participants with lower index scores also used one-foot strategies; for example, the participant with the lowest index score (-10.98) used the one-foot *forward motion* strategy.

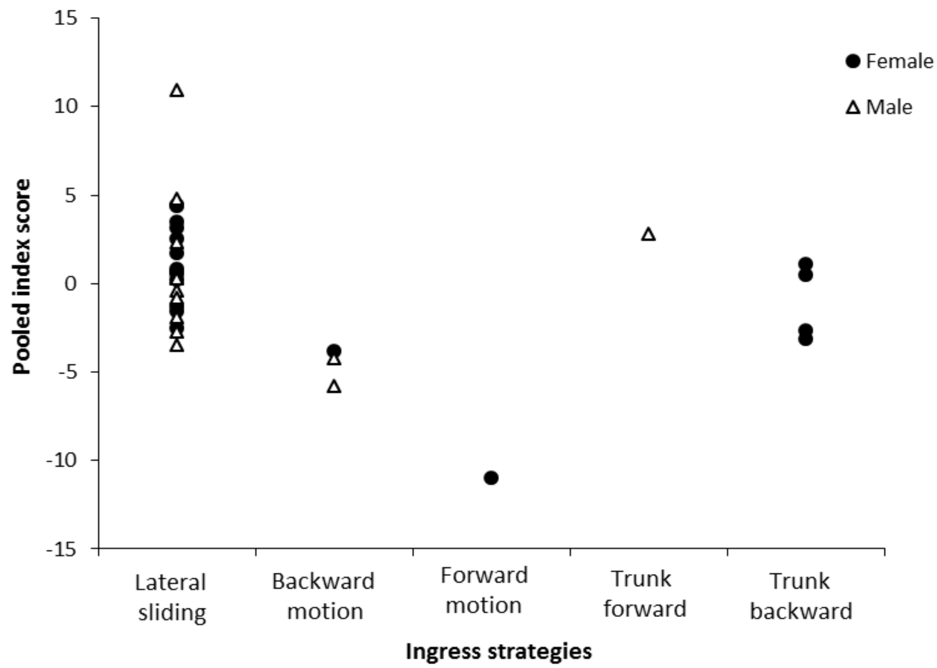

Figure 3-3. Ingress strategies according to physical mobility (as measured by pooled index score) and gender.

3.5 Ingress Strategies and Self-Reported Measures of Physical Mobility

3.5.1 Ingress Strategy based on Use of a Mobility Aid and Gender. There were a total of six participants (18.75%) who reported using a mobility aid. Of these six participants, two (1 female, 1 male) used the one-foot *lateral sliding* strategy during ingress. Two others used (1 female, 1 male) the one-foot *backward motion* strategy during ingress. One female participant used the one-foot *forward motion* strategy. Another female participant used the two-foot *trunk backward* strategy during vehicle ingress. In summary, five of the six participants who used a mobility aid used one-foot strategies during ingress.

3.5.2 Ingress Strategy based on Self-reported History of Falls and Gender. Of the participants (n=11) who reported having a history of falls in the past year, 21.88% (3 females, 4 males) used the *one-foot lateral sliding* strategy. Two participants (6.25%; 1 female, 1 male) who reported having a history of falls used the *one-foot backward motion* strategy. Two female participants (6.25%) with a history of falls performed the two-foot *trunk backward* strategy during ingress. In summary, 9 of 11 participants with a self-reported history of falls used one-foot strategies during ingress.

3.6 Vehicle Egress Strategies

All three egress strategies, as previously identified in the literature, were observed in our sample (i.e., one-foot *head forward, parallel to the vehicle,* two-foot *egress* strategies). However, participants did not use the same egress strategy across trials. Only 26 participants were consistent with their egress strategies across the five trials. Table 3-2 shows the strategy (in terms of the number and percentage observed) of the 26 participants. Fourteen participants (53.85%) used the *one-foot* head forward strategy as the most common egress strategy - 30.77% (*n*=8) were female and 23.08% (*n*=6) were male. Twelve participants (46.15%) used the *two-foot* egress strategy - 26.92% (*n*=7) female and 19.23% (*n*=5) male. Among the participants with consistent strategies, no one used the *one-foot parallel to vehicle* strategy.

Table 3-2.

Frequencies of Strategies during Egress according to Gender

	One-foot *n* (%)			
Gender	Head forward	Parallel to vehicle	Two-foot *n* (%)	Total *n* (%)
Female *n* (%)	8 (30.77%)	0 (0.00%)	7 (26.92%)	15 (57.69%)
Male *n* (%)	6 (23.08%)	0 (0.00%)	5 (19.23%)	11 (42.31%)
Total *N* (%)	14 (53.85%)	0 (0.00%)	12 (46.15%)	26 (100%)

3.6.1 Egress Strategy according to Age and Gender. Figure 3-4 shows the egress strategies according to age and gender. Participants who used the one-foot *head forward* strategy (n=14) were on average 69.79 years old (*SD* = 4.39) with a mean age of 70.50 years (*SD* = 5.26) for females and 68.83 (*SD* = 3.06) for males. The participants (n=12) who used the two-foot egress strategy were on average 72.92 years (*SD* = 8.29) and 76.80 years (*SD* = 7.40) for women and men respectively. While there were slightly more participants who used one-foot egress strategies, the sample was basically split with regard to type of strategies, although the oldest and youngest participants used two-foot egress strategy.

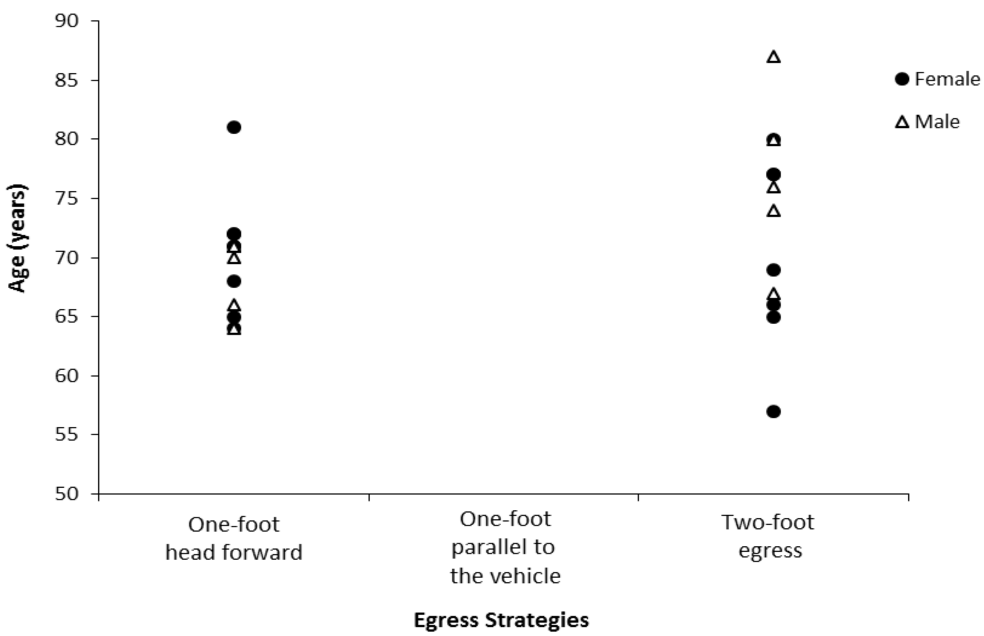

Figure 3-4. Egress strategies according to age and gender.

3.6.2 Egress Strategy according to Physical Mobility Index Score and Gender. Figure 3-5 shows the egress strategies according to gender and physical mobility, as measured by the pooled index. The mean index score of the participants (*n* =14) who used the *one-foot head forward* strategy was 1.67 (*SD* = 3.66) - 0.96 (*SD* = 2.74) for females and 2.63 (*SD* = 4.73) for males. The mean index score of the participants who used the *two-foot egress* strategy (*n* =12) was -1.88 (*SD* = 3.92) - -1.77 (*SD* = 4.54) for females and -2.04 (*SD* = 3.36) for males. In summary, the overall pooled index score of the participants who used the *one-foot head forward* strategy was higher indicating that they were more mobile than the index score of the participants who used *two-foot egress* strategy.

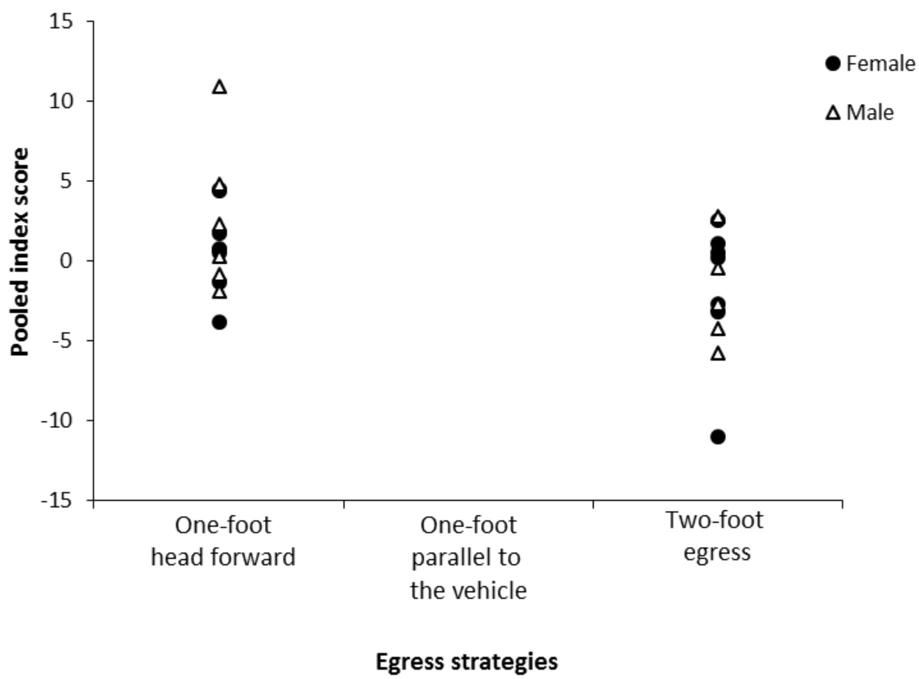

Figure 3-5. Egress strategies according to physical mobility (as measured by pooled index score) and gender.

3.7 Ingress Strategies and Self-Reported Measures of Physical Mobility

3.7.1 Egress Strategy based on Use of a Mobility Aid and Gender. Of six participants (23.07%) who used a mobility aid, three (11.54%; 2 female, 1 male) used the one-foot *head forward* strategy during egress. The other three participants who reported using a mobility aid used the two-foot egress strategy. None of the six used the one-foot *parallel to the vehicle* strategy across trials. In summary, of the six participants who reported using a mobility aid, there was no difference in one-foot or two-foot strategy with regard to egress.

3.7.2 Egress Strategy based on Self-reported History of Falls and Gender. Of the 26 participants, seven (26.92%) reported a history of falls. Of these seven participants, three participants or 11.54% (1 female, 2 males) performed the one-foot *head forward* strategy during egress. The four other participants (15.38%) (2 female, 2 male) used the *two-foot egress* strategy. In summary, participants who self-reported having a history of falls used both one-foot and *two-foot egress* strategies.

3.8 Hand Contact Locations during Vehicle Ingress and Egress

In this section, hand contact location during ingress and egress will be examined according to self-reported use of mobility aids and history of falling, as well as the standardized index of physical mobility. As detailed in Figure 3-6, there are many different parts of the car door and multiple combinations of locations with which the participants' hands can contact, as they enter or exit a vehicle.

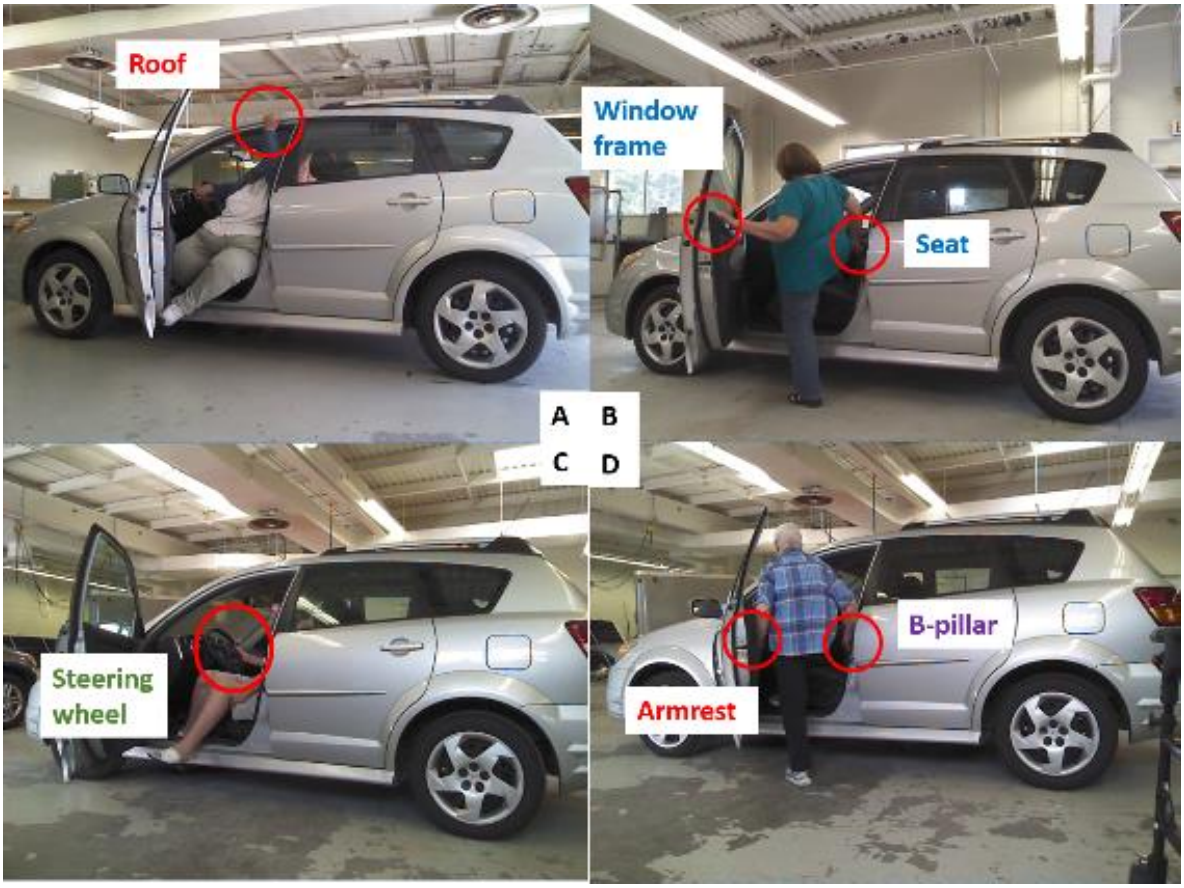

Figure 3-6. Still frames provides an example of different hand contact locations. A.) Participant used her left hand to hold on to the roof during egress. B.) Participant used the window frame for balance support with her right hand while pushing against the driver's seat with his left hand during ingress. C.) Participant utilized the steering wheel for support with her right hand during egress. D.) Participant held on to the arm rest for support with her left hand while holding on to the B-pillar with her right hand during ingress.

