STEP NEGOTIATION BIOMECHANICS DURING TRUCK CAB EGRESS AND THE EFFECTS OF ANTHROPOMETRICS AND CAB DESIGN ON DRIVER FALL BIOMECHANICS ETIOLOGY

by

Rami M. Shorti

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STATEMENT OF DISSERTATION APPROVAL

The dissertation of **Rami M. Shorti**

has been approved by the following supervisory committee members:

Andrew S. Merryweather	, Chair	**04 January 2016** Date Approved
Donald S. Bloswick	, Member	**04 January 2016** Date Approved
Matthew Reed	, Member	**04 January 2016** Date Approved
Stacy Morris Bamberg	, Member	**04 January 2016** Date Approved
K. Kenneth Foreman	, Member	**04 January 2016** Date Approved

and by **Timothy A. Ameel** , Chair/Dean of

the Department/College/School of **Mechanical Engineering**

and by David B. Kieda, Dean of The Graduate School.

ABSTRACT

Slips and falls during egress from heavy truck cabs are a major contributor to injury and disability for truck drivers. A large-scale laboratory study was conducted to quantify the dynamics of ingress/egress (IE) for Class 7 and 8 commercial truck cabs. A simulated truck cab was constructed in a laboratory allowing manipulation of many geometric variables affecting ingress and egress. Experienced commercial truck drivers were recruited to participate. Subjective responses and anthropometric information for all participants were obtained along with detailed biomechanical data, including whole-body kinematics and reaction forces on the ground, steps, and handholds.

This study involves three-dimensional reconstruction of truck driver egress motions, detailed analysis of spatiotemporal parameters and driver behaviors (i.e., IE tactics), as well as a description of access system egress cycles and methods of analyses. In addition, the influence of cab design and driver anthropometric and behavioral factors on biomechanical parameters are investigated. This research also provides a detailed quantitative description of the driver interaction with the cab elements (steps and handholds) and presents valuable insight into the dynamics of cab egress that will allow for a more accurate definition of etiological risk factors for slipping during truck cab egress.

In summary, driver biomechanics largely depends on their interaction with the cab, tactics, foot behaviors, and the quality of contact with the steps. In general, during egress, study participants used the right handhold most frequently, followed by the door handle

and then the steering wheel. Findings from this research also indicated that a portion of drivers performed egress facing away from the cab and given the prevalence of high body mass index (BMI) among this population, handhold and step location and design should incorporate the base of support (BoS) and stability metric calculations to allow such population for proper "footing" and allow for their center of mass (CoM) to be as close to the truck as possible in the event the drivers utilized the facing away egress tactic. Finally, BMI is a factor that has been associated as an indicator of increased level of risk. Therefore, driver training should include opportunities to get the drivers' weight lowered and fitness level increased. Additionally, drivers may also benefit from stability and strength training as stair stepping is physically more demanding and requires more stability when compared to walking.

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NOMENCLATURE

FC: Facing the Cab, facing towards the cab

FO: Facing Outward, facing away from the cab

LFF: Left Foot First, the left foot is used to lead the egress motion

RFF: Right Foot First, the right foot is used to lead the egress motion

E1: First Egress Transition Phase

E2: Second Egress Transition Phase

E3: Third Egress Transition Phase

PoC: Points of Contact during Egress.

SS: Single Limb Support. Single stance.

DS Double Limb Support. Double stance.