3.9 Hand Contact Locations for Ingress

Table 3-3 shows the hand contact locations observed among the participants during ingress according to gender. Hand contact locations that were observed in our sample included the *armrest* of the car door, *steering wheel*, as well as combinations of various locations: *armrest and steering wheel, armrest and seat*, *armrest and B-pillar, steering wheel and B-pillar, roof and seat*. Of the 32 participants, 25 consistently used the same hand contact locations across trials. Of these participants, 28% used the *armrest* location. The *armrest* was also used in combination with other locations, including the *steering wheel*, *seat*, and *B-pillar*. Five participants (20.00%) used the *steering wheel* only, and one participant used the *steering wheel with the B-pillar*. One participant used the *roof and seat*. Three participants did not come into contact with the vehicle. In summary, the majority of the participants used the *armrest* location during ingress.

Table 3-3.

Frequencies of Hand Contact Location during Ingress according to Gender

Hand contact locations	Female *n* (%)	Male *n* (%)	Total *n* (%)
No hand contact	1 (4.00%)	2 (8.00%)	3 (12.00%)
Armrest only	4 (16.00%)	3 (12.00%)	7 (28.00%)
Steering wheel only	3 (12.00%)	2 (8.00%)	5 (20.00%)
Armrest and steering wheel	3 (12.00%)	2 (8.00%)	5 (20.00%)
Armrest and seat	2 (8.00%)	0 (0.00%)	2 (8.00%)
Armrest and B-pillar	1 (4.00%)	0 (0.00%)	1 (4.00%)
Steering wheel and B-pillar	1 (4.00%)	0 (0.00%)	3 (12.00%)
Roof and seat	0 (0.00%)	1 (4.00%)	3 (12.00%)
Total *N* (%)	15 (60.00%)	10 (40.00%)	25 (100.00%)

3.9.1 Hand Contact Locations during Ingress according to Age and Gender. Figure 3-7 shows the hand contact locations by participant age and gender. Seven participants (4 females, 3 males) who used the *armrest only* during ingress had a mean age of 71.71 years (*SD* = 9.69). The age of the five participants (3 females, 2 males) who used the *steering wheel only* was 70.60 years (*SD* = 4.04). The mean age of the ten participants (7 females, 3 males) who used *multiple* hand contact locations was 72.40 years (*SD* = 5.32). Three participants (1 female, 2 males) who did not touch the vehicle during ingress was 73.67 years (*SD* = 7.77). In summary, the data indicates that the majority (22/25) of participants used the *armrest* or *steering wheel*, or *both* during ingress, but there were no notable trends with regard to age and gender.

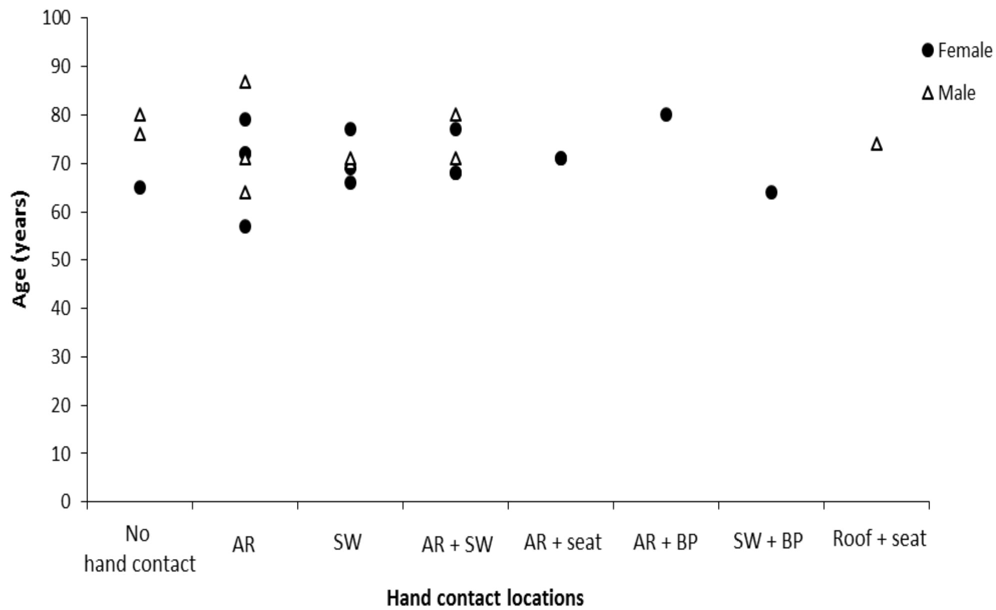

Figure 3-7. Hand contact locations according to age and gender. Hand contact locations on the x-axis was represented by different values on the graph, where *Armrest* = AR, *Steering wheel* = SW, and *B-pillar* = BP.

3.9.2 Hand Contact Location during Ingress according to Physical Mobility Index Score and Gender. Figure 3-8 shows the hand contact locations according to their pooled index score of physical mobility and gender. Seven participants (4 females, 3 males) who used the *armrest only* during ingress had a mean index score of 1.69 (*SD* = 3.06). Five participants (3 females, 2 males) who used the *steering wheel only* had a mean index score of -1.43 (*SD* = 1.62). Three participants who did not touch the vehicle during ingress. They had a mean score of 1.18 (*SD* = 1.60). Participants (*n* = 12) who used single a hand contact location (*armrest only* or *steering wheel only*) had a mean score of 0.39 (*SD* = 2.94). Participants (*n* = 10) who used multiple hand contact locations had a mean score of -1.67 (*SD* = 4.03). In summary, participants who did not have contact location with the vehicle had better physical mobility than participants who had at least one or more hand contact points.

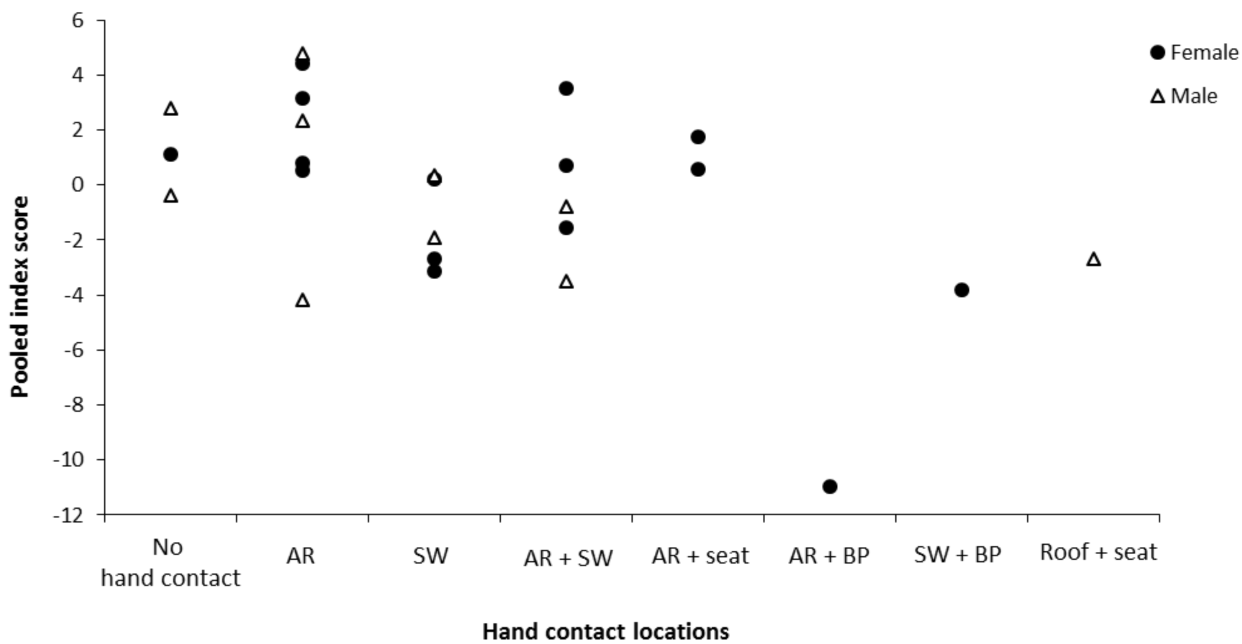

Figure 3-8. Hand contact locations according to physical mobility (as measured by pooled index score) and gender. Hand contact locations on the x-axis was represented by different values on the graph, where *Armrest* = AR, *Steering wheel* = SW, and *B-pillar* = BP.

3.9.3 Hand Contact Location during Ingress according to Self-reported Use of a Mobility Aid and Gender. Five participants self-reported using a mobility aid. Among these five participants, one female participant used the *armrest only* during ingress. Two participants (female *n* =1; male *n* =1) used the *armrest and steering wheel* during ingress. Another female participant used the *armrest and B-pillar* during ingress. One female participant used the *steering wheel and B-pillar* during vehicle ingress. In summary, all of the participants who self-reported using a mobility aid used the *armrest* when entering the vehicle, or the *armrest* in combination with other locations.

3.9.4 Hand Contact Location during Ingress according to Self-reported History of Falls and Gender. Nine participants (female *n* =5; male *n* =4) self-reported having a history of falls. Among these participants, two (female *n* =1; male *n* =1) used the *armrest only* during ingress. Three participants (female *n* =1; male *n* =2) used the *steering wheel only*. Furthermore, one female participant used both the *armrest and steering wheel*. Another female participant used the *steering wheel* and *B-pillar*. One male participant used the car *roof and seat*. One female participant did not come in contact with the vehicle during ingress. In summary, the majority (8/9) of the participants with self-reported history of falls used the *steering wheel* when entering the vehicle or the *steering wheel* in combination with the *armrest* location.

3.10 Hand Contact Location during Egress

Table 3-4 shows the hand contact locations observed across all of participants during egress. Hand contact locations that were observed included the *armrest* of the car door, *steering wheel*, *window frame* as well as combinations of various locations (i.e. *armrest and steering wheel*; *armrest and seat*; *steering wheel and seat*; *roof and B-pillar*). Of the 32 participants, 20 consistently used the same hand contact location across the five trials during egress. The *armrest* was the most common hand contact location. Of the 20 participants, five had *no hand contact* with the vehicle and four used *multiple hand contact locations* during egress.

Table 3-4.

Frequencies of Hand Contact Location during Egress according to Gender

Hand contact locations	Female *n* (%)	Male *n* (%)	Total *n* (%)
No hand contact	0 (0.00%)	5 (25.00%)	5 (25.00%)
Armrest only	8 (40.00%)	1 (5.00%)	9 (45.00%)
Steering wheel only	0 (0.00%)	1 (5.00%)	1 (5.00%)
Armrest and steering wheel	1 (5.00%)	0 (0.00%)	1 (5.00%)
Armrest and seat	0 (0.00%)	1 (5.00%)	1 (5.00%)
Window frame	0 (0.00%)	1 (5.00%)	1 (5.00%)
Steering wheel and seat	1 (5.00%)	0 (0.00%)	1 (5.00%)
Roof and B-pillar	1 (5.00%)	0 (0.00%)	1 (5.00%)
Total *N* (%)	11 (55.00%)	9 (45.00%)	20 (100.00%)

3.10.1 Hand Contact Locations during Egress according to Age and Gender. Figure 3-9 shows the hand contact locations based on their pooled index score of physical mobility and gender. Male participants' age ranged from 64 to 87 years, with a mean of 72.78 years (*SD* = 7.36); and, females ranged in age from 57 to 80 years with a mean of 70.91 years (*SD* = 6.79).

Nine participants (8 females, 1 male) who used the *armrest only* during egress had a mean age of 71.89 (*SD* = 6.09). One male participant (aged 76) used the *steering wheel only* and one male participant (aged 70) used the *window frame* during egress. The eleven participants (7 females, 4 males) who used a *single* hand contact locations had a mean of 72.09 years (*SD* = 5.63). The four participants (3 females, 1 males) who used *multiple* hand contact locations had a mean of 68.20 years (*SD* = 6.65). Five male participants who did not come into contact with the vehicle during egress had a mean age of 74.20 years (*SD* = 9.04). In summary, the mean age of participants who used *multiple* hand contact locations during egress had a lower mean age than those who used *a single hand contact* location.

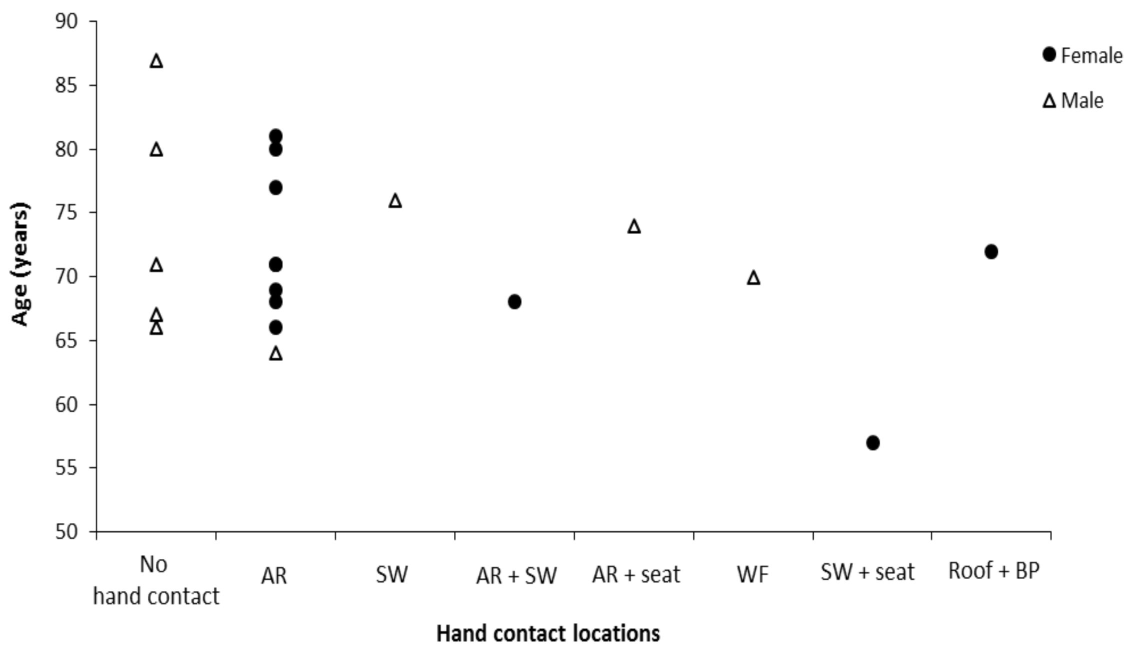

Figure 3-9. Hand contact locations according to age and gender. Hand contact locations was represented by different values, where *Armrest* = AR, *Steering wheel* = SW, *B-pillar* = BP, & *Window frame* = WF.

3.10.2 Hand Contact Location during Egress according to Physical Mobility Index Score and Gender. Figure 3-10 shows the hand contact locations according to the score on the pooled index of physical mobility and gender. Nine participants (8 females, 1 male) who used the *armrest only* during egress had a mean index score of -0.98 (*SD* = 4.36). One male participant only used the *steering wheel* had an index score of -0.38 and another male participant who used the window frame during egress had an index score of 0.34. The eleven participants (7 females, 4 males) who used a *single* hand contact locations had a mean score of -0.81 (*SD* = 3.93). The four participants (3 females, 1 males) who used *multiple* hand contact locations had a mean index score of 0.55 (*SD* = 2.54). The five participants (all males) who did not come into contact with the vehicle had a mean score of 1.24 (*SD* = 6.66). In summary, participants who did not come into contact with the vehicle during egress had better physical mobility, as per the pooled index, than participants who had at least one or more hand contact points.

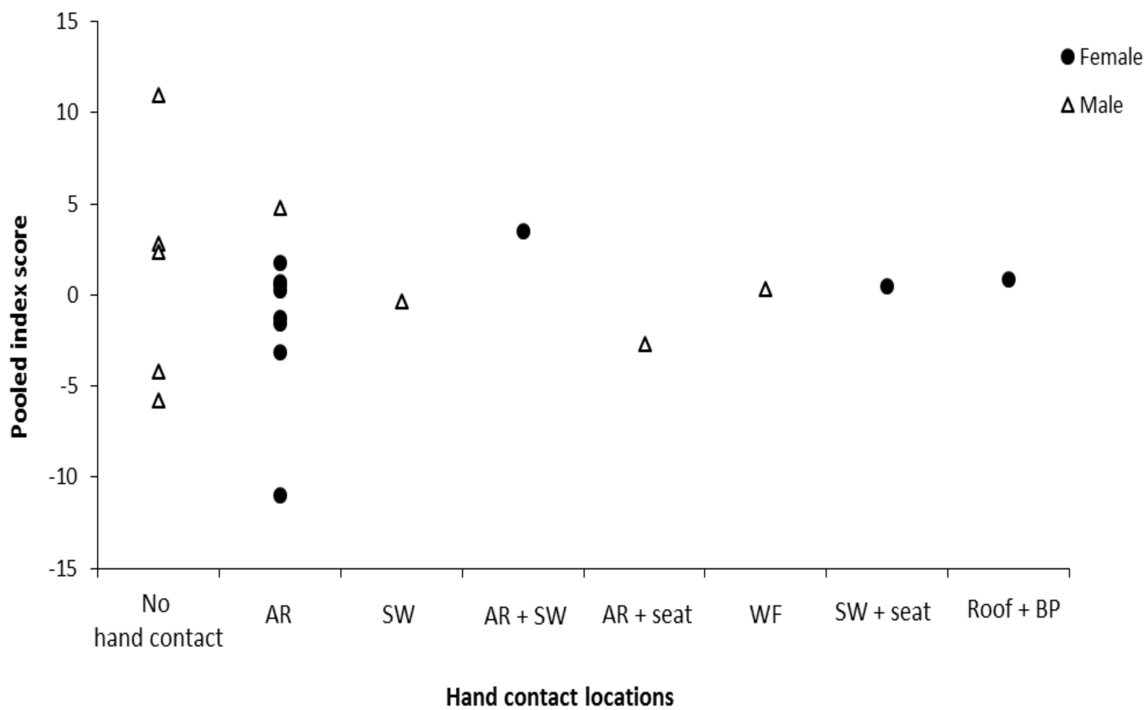

Figure 3-10. Hand contact locations according to physical mobility (as measured by pooled index score) and gender. Hand contact locations on the x-axis was represented by different values on the graph, where *Armrest* = AR, *Steering wheel* = SW, *B-pillar* = BP, and *Window frame* = WF.

3.10.3 Hand Contact Location during Egress according to Self-reported Use of a Mobility aid and Gender. Among four participants with consistent hand contact locations across trials, two female participants (10.00%) who self-reported using a mobility aid used the *armrest only*. Another female participant (5.00%), who used a mobility aid used the *steering wheel and seat*. One male participant (5.00%) did not come in contact with the vehicle. In summary, half of the participants who self-reported using a mobility aid used the *armrest only* during egress.

3.10. Hand Contact Location during Egress according to Self-reported History of Falls and Gender. Among the four participants with consistent hand contact locations across trials, one female participant who self-reported a history of falls used the *armrest and steering wheel*. One male participant used the *window frame only*. Another male participant used the *armrest and seat*. In summary, the majority (3 of 4) of the participants who self-reported having a history of falls used the *armrest only* or in combination with the seat during egress.

3.11 Foot Placement Strategy and Hand Contact Location

The results for ingress and egress respectively with regard to the following research question are outlined: *What are the observable patterns between foot placement strategy and hand contact location during ingress and egress*?

3.11.1 Patterns between Foot Placement Strategy and Hand Contact Location during Ingress. Table 3-5 shows the frequencies (*n* =25) and percentage of participants (male = 40%, female = 60%) who were consistent in both their hand contact locations and ingress strategies across trials according to gender. The mean age of the 25 participants was 72.00 years old (*SD* = 6.53) - 74.40 years (*SD* = 6.55) for males and 70.40 years (*SD* = 6.22) for females. The mean index score for this sample was -0.34 (*SD* = 3.40); with 0.04 (*SD* = 2.86) for male and -

0.27 (*SD* = 3.91) for female. Four participants (3 females, 1 male) self-reported using a mobility aid, and eight different participants self-reported having a history falls (5 females, 4 males). Only one participant of 25 reported having both used a mobility aid and a history of falls. The mean index score for participants who reported using a mobility aid and having a history of falls was -2.87 (*SD* = 4.88) and -0.79 (*SD* = 2.91), respectively. The one-foot *lateral sliding* strategy was the most common strategy in both males and females. During ingress, the *armrest* only and *armrest and steering wheel* were the most common hand contact locations among both genders. In summary, majority (12/17) of the participants who used the *one-foot lateral sliding* strategy used the *armrest* location during ingress.

Table 3-5.

Frequencies of Hand Contact Locations and Strategy during Ingress according to Gender

	One-foot *n* (%)			Two-foot *n* (%)		
Hand contact locations	Lateral sliding	Backward motion	Forward motion	Trunk forward	Trunk backward	Total *n* (%)
			Male participants			
No hand contact	1 (4.00%)	0 (0.00%)	0 (0.00%)	1 (4.00%)	0 (0.00%)	2 (8.00%)
Armrest only	2 (8.00%)	1 (4.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	3 (12.00%)
Steering wheel only	2 (8.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	2 (8.00%)
Armrest and steering wheel	2 (8.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	2 (8.00%)
Armrest and seat	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)

Armrest and B-pillar	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Steering wheel and B-pillar	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Roof and seat	1 (4.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	1 (4.00%)
Total male *n* (%)	8 (32.00%)	1 (4.00%)	0 (0.00%)	1 (4.00%)	0 (0.00%)	10 (40%)
			Female participants			
No hand contact	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	1 (4.00%)	1 (4.00%)
Armrest only	3 (12.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	1 (4.00%)	4 (16.00%)
Steering wheel only	1 (4.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	2 (8.00%)	3 (12.00%)
Armrest and steering wheel	3 (12.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	3 (12.00%)
Armrest and seat	2 (8.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	2 (8.00%)
Armrest and B-pillar	0 (0.00%)	0 (0.00%)	1 (4.00%)	0 (0.00%)	0 (0.00%)	1 (4.00%)
Steering wheel and B-pillar	0 (0.00%)	1 (4.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	1 (4.00%)
Roof and seat	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Total female *n* (%)	9 (36.00%)	1 (4.00%)	1 (4.00%)	0 (0.00%)	4 (16.00%)	15 (60%)
Total *N* (%)	**17 (36.00%)**	**2 (4.00%)**	**1 (4.00%)**	**1 (0.00%)**	**4 (16.00%)**	**25 (100.00%)**

3.11.2 Patterns between Foot Placement Strategy and Hand Contact Location during Egress. Table 3-6 shows the frequencies (*n* = 18) of the 18 participants (male = 50%, female = 50%) who were consistent in both their hand contact locations and egress strategies across trials. The mean age of the 18 participants was 71.67 years old (*SD* = 7.15). The mean age was 72.78 years (*SD* = 7.36) for male and 70.56 years (*SD* = 7.20) for female. The mean index score for this sample was -0.14 (*SD* = 4.55), with 0.92 (*SD* = 5.10) for male and t -1.20 (*SD* = 3.94) for female. Four participants (3 females and 1 male) used a mobility aid, while only three male participants self-reported having a history falls. The mean index score for participants who reported using a mobility aid and having a history of falls was -3.88 (*SD* = 5.61) and -2.18 (*SD* = 2.31), respectively. None of the participants of 18 utilized the one-foot *parallel to the vehicle* strategy during egress. In summary, participants who used the *one-foot lateral sliding* as well as the *two-foot egress* strategy both used the *armrest* most often during egress.

Table 3-6.

Frequencies of Hand Contact Locations and Strategy during Egress according to Gender

	One-foot *n* (%)			
Hand contact locations	Head forward	Parallel to the vehicle	Two-foot *n* (%)	Total *n* (%)
		Male participants		
No hand contact	2 (11.11%)	0 (0.00%)	3 (16.67%)	5 (27.78%)
Armrest only	1 (5.56%)	0 (0.00%)	0 (0.00%)	1 (5.56%)
Steering wheel only	0 (0.00%)	0 (0.00%)	1 (5.56%)	1 (5.56%)
Armrest and steering wheel	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)

Armrest and seat	0 (0.00%)	0 (0.00%)	1 (5.56%)	1 (5.56%)
Window frame	1 (5.56%)	0 (0.00%)	0 (0.00%)	1 (5.56%)
Steering wheel and seat	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Roof and B-pillar	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Total male *n* (%)	4 (22.22%)	0 (0.00%)	5 (27.78%)	9 (50.00%)
Female participants				
No hand contact	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Armrest only	4 (22.22%)	0 (0.00%)	3 (16.67%)	7 (38.89%)
Steering wheel only	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Armrest and steering wheel	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Armrest and seat	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Window frame	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Steering wheel and seat	0 (0.00%)	0 (0.00%)	1 (5.56%)	1 (5.56%)
Roof and B-pillar	1 (5.56%)	0 (0.00%)	0 (0.00%)	1 (5.56%)
Total female *n* (%)	5 (27.78%)	0 (0.00%)	4 (22.22%)	9 (50.00%)
Total *N* (%)	**9 (50.00%)**	**0 (0.00%)**	**9 (50.00%)**	**18 (100.00%)**

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CHAPTER 4

DISCUSSION

Prior to discussing the findings of the study, the design of the current study will be discussed in relation to protocols and method used in previous research on ingress and egress.

4.1 Sample Characteristics in the Current Study: A Comparison to Previous Research

A purposeful sampling method was used to recruit participants in the current study as it allowed us to select participants that aligned with the study purpose, and improve efficiency with recruitment (Suen, Huang, & Lee, 2014). This recruitment technique is comparable to previous studies where participants were either volunteers or older drivers chosen specifically for their studies (Causse, Chateauroux, Monnier, Wang, & Denninger, 2009; Chateauroux & Wang, 2010). This recruitment technique can influence the results of the study since the participant recruited for the study might create researcher bias, as the sample is chosen based on the research in question, and may not be representative of the older driver population.