1PoCF: Single Point of Contact at feet. Single stance limb support

2PoCF: Double Point of Contact at feet. Double stance limb support

0PoCH: No points of contact at hands. No hands used during egress motion

1PoCH: One point of contact at hands. One hand used during egress motion

2PoCH: Two points of contact at hands. Two hands used during egress motion

UMTRI: University of Michigan Transportation Research Institute

IE: Ingress/Egress

SoS: Step-Over-Step

SbS: Step-By-Step

SbSoS: Step-By-Step-Over-Step

SoSbS: Step-Over-Step-By-Step

ISO: International Organization for Standardization

SAE: Society of Automotive Engineers

DHM: Digital Human Model

DOF: Degrees of Freedom

RCoF: Required Coefficient of Friction

LR: Loading Rate

RF: Reaction Forces

GRF: Ground Reaction Forces

vRF: Vertical Reaction Forces

vGRF: Vertical Ground Reaction Forces

CoM: Center of Mass

CoMP: Center of Mass Position

CoMV: Center of Mass Velocity

CoMA: Center of Mass Acceleration

FCL: Foot Placement Clearance

FRA: Foot Rotation Angle Relative to Step

BoS: Base of Support Area

BoSAS: Base of Support Area on Step

COE: Cab-Over Engine

FMCSA: Federal Motor Carrier Safety Administration

RP: Recommended Practice

TMC: Technology and Maintenance Council

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Two datasets were used in this research dissertation. A cross-sectional study (*N*= 794) dataset from a collaborative effort between the University of Utah's Department of Family and Preventive Medicine and Mechanical Engineering Department, and the University of Wisconsin-Milwaukee, Occupational Science and Technology department. This work was supported by grants through the Centers for Disease Control and Prevention/National Institute for Occupational Safety and Health (1R01OH009155-01). The second dataset in this research effort from a large 4-year (2007-2012) experimental study (*N*=60) was conducted by the University of Michigan Transportation Research Institute (UMTRI). The study was funded with support from the U.S. National Institute for Occupational Safety and Health (R01 OH009153) and contributions from the truck industry.

CHAPTER 1

INTRODUCTION

Statement of the Problem

Falls are the second most common cause of workplace fatalities, and have been steadily increasing since 1992 (BLS, 2014). In addition, falls continue to be one of the leading causes of nonfatal, serious workplace injuries (Jones & Switzer-McIntyre, 2003). It has been reported that of the 16% of all compensable injuries for firefighters related to emergency vehicles, 37% involved stepping down from the vehicle (Giguère & Marchand, 2005). Similar data are present in the agricultural sector, which reports a large proportion of injuries associated with mounting and dismounting tractors (Day & Rechnitzer, 2004; Lee et al., 1996). Furthermore, falls while mounting and dismounting trucks account for nearly 25% of all injuries in the commercial trucking industry (Jones & Switzer-McIntyre, 2003).

Truck drivers are vulnerable to falls while mounting and dismounting vehicle cabs and these falls may result in serious injuries (Lin & Cohen, 1997). Heavy and tractor-trailer truck drivers, also referred to as commercial truck drivers including short- and long-haul drivers, constitute 1.6 million of US workers (BLS, 2014). According to the Bureau of Labor Statistics (BLS) 2014 data, incidence rates of falls, slips, or trips are highest among heavy truck drivers (BLS, 2014). Falls to a lower level, falls on the same level, and slips or trips without falls combined to account for 35% of the injuries and illnesses to heavy and tractor-trailer truck drivers in 2014 (BLS, 2014). Falls among truck drivers, particularly during cab egress, have been recognized as the leading cause of injuries as a result of slips and falls that could lead to fatalities (BLS, 2014; Jones & Switzer-McIntyre, 2003; Lin & Cohen, 1997; Williams & Goins, 1981).

According to the BLS, truck drivers experienced 41,840 injuries and illnesses in 2013, resulting in a median of 19 lost workdays (BLS, 2014), the highest among all reported occupations (BLS, 2014). More than a third of the cases (40%) resulted in a median of 29 days away from work, implying high severity (BLS, 2014). A slip, trip, or fall was the second leading injury event among truck drivers, accounting for 30% of the cases and only preceded by overexertion and bodily reaction at 36% (BLS, 2014). Furthermore, Helmkamp et al. (2013) conducted a Survey of Occupational Injuries and Illnesses (SOII) that utilized data from two independent sources—the National Health Interview Survey (NHIS) and the Bureau of Labor Statistics (BLS). Helmkamp et al. reported that in the trucking, warehouse, and utilities (TWU) sector, overexertion (28%), contact with objects (21%), and falls (21%) are the most common events contributing to higher injury rates (Helmkamp et al., 2013).

The cost of injuries from slips, trips, and falls in the transportation industry is high. A 3-year study of commercial truck drivers, conducted by Reed et al. over one large US fleet, reported direct costs due to slips and falls on and around trucks annually exceeded $20M (US) (Reed, 2010c). Reed (2010c) also noted that 50% of those falls occurred while dismounting the vehicle. In several related industries, data suggest that mounting/dismounting large vehicles may be hazardous (Day & Rechnitzer, 2004; Giguère

& Marchand, 2005; Lee et al., 1996). In one Canadian study analyzing injuries in the trucking industry that were sustained from falls from stationary vehicles, it was found that the mean cost per injured worker was just under $15,000 per individual with 4.5% of workers still off work or on modified duty 1 year after the injury (Jones & Switzer-McIntyre, 2003).