Several studies to date studying ingress and egress strategies have not described the recruitment procedures (Ait El Menceur, 2006; Shippen and May, 2016). In another study that focused on the egress motion used by younger and older drivers, Chateauroux and Wang (2010) indicated recruiting their older participants through newspaper advertisements, their younger participants were volunteers who came from the university staff and student population. Causse and his colleagues (2009) tracked the ingress and egress strategies of two volunteers who were staff at the French national institute for transport and safety research. To date, the literature examining ingress and egress strategies has not reported the specific sampling strategies, which can limit the interpretability of the results. Our participants were also purposefully recruited to reflect a range in terms of age, gender, and physical mobility, as our aim was to understand how these underlying characteristics might influence their ability to enter and exit an automobile. Therefore, this study provided additional context in terms of the sampling method for recruiting older drivers, and addressed the gaps of study design specific to their ingress and egress strategies.

4.2 Participant Characteristics

4.2.1 Sample Size, Age and Gender. The total number of participants in our sample was 32 (13 males and 19 females). Our sample size was comparable to previous studies. For example, Ait El Menceur et al. (2006) had 41 participants in their study on vehicle ingress and egress; 15 of which were younger participants and 26 of which were ≥ 65 years. Their participants were further classified into groups: 'able-bodied (n=19; 12 male; 7 female); the remaining older adults had hip or knee replacement surgery (i.e. gender was not reported for any of these groups). Chateauroux and Wang (2010) study that examined egress strategies of older drivers had only 18 older participants ≥ 65 (11 males and 7 females). Shippen and May (2016) had 30 participants (13 males and 17 females) in their study, which is similar to our sample size of 32, but were younger in terms of age (55 to 69 years).

In the current study, the average age of our participants was 71.88 years old, which is similar to the participants in the Ait El Mencur et al. (2006) study, where the mean age of the participants was 71.00, and Chateauroux and Wang (2010) study, where the mean age was also 71.00 (63 to 77 years old). None of the previous studies reported the mean and range of their participants' ages according to gender. Therefore, the current study has a comparable sample size with previous studies as well as comparable sample characteristics in terms of the age.

4.2.2 Physical Mobility Characteristics. Previous studies (Ait El Menceur et al., 2006; Causse et al., 2009; Shippen & May, 2016) focused on naming and framing the movements involved with entering and exiting a vehicle without capturing the underlying physical mobility characteristics of their sample with one exception. Chateauroux and Wang (2010) is the first and only study to examine physical mobility in an older adult sample by administering two tests: The Romberg's Test and the Get-up and-Go Test. The Romberg test (Jansen, Larsen, & Olesen, 2009) assesses balance, where individuals stand for period of time with both of their eyes open then closed, whereas the Get-up-and-Go test is a variation of the TUG. Using these tests as well as other subjective criteria (e.g., torso flexibility, weakness in lower limbs), Chateauroux and Wang grouped their participants into three groups: 1) severe problems with functional mobility: Participants had major weakness in their lower limbs and problems with flexing their torso, 2) poor functional mobility: Participants who performed poorly on Romberg and Get-up-and-Go test and had problems with torso flexion but were not severe, and; 3) No functional mobility problems: participants with no deficits in the balance tests and no problems with their torso flexibility. However, it was unclear as to how these groupings were determined as they were not reported in the study, and it was unknown as to how the testing criteria from the Get-up-and-Go or Romberg test was involved in the classification of participants. Chateauroux and Wang (2010), reported differences between these groups in relation to their egress strategies using only two categories(i.e., one foot vs. two-foot), rather than examining the specific sub-strategies employed (i.e., one-foot lateral sliding vs one-foot forward motion). Without reporting these strategies, important details are lost in terms of the motion seen during ingress and egress from the different sub-strategies (e.g., foot placement, torso rotation).

Similar to Chateauroux and Wang, the current study examined the individual strategies of each participant in relation to their performance, but used a more in-depth battery of physical mobility measures (i.e., TUG, OLS, RPW, BBS). Results of these measures provide a sense of the physical (e.g., strength) and balance (e.g., stability) abilities required to perform both ingress and egress strategies. For example, the one-legged stance test provides a measure of balance on a single foot; a motion common in both one-foot ingress and egress sub-strategies. These measures were consolidated to develop a physical mobility index, which provided a novel way to examine how ingress and egress strategies, as well as hand contact location of older drivers, might be influenced by their underlying physical mobility.

4.3 Data Collection Protocol: A Comparison with Previous Research on Ingress & Egress

4.3.1 Study Procedures and Analysis. To our knowledge, previous studies did not include the instructions of how they required their participants to perform ingress and egress (i.e., not clear if participants only performed the strategy once or multiple times) (Ait El Menceur et al., 2006; Causse et al., 2009; Chateauroux & Wang, 2010; Shippen & May, 2016). However, similar to previous studies (Ait El Menceur et al., 2006; Causse et al., 2009; Chateauroux & Wang, 2010; Shippen & May, 2016), participants were video-recorded performing ingress and egress on the same vehicle, which allowed a thorough review of this data. This review of the recordings ensured the correct strategy and hand contact location were identified. Participants in the current study were asked to perform ingress and egress as they normally would so that the strategies used in the study would better reflect the actual strategies used in real life (i.e., ecological validity).

The current study used an actual vehicle that was parked in a garage setting, which aimed to reflect a real world, vehicle environment as closely as possible. Previous studies have stripped down the vehicle in question, meaning only a vehicle door, seat, and steering wheel are present (Ait El Menceur et al., 2006; Causse et al., 2009). Use of an actual vehicle was also important in the present study, as it enabled the capture of the range of hand contact locations, which would not be possible if only parts of the vehicle were used. Although Chateauroux and Wang (2010) used four vehicle models in their study, some parts of car door were removed during the installation of their motion capture equipment. Participants in the study by Shippen and May (2016) wore sensor 'suits' so biomechanical factors, such as joint angles could be measured, whereas our participants wore their regular clothes. One of the main reason why other studies modified their vehicles or used a mock-up, was that they focused on very specific aspects of the ingress and egress motion in relation to the drivers, such as the biomechanics of the motion or discomfort evaluation during the motion (Ait El Menceur et al., 2009; Choi & Lee, 2015), and perceptions of older drivers in relation to particular aspects of vehicle design, such as with the door sill and seat (Causse et al., 2012; Herriotts, 2005).

When analyzing their data, Ait El Menceur et al. (2008) collapsed the ingress and egress strategies into two categories: one foot vs. two-foot ingress, as opposed to identifying each strategy independently. While collapsing the data in this way might ease the efficiency of analyzing relationships with physical mobility characteristics, important details may be lost with regard to the physical differences between participants who utilized different strategies. Furthermore, the collapsed data may yield misleading results. For example, Ait El Menceur et al. (2008) reported that two-foot ingress strategies are preferred among older adults with mobility problems (i.e. persons with prostheses in order to protect themselves from re-injury), whereas the results from the current study suggest otherwise - there are participants who had higher scores on the pooled index (good physical mobility) used the *two-foot (trunk backward)* ingress strategy as well. A possible explanation for this finding may be due to some participants being more cautious, and, as such, utilized a two-foot strategy, which is a more stable and safe strategy for vehicle ingress (Ait El Menceur et al., 2008). However, we did not ask participants to report their subjective reasons for using a particular strategy.

The current study used a descriptive approach to analyze the data of our participants and their ingress and egress strategies. This approach was used because our findings violated several statistical assumptions of the general linear model. These limitations made the quantitative analysis unsuitable, and so a descriptive approach was employed. The descriptive approach used in the current study was comparable with previous studies on vehicle ingress and egress. Descriptive reporting was used by Ait El Menceur et al (2008) in their analyses of the five ingress and three egress strategies. A similar approach was also used by Chateauroux and Wang (2010) study whereby they descriptively reported the different phases and specific motions associated with each phase. There are problems and, in turn, limitations of a descriptive approach. A descriptive approach summarizes the datasets, rather than statistically analyzing relationships between underlying patterns and trends of the population being studied. The section that follows discusses the results in relation to previous research, where possible.

4.4 Overview of Ingress Strategies

Our results support previous research where five ingress sub-strategies were identified, with the one-foot *lateral sliding* strategy being the most common during ingress (see Ait El Menceur et al. (2008).

Ingress strategies, age, and gender. Ait El Menceur et al. (2008), based on their sample, indicated that one-foot *backward motion* strategy is most often observed (but not limited to) younger participants (19 to 31 years old), whereas the current study indicates this strategy was also used by older participants (mean age of 67.00 years).

One-foot Ingress Strategies and Physical Mobility. The majority of the participants used one-foot strategies, with most using the one-foot lateral sliding strategy. Generally, these participants had good physical mobility compared to the overall sample, as reflected in their mean physical mobility index scores. However, it is important to note that participants that used a one-foot strategy also had lower physical mobility scores included those who reported a history of falls and used a mobility aid. Chateauroux and Wang (2010) indicated that one-foot strategies are the least stable. Hence, participants with lower physical mobility may be putting themselves at risk of a fall during vehicle transfer.

Two-foot Ingress Strategy and Physical Mobility. Two-foot ingress strategies (both *trunk forward* and *trunk backward*) are considered to be the more stable compared to one-foot ingress strategies (Ait El Menceur et al., 2008). Ait El Menceur et al. postulated that two-foot strategies might be used by participants to protect themselves from injury. Although a two-foot ingress strategy is considered to be a more stable strategy, the majority of the participants in the current study, including participants who self-reported using a mobility aid and having a history of falls within the past year, were observed using one-foot strategies. The four participants who used the two-foot *trunk backward* strategy had some problems with physical mobility, as reflected in their mean physical mobility index scores. These descriptive characteristics of mobility are congruent with the postulation by Ait El Menceur et al. (2008) that older participants with mobility limitations may be more likely to use a more stable two-foot ingress strategy. As such, these participants should be encouraged to use this strategy. Nevertheless, caution is warranted when interpreting the results in the current study due to small sample size and other issues that emerged with the data (i.e. lack of normality).

4.5 Overview of Egress Strategies:

Similar to ingress, our results support the previous research where three egress sub-strategies were identified, with the *one-foot head forward* strategy being the most common for egress (Ait El Menceur et al., 2008), which was also referred to as the *Left Leg First* strategy in other studies (Chateauroux & Wang, 2010; Shippen & May, 2016). However unlike ingress, only 26 of the 32 participants were consistent with their respective egress strategy across the five trials, and the *one-foot parallel to the vehicle* strategy was not observed among these 26 participants.

Egress strategies, age, and gender. Ait El Menceur and his colleagues (2008) found participants who used a two-foot egress strategy were older than the participants who used one-foot strategies. Findings of our study support their assertion, as the mean age of participants in the current study who used the two-foot *egress* strategy was indeed slightly older than participants who used the one-foot *head forward* strategy.

One-foot Egress Strategies and Physical Mobility. The results from our study support existing evidence that a *one-foot head forward* egress strategy is used most often among older drivers. Those participants who used this strategy scored generally well on the pooled index. However, participants with poor physical mobility, as indicated by their low index score, are also using the one-foot strategy. As well, participants who reported using a mobility aid as well as having a history of falls were also using the *one-leg head-forward* strategy during egress. As noted by Chateauroux and Wang, one-foot strategies are less the least stable strategy during egress. This result suggests these participants may be at a higher risk for falling.

Two-foot Egress Strategy and Physical Mobility. Two-foot egress strategy are considered to be the more stable compared to one-foot egress strategies (Ait El Menceur et al., 2008, Chateauroux and Wang, 2010). However, similar to previous studies, fewer participants used the more stable two-foot strategy during egress. To explain this phenomenon, Chateauroux and Wang (2010) suggested, based on their findings, that participants may avoid using two-foot egress strategies because it is actually a more difficult strategy to perform. They indicated that two foot egress strategies require considerable strength to lift (hip flexion) and rotate both feet over the door sill out of the vehicle while in a seated position. Then, stated the effort required due to friction with the seat also makes this strategy less efficient and might be the reason that individuals with mobility problems do not use a two-foot egress strategy. Despite these challenges, they indicated that two-foot *egress* strategies do not require a unipedal (i.e., one leg stance) phase as seen in one-foot strategy, and, as such, are considered a more stable strategy since it has a wilder base of support. Similarly, based on our observations, the centre of gravity of an individual during a two-foot trunk backward strategy might ease sit to stand transfer, as compared to a one-foot lateral sliding strategy where his/her centre of gravity has shifted to the left. Hence, the two-foot strategy is more stable and may be a preferable strategy during egress. However, as per ingress, caution is warranted when interpreting the results in the current study due to the size of the sample.

4.6 Hand Contact Locations during Ingress

Chateauroux and Wang (2010) was the only study that identified three hand contact locations: 1) *steering wheel*; 2) *seat*; and 3) armrest on vehicle *door*. Our study supports that these locations are common during both ingress and egress. In addition to these locations, our study also identified the car *roof*, *window frame*, and *B*-pillar as places the hands also come in contact with. This study is also the first to our knowledge to track hand contact locations in association with foot placement strategies.

The majority of participants used the *armrest* location alone or in combination with other hand contact locations during ingress (i.e., *steering wheel*, *seat*, *B-pillar*). Chateauroux and Wang (2010) postulated that the *armrest* was used to maintain balance during egress and, our results, support this assertion with ingress. In the current study, hand contact with the *armrest* was most commonly observed among participants using one-foot strategies, such as the *lateral sliding* strategy. However, like the *lateral sliding* strategy, contact with the *armrest* at the door is convenient during ingress, it could be a concern for fall risk, given that it is on a swinging (moveable) hinge. Another reason the armrest may be used by participants is because of efficiency. Having the hand on the door armrest while entering a vehicle can be used to close the car door after seated.

Interestingly, hand contact on the *steering wheel* was most commonly observed during two-foot ingress strategies, such as the *trunk backward* strategy. Given that some had postulated that two-foot strategies as more challenging to perform (Chateauroux & Wang, 2010), older drivers may be supporting themselves using the *steering wheel* to help rotate and lower their body into as well as out of the vehicle.

Participants who used multiple hand contact locations were generally older than participants who used a single hand contact location, regardless of the actual location. Moreover, participants who self-reported using a mobility aid and/or having a history of falling, all had at least one or more hand contact with the vehicle during ingress, and appears to be more likely to use multiple hand contact locations. This evidence was support as reflected by the pooled index scores. Participants who used multiple hand contact locations had poorer physical mobility, as measured by the pooled index, than persons who used a single hand contact locations, or no contact at all with the vehicle.

4.7 Overview of Hand Contact Locations during Egress

Most participants used the *armrest* alone or in combination with the *steering wheel* or *seat* during egress in the current study. Once the door was open, some participants used the armrest when moving from sitting to standing. Participants who used the *two-foot egress* strategy were more likely to rotate their body first before placing their hand on the armrest. This observation was also reported by Chateauroux and Wang (2010), where they stated that hand contact may be used to ease egress and to unload the lower extremities by pushing or pulling against gravity, such as the armrest.

Only a small number of participants were observed using the *steering wheel*. This finding was different from previous studies, where the steering wheel was used most often for egress (Causse et al., 2009; Chateauroux & Wang, 2010). This difference may be related to the underlying physical mobility of their sample (age, gender, physical mobility), although this is not known as it could be due to other cofounding factors (i.e. vehicle design).

The majority of participants who self-reported using a mobility aid and/or having a history of falling had at least a single hand contact location with the vehicle during egress. This is expected, as participants, who used a mobility aid and/or having a history of falling, are more likely to have lower physical mobility, which may require additional hand supports when exiting a vehicle to remain stable, particularly if using a one-foot strategy. Pooled index scores further support this claim, as participants who used multiple hand contact locations had poorer physical mobility, as measured by the index score, than persons who used a single hand contact locations or had no contact with the vehicle at all. Given this study is the first to examine hand contact locations, caution is warranted when interpreting the data due to the limitations of the study.

4.8 Study Limitations

It is important to consider the limitations associated with this study. Our recruitment approach was comparable to previous studies examining ingress and egress (Ait El Menceur et al., 2008; Chateauroux & Wang, 2010). However, the sample recruited using convenience sampling method, and, as such, introduced selection bias, meaning the sample may not be the best representative of the population of older drivers. To address this issue, future studies on vehicle ingress/egress could consider using a stratified random sampling method instead. Using this method, the sample could be partition into groups based on their level of physical mobility. This could provide a clearer picture with regard to determining the relationship of physical mobility and its influence on vehicle ingress and egress.

Another limitation was the small sample size of our study. An increase in the number of participants, may have allowed us to have sufficient power to test statistically differences between strategies and relationships between variables. A larger sample size would also allow us to have a more representative sample. Furthermore, participant was also asked to self-report whether or not they used mobility aid or had history of falls within the past year. This approach may introduced recall bias, meaning participants might not have remember or "recall" past events or experiences accurately or completely. As part of the study procedures, participants completed both the physical mobility clinical measures, as well as the ingress and egress trials within the same session. As a result, some participants may have become fatigued, which may have influenced their strategies. While we know from the literature that older drivers are likely to enter and exit a vehicle on more than one occasion when driving in their community (i.e., trip chaining; see Molnar et al., 2013]), they will typically only complete a single entry and exit of their vehicle per location. Hence, the protocol of our study may not reflect what is required with regard to ingress and egress during their everyday driving, particularly with regard to the environment in which this motion is sometimes performed. For example, the weather, such as rain or snow, uneven or slippery surfaces, parking next to other vehicles in parking lots and other issues are also important considerations that could influence performance of ingress and egress in a real-world context. As well, it is important to note that the order of the protocol differed between participants, meaning that some participants completed the clinical assessments first then proceeded to the garage to do the ingress and egress trials, whereas others did the converse. In this case, confounding factors such as fatigue, might also have been an issue that might have affected the performance of the participants during ingress and egress.

Another consideration is that we examined ingress and egress separately as they are typically considered as isolated events. Hence, it was not explored as to how a participant's ingress strategy might be related to their egress. For example, it is unknown whether someone who uses a one-foot ingress strategy is also more likely to also use a one-foot egress strategy, and vice versa. Furthermore, due to the small sample size of our study, we are unable to determine if there is a clear relationship between the different combinations of hand contact locations and the foot placement strategy in question. Again, by increasing the sample size of our study we may be able to evaluate whether a sub-group of participants who used a specific foot placement strategy and certain hand contact locations (i.e. lateral sliding strategy and steering wheel) are in fact related to one another.

Lastly, there are other confounding variables that may have affected the results of this study. There are known gender differences in terms of mobility and physical performance, which was considered, as the respective findings were reported for male and female participants. Vehicle geometry is another consideration that could have influenced the ingress and egress strategy of our participants and their corresponding hand contact locations. In this study, participants performed the ingress and egress motion on the same vehicle model, which is a limitation as vehicle design might influence the strategies used by older drivers. Although some studies (Ait El Menceur et al., 2008; Causse et al., 2009; Chateauroux & Wang, 2010; Shippen & May, 2016) have examined vehicle ingress and egress using different vehicles (e.g., mid-size sedan, minivan), Ait El Menceur et al. (2008), for example, reported that the different strategies were equitably distributed across all models, except for the one-foot forward motion strategy, which was observed only in the minivan. This difference may be explained by the anthropometry of the participants (i.e., short stature, BMI) and the design of the vehicle itself (i.e., a higher ground to vehicle difference). Other studies (Chateauroux & Wang, 2010; Shippen & May, 2016) have tracked the correlation between certain vehicle designs and older driver comfort in relation to ingress and egress. According to Shippen and May (2016) vehicle designs that reduce the need for body rotation and joint movement are preferred among older participants. Another limitation to the current study is the possible familiarity with the environment (i.e. vehicle in this case). Familiarity with the vehicle may have influenced how participants performed during the study, as they were oriented, albeit briefly to the vehicle and could also adjust the seat. Some participants may have had vehicles that were similar in terms of size and set-up to the model used, but this was not tracked in relation to the results in this study. Other participant factors, such as their balance confidence and self-perceived mobility, may have also influenced the findings, which should be considered in future research. Further considerations for future research are outlined in the next chapter.

4.9 Summary of Findings

Overall, the current study identified the following major findings:

- Participants who used one-foot strategies_(*One-foot lateral sliding* strategy for ingress and *One-foot head forward* strategy for egress) generally have better mobility, as measured by the pooled index scores, than participants who used two-foot strategies (*Two-foot trunk backward* strategy for ingress & *two-foot egress strategy* for egress).
- During both ingress and egress, older drivers in this study were more likely to use the one-foot strategies which are considered the least stable strategy, and participants with poor mobility are more likely to be at risk for falls.
- During both ingress and egress, participants who used the more stable two-foot strategies include persons with poor mobility as well as generally good mobility. The *armrest* hand contact location, or *armrest* in conjunction with other contact locations, was used by the majority of older drivers for both ingress and egress, and is observed to be used most often with one-foot strategies.
- Persons who used multiple hand contact locations for ingress/egress had poorer physical mobility than participants who used a single hand contact location or made no contact with the vehicle.

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CHAPTER 5

CONCLUSION

This study employed a novel approach to investigate the relationship between physical mobility, using a consolidated index of physical mobility, and ingress/egress strategies of older drivers. The objective of this project was to examine ingress and egress strategies (foot and hand locations) in a group of older drivers, according to age, gender, and mobility. Findings from this study indicate that older drivers used ingress and egress strategies that have been previously identified. The results suggest that the respective strategies that one might expect to be used by participants are not always congruent with their level of physical mobility, particularly balance. For example, the results indicate that most participants used the one-foot lateral sliding strategy when entering the vehicle. This strategy, alongside other one-foot strategies, has been identified as being less stable than two-foot strategies. Most of these participants were identified as having good physical mobility, as reflected in their physical mobility index scores. However, participants with lower scores also used this less stable strategy. While participants that used a more stable two-foot ingress and egress (e.g., two-foot trunk backward strategy) were still in relatively good physical health based on their respective range of scores on the index, their mean scores were generally lower than participants who used the most common one-foot strategies. Although caution is warranted regarding the interpretation of these findings given the study limitations, there is an opportunity to consider the potential impact and contribution of this research.

5.1 Potential Impact and Contribution of this Research.

Impact to the clinical field. Results from this study have the potential to inform public health approaches that aim to keep older drivers safe during ingress and egress. For example, educating older adults on the use of safe ingress and egress strategies could be added as part of existing fall prevention programs or older drivers' rehabilitation programs, that often include the provision of educational materials, prescription of physical activity, and other suggestions (Buchner, Beresford, Larson, LaCroix, & Wagner,1992; McPhee et al., 2016). Clinicians may want to consider educating their clients with poor physical mobility who might be at risk for falls about how to more safely enter and exit their vehicles to prevent potential injury. For example, they may want to observe their clients, as to how they perform this transfer, and advise accordingly.

Impact to the research field. As noted previously, the findings of the study can be used inform future research in the field of rehabilitation science with regard to perceived risk of falls and balance confidence, as the perspective of the older driver in terms of his or her physical mobility may impact a chosen ingress and egress strategy. Intervention studies could also be developed to enhance upper and lower body strength of those with problems with their physical mobility, and whether this might result in differences in how older people enter and exit a vehicle or even their perceived risk.

As previously stated, use of a larger, more representative sample is important for future research. Additionally, there is an opportunity to understand the exact movements, including forces at work, during such complex person-vehicle interactions. With advancements in technology, the pressure exerted by the hand, for example, can be objectively measured using a pressure glove that can extract data on the exact location and forces applied to particular parts of the vehicle. Such data can provide critical information to inform the vehicle design, such as a more ergonomic armrest. Tracking the use of left and right hand as well as the order of hand contact locations may also add to our understanding of how a participants' body, foot, and hands are oriented during both ingress and egress.

During the course of this study, our research team developed a partnership with the Ontario College of Art and Design (OCAD) where preliminary findings were used to inform the design of 'add-ons' to the vehicle that could support older drivers during ingress and egress. For example, a student designer from OCAD used the hand contact locations that were captured in the present study to create a handle that could be added to a vehicle in the identified locations (See Figure 4-1).

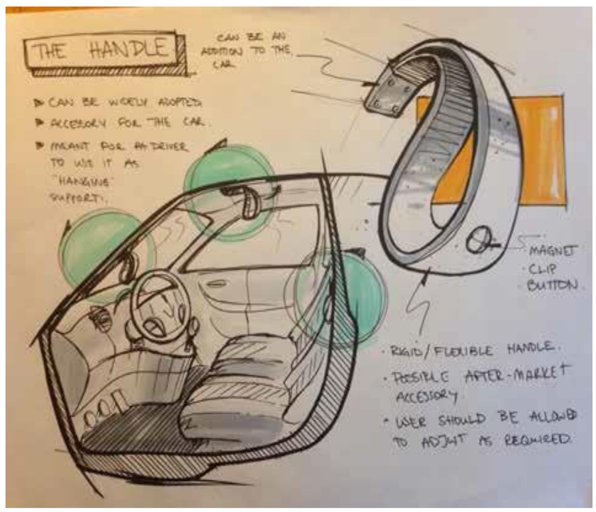

Figure 4-1. Concept design of a flexible handle that was informed from data from the current study in collaboration with the Ontario College of Art and Design to facilitate safe ingress and egress.

As well, it was observed in this study that participants who were more limited in their balance typically used the armrest in addition to other locations on the car during ingress and egress. The student designer developed the concept of a 'door stabilizer' (Figure 4-2) that could ensure the vehicle door remained in one location to prevent a swinging motion. By preventing this motion, the door would provide an anchor point for participants with physical mobility problems to improve their stability during ingress and egress. Going forward, it would be critical to include feedback from older drivers on any designs that are developed. Such feedback would help improve our understanding of how they might use such modifications in a real-world context even at the most preliminary stage of the design process.

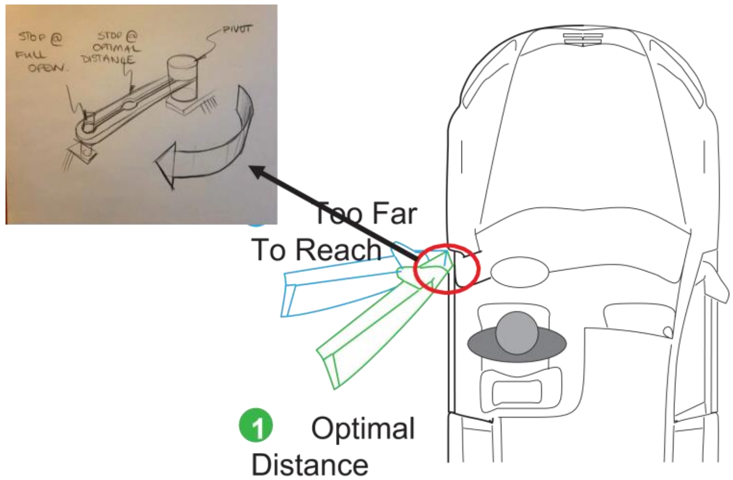

Figure 4-2. Concept design of a door stabilizer that was informed from data from the current study in collaboration with the Ontario College of Art and Design to facilitate safe ingress and egress.