These data demonstrate a large incidence and cost associated with injuries from slips and falls among vehicle operators in the trucking industry. The literature also indicates that slips leading to falls are a major cause of driver injury, particularly during cab egress. Therefore, these findings suggest the need for systematic interventions to control the risks of work-related slip, trip, or fall injuries in the trucking industry. A review of existing fall risk factors follows.

Summary of Fall Risk Factors

Several important factors influence trips and/or falls and include driver fatigue, environmental factors, cab layout step and handhold configurations, driver ingress/egress (IE) techniques, movement coordination, and driver personal factors such as body mass index (BMI) and physique (Reed, 2010c).

Truck driver behavior during truck cab egress is an important factor for safe cab egress and injury etiology and has been studied by a few researchers. Spielholz et al. (2008) conducted a self-reported survey of perceived injury risks among trucking companies in Washington state and found that worker behavior frequently contributes to musculoskeletal and slip, trip, fall injuries. Other studies have investigated the trajectories of the feet during ingress motions of the truck cab (Reed, Hoffman, & Ebert-Hamilton, 2010c), the influence of truck egress tactics on ground reaction forces (Reed, Hoffman, & Ebert-Hamilton, 2010b), and the hand positions and forces during truck ingress (Reed, Hoffman, & Ebert-Hamilton, 2010a). Furthermore, digital human models (DHMs) have been applied to investigate cab driver ingress motions to validate the dynamic motion reconstruction method as a discomfort evaluation tool for truck cab access (Monnier, Chateauroux, Wang, & Roybin, 2009).

Currently in the trucking industry, truck drivers are trained to maintain three points of contact during ingress and egress of the truck cab. Furthermore, egress while facing toward the cab is also recommended to enable the driver to maintain three points of contact and to reduce the consequences of a slip. This tactic is believed to reduce the probability of loss of balance and the possibility of falling. Several studies concluded that greater forces are sustained when drivers perform egress using the facing outward (FO) tactic (Fathallah & Cotnam, 2000; Giguère & Marchand, 2005; Patenaude, Marchand, Samperi, & Belanger, 2001; Reed et al., 2010b). Additionally, several studies have reported observing truck drivers ignoring these occupational health and safety recommendations, and instead, employing alternative egress techniques (Fathallah & Cotnam, 2000).

Speed is one motivating factor for truck drivers to adopt alternative egress tactics, e.g., facing outward, and some truck drivers may jump, skipping one or two steps, while using handles only to direct the jump (Patenaude et al., 2001). Patenaude et al. (2001) reported increased compressive forces exerted on the back for outward-facing egress when compared to inward facing. The effects of different tactics, facing outward vs facing the cab, were not differentiated from the effects of speed in their work. The previous research suggests that truck drivers may adopt ingress/egress tactics that compensate for truck cab design inadequacies, suggesting further research is needed to identify the optimal design to facilitate safe egress. Moreover, the influence of cab configuration on driver tactic selection has not been reported. It is possible that a truck cab could provide good affordance for low-risk egress but have other features that encourage drivers to adopt more risky tactics.

Currently, two major standards are referenced in the design of ingress and egress systems for commercial trucks. ISO 2867:2006 "specifies criteria for access systems (steps, ladders, walkways, platforms, grab rails/handrails, grab handles, guardrails and enclosure entrance and exit openings) as they relate to aiding the operator, maintenance personnel and service personnel in performing their functions on earth-moving machinery" (ISO, 2006). SAE J185:200305 provides "minimum criteria for steps, stairways, ladders, walkways, platforms, handrails, handholds, guardrails, and entrance openings which permit ingress to and egress from operator, inspection, maintenance or service platforms on off-road work machines parked in accordance with the manufacturer's instructions" (SAE, 2003). Although these ISO and SAE requirements for fixed ladders and fixed stairs are not specifically applicable to on-road trucks, they are widely used because no standard specific to heavy trucks is available from ISO or SAE. In addition to these standards, the Federal Motor Carrier Safety Administration, FMCSA Part 399, Subpart L (FMCSA, 2007), and the Technology and Maintenance Council (TMC) of the American Trucking Associations, TMC RP-404B (TMC, 1989), have promulgated recommended step lengths, widths, and spacing for cab-over engine (COE) highway and heavy truck tractors. Many heavy truck manufacturers reference the FMCSA standard and the TMC RP-404B practice for their heavy truck configurations as well.