Future work could build on the scope of the current study by addressing how environmental factors, such as different weather conditions or slope, can impact vehicle ingress and egress. Recently, members of our team toured the iDAPT facility at the Toronto Rehabilitation Institute (TRI). TRI is home to some of the world's most technologically advanced rehabilitation research facilities, including the Challenging Environment Assessment lab (CEAL). CEAL features the world's first hydraulic motion simulator where one can set-up environmental challenges that mirror demands of performing complex mobility scenarios, such as climbing stairs, or walking on snowy, icy and/or other slippery surfaces. For example, in the Winterlab simulator, and using advanced motion capture technology, an adjustable vehicle mock-up could be constructed, such as the one depicted in Figure 4-3a. The hydraulic platform could be moved at various angles. In turn, older participants, in a safety harness, could enter and exit various vehicles (Figure 4-3b). The safety harness is particularly critical, as it would protect the participants from serious injury during experimental protocol.

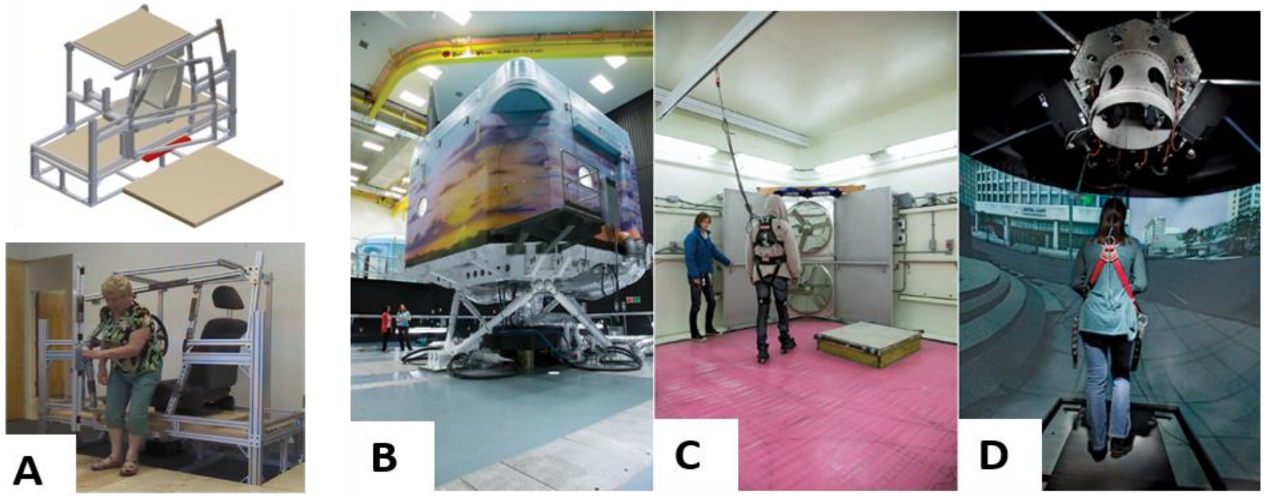

Figure 4-3. A.) Concept image and photo of a vehicle mock-up B.) Winterlab simulator C.) Inside of the Winterlab simulator and a participant with the safety harness strapped on D.) Inside of the Challenging Environment Assessment lab (CEAL) for complex mobility simulation from the iDAPT facility at the Toronto Rehabilitation Institute (TRI) (Image retrieved from Fraumeni, 2011).

While such simulators and other technology certainly offer possibilities in terms of experimentation when it comes to vehicle ingress and egress, there are also potential modifications that could be highly effective but involve less sophisticated protocols. Even simple reminders to use these strategies could prompt older drivers when entering and exiting a vehicle to prevent injuries. For example, the OCAD student designed a visual cue (i.e., sticker) that could be placed next to the door to prompt older drivers to use the safest (two-foot) egress strategies (see Figure 4-4). Evaluating and tracking of how older adults use such cures is critical with regard to determining if such innovations or interventions translate to real world performance. As current and future generations of older adults' transition from driving to driving cessation, this area of study remains important given that as passengers it is not known if the same relationships in terms of foot placement strategies and hand contact locations hold true. There is also an added risk for caregivers when assisting older passengers with mobility problems during ingress and egress that should also be investigated.

Figure 4-4. Still image of how visual cues, such as a sticker that reminds older adults to use the more stable two-foot egress strategy during vehicle egress

In summary, individuals ≥ 65 years are the fastest growing segment of all drivers in Canada (Turcotte, 2012). Given the importance of this mode of transportation in later life, there is much opportunity to consider how research specific to the 'person-vehicle' interface can be used to promote older driver safety. Developing innovations specific to the automobile that consider the needs of older drivers is critical given this mode of transportation is expected to remain the principal means of community mobility for older Canadians in the years to come.

REFERENCES

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APPENDIX A – INFORMED CONSENT FORM

INFORMATION AND CONSENT FORM

Title of Study: Innovations in Vehicle Design that Promote Safety and Usability in an Aging Society

Principal Investigator: Brenda Vrkljan, PhD, OT Reg. (Ont.)

McMaster University

1400 Main Street West IAHS 450

Hamilton, ON L8S 1C7

Funded by: Labarge Optimal Aging Initiative Fund

You are being invited to participate in a research study conducted by McMaster University because you are a licensed driver age 60 or older.

In order to decide whether or not you want to be a part of this research study, you should understand what is involved and the potential risks and benefits. This form gives detailed information about the research study, which will be discussed with you. Once you understand the study, you will be asked to sign this form if you wish to participate. Please take your time to make your decision. Feel free to discuss it with your friends and family.

WHY IS THIS RESEARCH BEING DONE?

Approximately 40% of injuries result from falls as older drivers enter and exit their vehicles, which can result in serious injury, disability and early mortality. While most research focuses on the impact of medical conditions on driving, aspects of the driving environment have been largely under-researched. Details of why falls occur within the driving environment, including the type and designs of vehicles, are not usually recorded in medical charts, but may be critical to understanding and preventing them from happening in the first place. To date, there is no research that has examined this issue. Given the importance of mobility to health and well-being in later life, interventions must be developed that prevent serious injuries in older drivers when using an automobile.

Another key component of this study is learning about what your feelings as an older driver with respect to your level of comfort in terms of the design of the vehicle specific to entering and exiting a car.

WHAT IS THE PURPOSE OF THIS STUDY?

Problems with accessibility (e.g., getting in/out of vehicle, storage/trunk space), visibility (e.g., mirrors, instrumentation displays, exterior of vehicle), and adjustability (e.g., steering, seat, brake/gas pedals) are the most frequently reported problems amongst older users. The next step in this research is to examine how older users actually interface with their automobile and whether this impacts on falls. The proposed study will focus on the vehicle environment as the point of intervention for enhancing safe mobility for older drivers and passengers. We are recruiting 55 older drivers for this study. Results from this study will inform specific changes to vehicle design that can best facilitate safe transfer motions in older adults.

WHAT WILL MY RESPONSIBILITIES BE IF I TAKE PART IN THE STUDY?

If you volunteer to participate in this study, we will ask you to do the following things:

You will be asked to visit McMaster University on 2 separate occasions. The first visit will require approximately 2 hours of your time. You will be videotaped getting into and out of your own vehicle and another vehicle in a garage. You will then proceed to the lab where you will complete a functional assessment (i.e. testing of balance, flexibility, strength, mental capacity, vision and hearing) with the Project Coordinator/Research Assistant. No blood or x-ray testing will be done. On your second visit to McMaster University you will be asked to enter and exit a vehicle mock-up a series of times. The vehicle mock-up will be adjusted to reflect 4 different vehicle designs. As part of this process, you will be asked to fill out a questionnaire to assess your perceptions and comfort getting into and out of different cars.

You may also be asked by research staff to observe how you use your own vehicle as you complete an everyday errand. A Research Assistant would come to your home and go with you in your own vehicle as you complete the chosen errand (e.g., grocery shopping, mailing a letter). You will be involved with deciding which type of errand . You can expect that the Research Assistant will write down notes about what they see you doing. After the observation is completed, the Research Assistant, with your permission, will conduct a brief 30 minute in-depth interview in which they will ask you more questions about your experience getting into and out of a vehicle. The interviews will be recorded electronically and transcribed. Quotations from the interviews and written descriptions from observation may be used in writing for this research.

The study Coordinator/Research Assistant will schedule appointments with you by telephone and will call at least one week in advance as a reminder of your appointment.

Length of Study. This study will require 2 visits to McMaster University (Ancaster Facility) and another visit when the research assistant comes to your home; A Research Assistant may come to your home only once or as many as three times depending on your interest in this part of the project. After the first appointment, we will schedule the next assessment with you. We will make contact with you one week prior to your next scheduled appointment.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

None of the tests that you will complete on-campus have any side-effects or risks associated with them. You will be asked questions that people rarely find upsetting. Some of the physical tests can result in a loss of balance although this risk is minor. To ensure the safety of all participants, the Project Coordinator/Research Assistant will: guide participants to all testing stations, follow at a close distance, and provide a chair in close proximity if the participant becomes unsteady. If you are interviewed for this research at your home, there is a small chance that you may find some of the questions emotionally upsetting, but this is very unlikely.

HOW MANY PEOPLE WILL BE IN THIS STUDY?

We are recruiting approximately 55 drivers age 60 and older from the Hamilton area.

WHAT ARE THE POSSIBLE BENEFITS FOR ME AND/OR FOR SOCIETY?

There are no proven direct benefits to you for participation in this study. However, findings from the study will inform changes to vehicle design that can reduce the risk of falling and prevent serious injuries from occurring.

IF I DO NOT WANT TO TAKE PART IN THE STUDY, ARE THERE OTHER CHOICES?

Voluntary Participation. You are under no obligation to participate, and you may withdraw from the study at any time and for any reason by notifying the Project Coordinator/Research Assistant or principal investigator.

WHAT INFORMATION WILL BE KEPT PRIVATE?

Confidentiality. If you choose to participate, all information gathered about you will be held in confidence and will be securely stored. No one except the study personnel will have access to information that is identifiable to you (Information that is identifiable to individual study participants will *not* be shared by with any other organizations). Your data will not be shared with anyone except if required by law. All personal information such as your name, address, and phone number will be removed from the data and will be replaced with a number or a pseudonym. A list linking the number and pseudonym with your name will be kept in a secure place at McMaster University, separate from your data file. The data, with identifying information removed will be securely stored in a locked office in the research office/on a secure server/on an encrypted hard drive, etc. The data for this research study will be retained for 10 years.

If the results of the study are published, your name will not be used and no information that discloses your identity will be released or published without your specific consent to the disclosure.

CAN PARTICIPATION IN THE STUDY END EARLY?

You may withdraw from this study at any time and for any reason, by writing or phoning study personnel at McMaster University. If you decide to withdraw, then you will not be required to make any further visits to McMaster for this study. Your study information (e.g. paper and pencil tests, clinical assessments) up to and including the date of withdrawal will be retained for study purposes for 10 years.

New Information and Questions about the Study. If any new information about the study is available that might affect your willingness to participate, the study team will inform you. If you have any questions or concerns about this study please feel free to contact the research team: Dr. Brenda Vrkljan, Principal Investigator, can be reached at: (905) 525-9140 ext. 27817 vrkljan@mcmaster.ca. If you have any questions about your rights as a research participant, you may contact: the Office of the Chair of the Hamilton Integrated Research Ethics Board at 905-521-2100, ext. 42013.

WILL I BE PAID TO PARTICIPATE IN THIS STUDY?

No, you will not be paid to participate, however you will be reimbursed for parking costs while attending each visit.

Thank you for considering participating in this project. A copy of this form will be given to you to take home.

Brenda Vrkljan, PhD, OT Reg. (Ont.)

Local Principal Investigator

CONSENT STATEMENT

I have read the preceding information thoroughly. I have had the opportunity to ask questions, and all of my questions have been answered to my satisfaction. I agree to participate in this study. I understand that I will receive a signed copy of this form.

____

Name of Participant

____

____

Signature of Participant Date

Consent form administered and explained in person by:

____

Name and title

____

____

Signature Date

Signature of Witness to Participant's Signature:

My signature as witness, certifies that I witnessed the participant (or the participant's legally authorized representative) voluntarily sign this consent form in my presence.

_____________________________________ _______________

Signature Date

9877043211

CANDRIVE COMMON COHORT ANNUAL

SITE # – PT ID Date: __ / __ / 20__ (dd mm yyyy)

candrive — Driving research for older adults. Au volant de la recherche sur les aînés.

Visit: O *Year 1 (Baseline)* O *Year 2* O *Year 3* O *Year 4* O *Year 5*

Historical Driving Factors

12. How old were you when you first obtained your driver's licence? ☐☐

13. What is the highest driver's licence you have ever obtained?

O Class 5 O Class 1 O Class 2 O Class 3 O Class 4 O Class 6

14. Have you ever taken a non-mandatory driver refresher course? .... O No O Yes

14a. If yes, O Within past year O Within 1-5 years O Within 6-10 years O > 10 years O Unsure

14b. Did it include on road training? .... O No O Yes

15. Have you ever had to go for an in-depth mandatory driving assessment? .... O No O Yes

15a. If yes, when was this assessment?

O Within past year O Within 1-5 years O Within 6-10 years O > 10 years O Unsure

16. Have you ever spoken to your family doctor or any other doctor about your driving safety? O No O Yes

If no, go to question 17

16a. If yes, who initiated it?

O Self O Doctor O Family Member O Licensing Authority O Other O Cannot recall

16b. What triggered this discussion?

O Health issue(s)

O Driving infraction (e.g speeding ticket)

O Motor-vehicle accident

O Driving safety concern

O Cannot recall

O Other ____________

Comments:

CANDRIVE COMMON COHORT ANNUAL

SITE # - PT ID   Date: dd / mm / 2 0 yyyy

candrive

Visit: O *Year 1 (Baseline)* O *Year 2* O *Year 3* O *Year 4* O *Year 5*

Historical Driving Factors

16c. What was the outcome of this discussion?

- O Medical/physical assessment
- O Education/advice from your doctor
- O Follow-up visit with the doctor to monitor health concerns
- O Treatment
- O Referral for driving assessment with occupational therapist
- O Referral for driving assessment with licensing bureau
- O Driver re-training (i.e. driving school)
- O No action
- O Other ____________________

17. Have you ever had a discussion with a family member about your driving safety? O No O Yes O N/A

17a. If yes, who initiated it? O Self O Family Member O Cannot recall

17b. What triggered the discussion?

- O Health issue(s)
- O Driving infraction (ticket)
- O Motor-vehicle accident
- O Driving safety concern ____________________
- O Other ____________________

18. Administer Cognitive Test: O MMSE O MoCA O Demtect O Not Completed

Comments:

CANDRIVE COMMON COHORT ANNUAL

SITE # - PT ID   Date: dd / mm / 2 0 yyyy

Visit : ○ *Year 1 (Baseline)* ○ *Year 2* ○ *Year 3* ○ *Year 4* ○ *Year 5*

Current Driving Factors

19. How frequently do you drive ?

○ Daily ○ 4-6 times per week ○ 2-3 times per week ○ Once a week ○ < Once a week but > once per month

20. Please estimate the number of kilometers you have driven in the past year.

○ 0-1000 kms	○ 10,001-15,000 kms
○ 1001-3000 kms	○ 15,001-20,000 kms
○ 3001-5000 kms	○ 20,001-25,000 kms
○ 5001-10,000 kms	○ > 25,000 kms

20a. How many of these kilometers were driven in your primary vehicle?

○ 0-1000 kms	○ 10,001-15,000 kms
○ 1001-3000 kms	○ 15,001-20,000 kms
○ 3001-5000 kms	○ 20,001-25,000 kms
○ 5001-10,000 kms	○ > 25,000 kms

20b. How many of these kilometers were driven in all other vehicles? ○ N/A

○ 0-1000 kms	○ 10,001-15,000 kms
○ 1001-3000 kms	○ 15,001-20,000 kms
○ 3001-5000 kms	○ 20,001-25,000 kms
○ 5001-10,000 kms	○ > 25,000 kms

21. Do you <u>sometimes</u> engage in any of the following <u>while you are driving</u>?

a) Eating	○ No	○ Yes
b) Drinking (coffee, soft drink etc... we are not asking about alcohol)	○ No	○ Yes
c) Listening to the radio..........	○ No	○ Yes
d) Listening to CD, MP3, or IPOD..........	○ No	○ Yes
e) Talking with passengers	○ No	○ Yes
f) Using a cell phone..........	○ No	○ Yes
g) Smoking	○ No	○ Yes
h) Personal grooming (combing hair, apply make-up)	○ No	○ Yes

Comments:

SITE # ☐☐ - PT ID ☐☐☐☐ Date: ☐☐ / ☐☐ / 2 0 ☐☐ (dd / mm / yyyy)

Visit: O Year 1 (Baseline) O Year 2 O Year 3 O Year 4 O Year 5

Vehicle Factors

21. cont'd

i) Using a GPS (personal other than Candrive) .... O No O Yes

j) Driving with young children .... O No O Yes

k) Driving with pets .... O No O Yes

l) Using a road map .... O No O Yes

22. Do you drive more than one vehicle? O No O Yes

22a. ***If yes, how many vehicles do you drive on a regular basis?*** O Two O Three O Four

23. What is the make, year and model of your primary vehicle? (e.g. Toyota, Corolla)

Make: ____________________ ***Year:*** ☐☐☐☐

Model: ____________________ ***Code:*** ☐☐☐☐☐ *Refer to list for code*

24. How long have you driven your present primary vehicle for?

O < one year O >1 or <3 years O 3-5 years O >5 years

25. Are there any other drivers using this car? O No O Yes

If yes, please list the drivers (ie. son/daughter/spouse/friend) - ***(do not list names)***

Who?	*How often (# times/week)?*
1. ____________	☐☐☐/week O Less than 1x/week
2. ____________	☐☐☐/week O Less than 1x/week
3. ____________	☐☐☐/week O Less than 1x/week

Comments:

SITE # - PT ID Date: dd / mm / 2 0 yyyy

candrive

Visit: O Year 1 (Baseline) O Year 2 O Year 3 O Year 4 O Year 5

General Health

30. Do you ever drink alcohol? .... O No O Yes

30a. ***If 'yes', on average how often do you drink?***

- O Daily basis ______ # of drinks
- O Less than daily basis ______ # of drinks per week
- O Less than weekly

30b. ***Do you typically drink more than three drinks in one sitting?*** O No O Yes

Mobility

31. Do you sometimes have trouble with your balance?............ O No O Yes

32. Have you had any unexpected falls in the past year? .... O No O Yes

32a. ***If yes, # of falls***............ ______

33. Do you use a cane ? .... O No O Yes

33a. ***If yes, do you use the cane***............ O Inside O Outside O Both

34. Do you use a walker? .... O No O Yes

34a. ***If yes, do you use the walker***............ O Inside O Outside O Both

35. Do you use a non-motorized wheelchair ? .... O No O Yes

35a. ***If yes, do you use the wheelchair***............ O Inside O Outside O Both

36. Do you use a motorized scooter or wheelchair?............ O No O Yes

36a. ***If yes, do you use the scooter or wheelchair***............ O Inside O Outside O Both

Comments:

3985043215

CANDRIVE COMMON COHORT ANNUAL

SITE # - PT ID

Date: dd / mm / 2 0 yyyy

Visit : O Year 1 (Baseline) O Year 2 O Year 3 O Year 4 O Year 5

General Health

26. Have you seen your family physician in the past four months? O No O Yes

26a. ***If yes, how many times?*** O 1-2 O 3-4 O 5 or more

26b. ***If yes, please indicate the reason(s): (fill in all that apply)***

O Prescription renewal
O Blood pressure check
O Annual check-up
O Referral to a specialist
O Health concern: ______
O Blood work
O Counselling
O Other: ______

Complete questions #27 and #27a only at Annual visit in years 2-5.

27. As part of our protocol, we are screening for medical conditions that are known to affect driving. Have you experienced or been diagnosed with any of the following in the past four months?

Untreated obstructive sleep apnea or any other significant sleep disorder (eg. falling asleep at inappropriate times during the day)	O No	O Yes
Any seizure activity	O No	O Yes
Vision problems not corrected by lenses (e.g. macular degeneration)	O No	O Yes
Heart attack	O No	O Yes
Unstable cardiac condition (eg. angina chest pain, very fast or very slow pulse)	O No	O Yes
Stroke or transient ischemic attack (also called TIA or mini stroke)	O No	O Yes
2 or more episodes of low blood sugar (symptomatic)	O No	O Yes
Trouble with hallucinations	O No	O Yes
Any unexplained fainting spells or loss of consciousness	O No	O Yes
An episode of driving over the legal blood limit for alcohol or driven under the influence of illicit drugs/illegal drugs	O No	O Yes

27a. If 'yes' to any of the above "have you sought medical attention from your family physician or any other physician for all of these conditions?" O No O Yes

Comments:

______

______

______

SITE # - PT ID Date: dd / mm / 2 0 yyyy

candrive

Visit: O *Year 1 (Baseline)* O *Year 2* O *Year 3* O *Year 4* O *Year 5*

Physical Assessments

41.

42. **One Leg Stance:** ***Participant stands at right angle to fixed object with examiner on other side.***
Left foot ☐☐☐ seconds O cannot do *Right foot* ☐☐☐ seconds O cannot do

43. **Current height and weight:**
Participant removes shoes. ***Height:*** ☐☐☐.☐ O Cm O Inches ***Weight:*** ☐☐☐.☐ O Kgs O Pounds

Comments:

CANDRIVE COMMON COHORT ANNUAL

SITE # - PT ID   Date: dd / mm / 2 0 yyyy

Visit: O *Year 1 (Baseline)* O *Year 2* O *Year 3* O *Year 4* O *Year 5*

Physical Assessments

44. Marottoli Method: (tests both neck rotation and peripheral vision)
Participant stands with shoulders against the wall, turning head to one side to read the number.

Can read number on wall behind **left** shoulder O Pass test O Fail test

Can read number on wall behind **right** shoulder O Pass test O Fail test

45.

46. Rapid Pace Walk: ***Participant walks 10 feet, turns and comes back as quickly as possible.***

46a. Was cane used? O No O Yes **46b. Was walker used?** O No O Yes

[ ] seconds O cannot do because ____________

47. Sequential Finger-Thumb Opposition
Participant touches their finger to their thumb in sequence and back again. (four times as quickly as possible)

Dominant hand - O Left O Right

Left hand - Trials to do accurately: [ ] **Time:** [ ] seconds

O cannot do because ____________

Right hand - Trials to do accurately: [ ] **Time:** [ ] seconds

O cannot do because ____________

Comments:

____

SITE # - PT ID　　Date: __ / __ / 20__ (dd / mm / yyyy)

Candrive

Visit: O *Year 1 (Baseline)* O *Year 2* O *Year 3* O *Year 4* O *Year 5*

Physical Assessments

48. Rapid Foot Taps: ***Seated in a comfortable position, heel resting on floor, participant taps toes as big and fast as possible for 10 seconds.***

Left foot - ___ # of times O cannot do because: ____________________

Right foot - ___ # of times O cannot do because: ____________________

49.

50.

Comments:

☐☐-☐☐☐☐ Date: ☐☐/☐☐/20☐☐
SITE # PT ID dd mm yyyy

Visit: O Year 1 (Baseline) O Year 2 O Year 3 O Year 4 O Year 5

Physical Assessments

52. Timed Up and Go (TUG) Test:
From seated position, participant stands up, walks 10 feet, and returns to a seated position.

52a. Was cane used? O No O Yes **52b. Was walker used?** O No O Yes

O < 10 seconds (normal unlimited) ☐☐☐ seconds
O 10-20 seconds (limited outdoors)
O 21-30 seconds
O >30 seconds
O cannot do due to ______________________

53. Range of Motion (ROM)Testing:
Specify 'Within Normal Limits' or 'Not Normal'.
Record range of motion value only if not normal

Joint ROM	LEFT	RIGHT
Neck Rotation:	O normal O not normal: ☐☐☐	O normal O not normal: ☐☐☐
Finger curl:	O normal O not normal: ☐☐☐	O normal O not normal: ☐☐☐
Shoulder flexion:	O normal O not normal: ☐☐☐	O normal O not normal: ☐☐☐
Elbow flexion:	O normal O not normal: ☐☐☐	O normal O not normal: ☐☐☐
Ankle plantar flexion:	O normal O not normal: ☐☐☐	O normal O not normal: ☐☐☐
Ankle dorsiflexion:	O normal O not normal: ☐☐☐	O normal O not normal: ☐☐☐

Comments: ______________________

Berg Balance Scale

Description:
14-item scale designed to measure balance of the older adult in a clinical setting.

Equipment needed: Ruler, 2 standard chairs (one with arm rests, one without) Footstool or step, Stopwatch or wristwatch, 15 ft walkway

Completion:

Time: 15-20 minutes

Scoring: A five-point ordinal scale, ranging from 0-4. "0" indicates the lowest level of function and "4" the highest level of function. Total Score = 56

Interpretation: 41-56 = low fall risk
21-40 = medium fall risk
0 –20 = high fall risk

Criterion Validity:
"Authors support a cut off score of 45/56 for independent safe ambulation".

Riddle and Stratford, 1999, examined 45/56 cutoff validity and concluded:

- Sensitivity = 64% (Correctly predicts fallers)
- Specificity = 90% (Correctly predicts non-fallers)
- Riddle and Stratford encouraged a lower cut off score of 40/56 to assess fall risk

Comments: Potential ceiling effect with higher level patients. Scale does not include gait items

Minimal Detectable Change:
"A change of **4 points** is needed to be 95% confident that true change has occurred if a patient scores within 45-56 initially, **5 points** if they score within 35-44, **7 points** if they score within 25-34 and, finally, **5 points** if their initial score is within 0-24 on the Berg Balance Scale."

Donoghue D; Physiotherapy Research and Older People (PROP) group, Stokes EK. (2009). How much change is true change? The minimum detectable change of the Berg Balance Scale in elderly people. *J Rehabil Med.* 41(5):343-6.

Norms:
Lusardi, M.M. (2004). Functional Performance in **Community Living Older Adults**. *Journal of Geriatric Physical Therapy*, 26(3), 14-22.

Table 4. Berg Balance Scale Scores: Means, Standard Deviations, and Confidence Intervals by Age, Gender, and Use of Assistive Device

Age (y)	Group	N	Mean	SD	CI
60-69	Male	1	51.0	—	35.3 – 66.7
	Female	5	54.6	0.5	47.6 – 61.6
	Overall	6	54.0	1.5	52.4 – 55.6
70-79	Male	9	53.9	1.5	48.7 – 59.1
	Female	10	51.6	2.6	46.6 – 56.6
	Overall	19	52.7	2.4	51.5 – 53.8
80-89	Male	10	41.8	12.2	36.8 – 46.8
	Female	24	42.1	8.0	38.9 – 45.3
	No Device	24	46.3	4.2	44.1 - 48.5
	Device	10	31.7	10.0	28.3 – 35.1
	Overall	34	42.0	9.2	38.8 – 45.3
90-101	Male	2	40.0	1.4	28.9 – 51.1
	Female	15	36.9	9.7	32.8 – 40.9
	No Device	7	45	4.2	40.9 – 49.1
	Device	10	31.8	7.6	28.4 – 35.2
	Overall	17	37.2	9.1	32.5 – 41.9

Berg Balance Scale

Name: ______________________ Date: ______________

Location: ______________________ Rater: ______________

ITEM DESCRIPTION	SCORE (0-4)
Sitting to standing	_____
Standing unsupported	_____
Sitting unsupported	_____
Standing to sitting	_____
Transfers	_____
Standing with eyes closed	_____
Standing with feet together	_____
Reaching forward with outstretched arm	_____
Retrieving object from floor	_____
Turning to look behind	_____
Turning 360 degrees	_____
Placing alternate foot on stool	_____
Standing with one foot in front	_____
Standing on one foot	_____

Total _____

GENERAL INSTRUCTIONS
Please document each task and/or give instructions as written. When scoring, please record the lowest response category that applies for each item.