Patenaude et al. (2001) report that, based on the results from interviews, truck driver participants (*N*=10) appear to be satisfied with the layout of the cab. On the other hand, half of the study participants reported their inability to see where they placed their feet during truck cab dismount, indicating a failure to meet user needs for safe egress in cab step layout/design. The risk of fall presented from foot placement uncertainty may be further amplified with the presence of contaminants on the steps, such as oil, ice, or mud. In one study composed of two separate industry-wide surveys of 359 trucking companies and 397 commercial truck drivers, nearly a quarter of drivers identified slippery conditions as an environmental factor that led or nearly led to falls (Spielholz et al., 2008). Importantly, 75% of the truckers stated that they use the steering wheel as support during the descent, suggesting that the steering wheel must be considered as part of the IE system (Patenaude et al., 2001). Similar findings that environmental factors such as rain, snow, and heat have been reported (Shorti et al., 2014).

The large range of egress tactics exhibited by truck drivers may be due in part to differences in truck design as well as personal factors such as BMI (Reed et al., 2010b). Interestingly, Reed et al. (2010b) reported that drivers with higher BMI were more likely to dismount facing the cab, a lower-stress tactic, providing some evidence of risk compensation. In a recent study conducted by Turner and Reed (2011), a high prevalence of obesity was found in a sample of 300 commercial truck drivers, with 93.3% of study participants having a body mass index (BMI) of 25 or higher (Turner & Reed, 2011). These findings are consistent with two large studies of truck drivers. One is a cross-sectional study of U.S. truck drivers (*N*=797, 685 males and 112 females) reporting that most drivers were considered obese having a mean BMI of 33.2 kg/m2 (*SD*=5.5) (Shorti et al., 2014).

The other study is an anthropometric study of U.S. truck drivers (*N*=1,950, 1,779 males and 171 females) who reported a mean stature (mm) of 1,757 (*SD*=69.11) and mean weight (kg) of 102.8 (*SD*=23.83) (Guan et al., 2012). Interestingly, this study reports that, compared to truck drivers' weight and physique 25 to 30 years ago, current truck drivers are heavier and different in physique (Guan et al., 2012).

Some previous ergonomic and biomechanical research on truck cab egress has focused on the landing forces on lower limbs (Fathallah & Cotnam, 2000; Giguère & Marchand, 2005; Patenaude et al., 2001). Results from Patenaude et al. (2001) show that truck drivers' weight influences the ground impact force during the descent from the cab. Other research has focused on the initiation of the egress motion to better understand the way handles are used. These studies indicated a need for assessing the effect of individual personal factors, i.e., anthropometry and BMI, and architectural parameters, i.e., the cab step and handhold design parameters, on egress strategies (Chateauroux, Wang, & Roybin, 2012).

Dissertation Outline, Intent, and Rationale

In spite of the previous research in this area, little is known about the specific effects of cab configuration on truck driver interaction with the cab elements and the role that driver personal factors, such as BMI, play in modifying these effects. What has been published only discusses overall kinetic parameters, such as reaction forces (Fathallah & Cotnam, 2000; Giguère & Marchand, 2005; Patenaude et al., 2001; Telonio et al., 2014), or reports of the application of DHM software to cab ergonomics including assessments of visibility and driver accommodations (Foster, De Asha, Reeves, Maganaris, & Buckley, 2014), and comfort evaluations (Monnier et al., 2009). Furthermore, sample sizes for biomechanical studies have generally been small, typically around 10 participants, limiting the ability to assess interindividual differences.

The current research examines the effects of truck cab IE elements, including handholds and steps, truck driver personal factors, egress tactics, and anthropometry, on temporal and biomechanical (kinetic and kinematic) parameters during truck driver egress. This effort includes a systematic evaluation of truck driver egress motions and behaviors in order to develop a more accurate definition and interpretation of risk factors for slipping and loss of contact, which may lead to falls.

The main hypotheses behind the proposed research are that (1) truck cab configuration, driver anthropometry, and egress tactics affect driver behavior, and (2) understanding the foot interaction with the step will improve prediction of slips that may lead to falls.