In most items, the subject is asked to maintain a given position for a specific time. Progressively more points are deducted if:

- the time or distance requirements are not met
- the subject's performance warrants supervision
- the subject touches an external support or receives assistance from the examiner

Subject should understand that they must maintain their balance while attempting the tasks. The choices of which leg to stand on or how far to reach are left to the subject. Poor judgment will adversely influence the performance and the scoring.

Equipment required for testing is a stopwatch or watch with a second hand, and a ruler or other indicator of 2, 5, and 10 inches. Chairs used during testing should be a reasonable height. Either a step or a stool of average step height may be used for item # 12.

Berg Balance Scale

SITTING TO STANDING
INSTRUCTIONS: Please stand up. Try not to use your hand for support.
( ) 4 able to stand without using hands and stabilize independently
( ) 3 able to stand independently using hands
( ) 2 able to stand using hands after several tries
( ) 1 needs minimal aid to stand or stabilize
( ) 0 needs moderate or maximal assist to stand

STANDING UNSUPPORTED
INSTRUCTIONS: Please stand for two minutes without holding on.
( ) 4 able to stand safely for 2 minutes
( ) 3 able to stand 2 minutes with supervision
( ) 2 able to stand 30 seconds unsupported
( ) 1 needs several tries to stand 30 seconds unsupported
( ) 0 unable to stand 30 seconds unsupported

If a subject is able to stand 2 minutes unsupported, score full points for sitting unsupported. Proceed to item #4.

SITTING WITH BACK UNSUPPORTED BUT FEET SUPPORTED ON FLOOR OR ON A STOOL
* INSTRUCTIONS: Please sit with arms folded for 2 minutes.
( ) 4 able to sit safely and securely for 2 minutes
( ) 3 able to sit 2 minutes under supervision
( ) 2 able to able to sit 30 seconds
( ) 1 able to sit 10 seconds
( ) 0 unable to sit without support 10 seconds

STANDING TO SITTING
INSTRUCTIONS: Please sit down.
( ) 4 sits safely with minimal use of hands
( ) 3 controls descent by using hands
( ) 2 uses back of legs against chair to control descent
( ) 1 sits independently but has uncontrolled descent
( ) 0 needs assist to sit

TRANSFERS
INSTRUCTIONS: Arrange chair(s) for pivot transfer. Ask subject to transfer one way toward a seat with armrests and one way toward a seat without armrests. You may use two chairs (one with and one without armrests) or a bed and a chair.
( ) 4 able to transfer safely with minor use of hands
( ) 3 able to transfer safely definite need of hands
( ) 2 able to transfer with verbal cuing and/or supervision
( ) 1 needs one person to assist
( ) 0 needs two people to assist or supervise to be safe

STANDING UNSUPPORTED WITH EYES CLOSED
INSTRUCTIONS: Please close your eyes and stand still for 10 seconds.
( ) 4 able to stand 10 seconds safely
( ) 3 able to stand 10 seconds with supervision
( ) 2 able to stand 3 seconds
( ) 1 unable to keep eyes closed 3 seconds but stays safely
( ) 0 needs help to keep from falling

STANDING UNSUPPORTED WITH FEET TOGETHER
INSTRUCTIONS: Place your feet together and stand without holding on.
( ) 4 able to place feet together independently and stand 1 minute safely
( ) 3 able to place feet together independently and stand 1 minute with supervision
( ) 2 able to place feet together independently but unable to hold for 30 seconds
( ) 1 needs help to attain position but able to stand 15 seconds feet together
( ) 0 needs help to attain position and unable to hold for 15 seconds

Berg Balance Scale continued.....

REACHING FORWARD WITH OUTSTRETCHED ARM WHILE STANDING
INSTRUCTIONS: Lift arm to 90 degrees. Stretch out your fingers and reach forward as far as you can. (Examiner places a ruler at the end of fingertips when arm is at 90 degrees. Fingers should not touch the ruler while reaching forward. The recorded measure is the distance forward that the fingers reach while the subject is in the most forward lean position. When possible, ask subject to use both arms when reaching to avoid rotation of the trunk.)

( ) 4 can reach forward confidently 25 cm (10 inches)
( ) 3 can reach forward 12 cm (5 inches)
( ) 2 can reach forward 5 cm (2 inches)
( ) 1 reaches forward but needs supervision
( ) 0 loses balance while trying/requires external support

PICK UP OBJECT FROM THE FLOOR FROM A STANDING POSITION
INSTRUCTIONS: Pick up the shoe/slipper, which is place in front of your feet.

( ) 4 able to pick up slipper safely and easily
( ) 3 able to pick up slipper but needs supervision
( ) 2 unable to pick up but reaches 2-5 cm(1-2 inches) from slipper and keeps balance independently
( ) 1 unable to pick up and needs supervision while trying
( ) 0 unable to try/needs assist to keep from losing balance or falling

TURNING TO LOOK BEHIND OVER LEFT AND RIGHT SHOULDERS WHILE STANDING
INSTRUCTIONS: Turn to look directly behind you over toward the left shoulder. Repeat to the right. Examiner may pick an object to look at directly behind the subject to encourage a better twist turn.

( ) 4 looks behind from both sides and weight shifts well
( ) 3 looks behind one side only other side shows less weight shift
( ) 2 turns sideways only but maintains balance
( ) 1 needs supervision when turning
( ) 0 needs assist to keep from losing balance or falling

TURN 360 DEGREES
INSTRUCTIONS: Turn completely around in a full circle. Pause. Then turn a full circle in the other direction.

( ) 4 able to turn 360 degrees safely in 4 seconds or less
( ) 3 able to turn 360 degrees safely one side only 4 seconds or less
( ) 2 able to turn 360 degrees safely but slowly
( ) 1 needs close supervision or verbal cuing
( ) 0 needs assistance while turning

PLACE ALTERNATE FOOT ON STEP OR STOOL WHILE STANDING UNSUPPORTED
INSTRUCTIONS: Place each foot alternately on the step/stool. Continue until each foot has touch the step/stool four times.

( ) 4 able to stand independently and safely and complete 8 steps in 20 seconds
( ) 3 able to stand independently and complete 8 steps in > 20 seconds
( ) 2 able to complete 4 steps without aid with supervision
( ) 1 able to complete > 2 steps needs minimal assist
( ) 0 needs assistance to keep from falling/unable to try

STANDING UNSUPPORTED ONE FOOT IN FRONT
INSTRUCTIONS: (DEMONSTRATE TO SUBJECT) Place one foot directly in front of the other. If you feel that you cannot place your foot directly in front, try to step far enough ahead that the heel of your forward foot is ahead of the toes of the other foot. (To score 3 points, the length of the step should exceed the length of the other foot and the width of the stance should approximate the subject's normal stride width.)

( ) 4 able to place foot tandem independently and hold 30 seconds
( ) 3 able to place foot ahead independently and hold 30 seconds
( ) 2 able to take small step independently and hold 30 seconds
( ) 1 needs help to step but can hold 15 seconds
( ) 0 loses balance while stepping or standing

STANDING ON ONE LEG
INSTRUCTIONS: Stand on one leg as long as you can without holding on.

( ) 4 able to lift leg independently and hold > 10 seconds
( ) 3 able to lift leg independently and hold 5-10 seconds
( ) 2 able to lift leg independently and hold ≥ 3 seconds
( ) 1 tries to lift leg unable to hold 3 seconds but remains standing independently.
( ) 0 unable to try of needs assist to prevent fall

( ) TOTAL SCORE (Maximum = 56)

APPENDIX D – STRATEGIES TRACKING FORM

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1			Vibe											
2			Ingress Strategy							Egress Strategy				
3			One-Foot			Two-Foot		Hands Contact		One-Foot		Two-Foot	Hands Contact	
4	Particpant ID	Trial #	Lateral sliding	Backward motion	Forward Motion	Trunk Forward	Trunk Backward	Left	Right	Head Forward	Parallel to Vehicle	Two feet egress	Left	Right
5	P01	1	1						SW	1				WF
6		2	1						SW	1				WF
7		3	1						SW	1				WF
8		4	1						SW	1				WF
9		5	1						SW	1				WF
10	P02	1	1					AR		1			CS	
11		2	1					AR		1			CS	
12		3	1					AR		1			CS	
13		4	1					AR		1				
14		5	1					AR		1				
15	P03	1	1					AR	SW	1				AR
16		2	1						SW			1		
17		3	1						SW			1		
18		4	1						SW	1				AR
19		5	1						SW	1			AR	SW
20	P04	1	1					AR	CS	1				AR
21		2	1					AR	CS	1				AR
22		3	1					AR	CS	1				AR
23		4	1					AR	CS	1				AR
24		5	1					AR	CS	1				AR
25	P05	1	1					AR	SW	1				AR
26		2	1					AR	SW			1		AR
27		3	1					AR	SW			1		AR
28		4	1					AR	SW	1				AR
29		5	1					AR	SW			1		AR
30	P06	1	1						SW	1				AR
31		2	1						SW	1				SW
32		3	1						SW	1				SW
33		4	1						SW	1				SW
34		5	1						SW	1				SW
35	P07	1	1									1		SW
36		2	1									1		SW
37		3	1									1		SW
38		4	1									1		SW
39		5	1									1		SW
40	P08	1	1					AR	SW			1		
41		2	1					AR	SW	1				AR
42		3	1					AR	SW	1				AR
43		4	1					AR	SW	1			AR	AR

APPENDIX E – DEMOGRAPHIC DATA FORM

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Participant ID	Age	BMI	Gender (M=0, F=1)	Driving Frequency	Mobility Aids (No = 0, Yes = 1)	History of Falls (No = 0, Yes = 1)	BBS(noraml ≥ 41)	TUG(normal: < 13.5 s)	OLS (left leg)(normal: ≥5 s)	OLS (right leg)(normal: ≥5 s)	RPW(normal ≤7.5 s)	
2	1	70	24.3	0	4-6 Times per week	0	1	53	9.1	**3.3**	10.7	7.5	
3	2	72	27.3	1	4-6 Times per week	0	0	56	7.39	32	30	6.9	
4	3	83	30.3	1	4-6 Times per week	0	1	52	12.7	**2.5**	**3**	**9**	
5	4	71	27.9	1	4-6 Times per week	0	0	56	8.1	7.3	**4.6**	6.3	
6	5	77	26.8	1	4-6 Times per week	0	0	51	11.24	**4**	13	**9.16**	
7	6	71	31.1	0	Daily	0	1	**43**	9	6	**2**	**8**	
8	7	76	33.3	0	4-6 Times per week	0	0	49	8	**0**	**0**	7	
9	8	80	26	0	4-6 Times per week	0	0	**42**	12	**2**	**3**	**8**	
10	9	57	25.8	1	4-6 Times per week	1	0	53	**14.2**	36.1	23.2	**7.7**	
11	10	60	33.7	0	Daily	0	1	51	9.11	**1.95**	**1.9**	5.74	
12	11	80	26.2	0	Daily	0	0	53	8	19	19	6	
13	12	81	27.4	1	2-3 times per week	0	0	54	10.16	**2.98**	11.4	**10.28**	
14	13	66	22.1	0	2-3 times per week	0	0	56	9.1	90	90	4.8	
15	14	79	23.9	1	4-6 Times per week	0	1	55	9.7	30	30	6.92	
16	15	65	35.3	1	4-6 Times per week	0	0	55	10	15	55	5	
17	16	64	52.4	1	Daily	1	1	**39**	11	**0**	**1**	**8**	
18	17	67	36	0	Less than once per week	1	0	47	**16**	**2**	**3**	**11**	
19	18	80	25.9	1	4-6 Times per week	1	0	**32**	**17**	**0**	**0**	**15**	
20	19	71	31.4	0	4-6 Times per week	0	0	55	10	30	18	7	
21	20	65	27.3	1	Daily	0	1	50	12	30	17	6	
22	21	69	56	1	Daily	0	0	**42**	13	**0**	**1**	6	
23	22	68	28.2	1	Daily	0	1	56	11	30	30	6	
24	23	74	19.9	0	4-6 Times per week	0	1	47	12	**2**	**2**	**8**	
25	24	64	28.9	0	Daily	0	0	53	8	27	30	4	
26	25	71	37.9	1	4-6 Times per week	0	0	49	8	6	**3**	6	
27	26	77	25.9	1	Daily	0	0	53	9	30	30	**8**	
28	27	77	26.3	1	Daily	0	1	49	12	**4**	**3**	**9**	
29	28	68	36.2	1	Daily	1	0	52	13	30	30	**8**	
30	29	71	30.4	0	Daily	1	0	51	9	7	5	**9**	
31	30	66	35.8	1	Daily	0	0	49	9	17	**2**	7	
32	31	87	31.4	0	Daily	0	1	**41**	13	**0**	**3**	**8**	
33	32	72	37.4	1	Daily	0	0	56	10	5	11	7	
34							**Sample average**	50.00	10.65	14.75	15.18	7.54	
35							**Male average**	49.31	10.18	14.63	14.43	7.23	
36							Std Deviation	4.97	2.40	24.86	24.42	1.83	
37							**Female average**	50.47	10.97	14.84	15.69	7.75	
38							Std Deviation	6.43	2.38	13.58	15.18	2.22	