This dissertation includes research based on data from two studies. The first study, included as Chapter 2, resulted in a publication in a special issue of the Journal of Ergonomics on driver safety. The article entitled "Fall Risk Factors for Commercial Truck Drivers" identified risk factors associated with falls and near falls among a population of commercial truck drivers through a large cross-sectional study of 794 commercial truck drivers. The analysis presented therein was the result of a collaborative effort between the University of Utah's Department of Family and Preventive Medicine and Mechanical Engineering Department, and the University of Wisconsin-Milwaukee, Occupational Science and Technology department. This work was supported by grants through the Centers for Disease Control and Prevention/National Institute for Occupational Safety and

Health (1R01OH009155-01). This chapter provides an understanding of the relationship between commercial truck operators' health and physical behavior during IE, as well as valuable information related to identifying risk factors associated with falls.

Chapters 3-5 present results from analysis of a data from large-scale laboratory study of ingress and egress motions conducted at the University of Michigan Transportation Research Institute (UMTRI). That study was funded with support from the US National Institute for Occupational Safety and Health (R01 OH009153) and contributions from the trucking industry. A simulated truck cab was constructed in the lab and allowed for manipulation of many geometric variables that affect ingress and egress. Subjective responses and anthropometric information for 60 experienced truck drivers were obtained along with detailed three-dimensional data, including motion markers and reaction forces on the ground, steps, and handholds.

Chapter 3 provides a detailed description of truck driver behaviors during egress, including results of driver tactics, behavior patterns, contact with cab elements, and temporal parameters. Importantly, this chapter also defines the phases of cab egress that were used in analysis. Driver egress varies widely, but certain types of movements are typical. In evaluating truck cab access systems used during ingress and egress, it is very important to consider the truck driver behaviors employed during step negotiations. Accurate interpretation of biomechanical data, incorporating whole body motion and hand/foot forces and moments, requires knowledge of handhold use and the different stepping methods and patterns employed by drivers. Foot behaviors alter the mechanics of step interaction. Identifying the patterns of egress behaviors assists in understanding the effects of personal and cab design factors that may affect the potential for slips and/or falls.

In Chapter 3, the goal was to be able to identify common egress patterns and behaviors. In later chapters, Chapters 4 and 5, the goal was to discern whether differences from ‘‘common’’ egress biomechanical and behavioral factors are attributable solely to changes in the cab design, or whether additional compensations are at work due to personal factors, design, or both design and personal factors. Therefore, truck driver stair egress patterns were investigated prior to performing biomechanical data analysis. At present, there are no in-depth analyses of the gait patterns and observed biomechanics made during driver ingress and egress of truck cabins or related access systems.

Chapter 4 examines more closely the most commonly observed driver stepping pattern, step-over-step (SoS) foot pattern. In this chapter, the goal was to investigate and describe the variability in truck cab layout and its effects on drivers' points of contact (PoC) during egress. Another goal was to investigate the effect of driver egress tactics, when facing away from the cab vs. facing the cab, on a driver's points of contact (PoC). The specific aim of this chapter is based on the hypothesis that drivers use a wide variety of behaviors that include multiple different points of contact during egress and those behaviors are affected by elements of cab design and driver personal factors. Successful completion of this step of the research effort requires knowledge of handrail and step use during each instance of the egress phases. To date, no study in the literature provides an in-depth analysis of the driver-cab interaction, points of contact, durations, or descriptions of phases during cab egress.

In Chapter 5, further analyses were performed on the same dataset used in Chapter 4, SoS. The main objective of this chapter was to develop an understanding of the effect of driver tactics and cab configuration on driver-cab biomechanical parameters that may influence the probability of injury or slip or fall, and investigate how those tactics are associated with personal or vehicle characteristics. This chapter presents a detailed description of the foot interaction with the step, including details of relative foot kinematics, foot placement clearance, and foot base of support area profiles. These results provide a more complete definition of risk factors for slipping and loss of contact. Finally, the effects of egress tactic, cab layout, and drivers' personal factors, such as BMI will also be investigated in this chapter. Furthermore, work from this chapter adds to the literature an in-depth analysis of the driver-cab interaction variables during egress of the truck, such as required coefficient of friction, loading rate, foot placement clearance, foot rotation angle relative to step, and base of support area on steps.

The conclusions of this dissertation are presented in Chapter 6 along with a discussion of the findings from the entire dissertation research. Recommendations and practical information relating to slip potential are presented and may facilitate the development of improvements in truck cab design and other behavioral interventions.

Together, these chapters form a more complete and detailed analysis of driver egress than has previously been reported. This information contributes new knowledge in stair and access systems research. These data may further aid with identifying additional areas of focus for future studies and provide pilot work to develop additional guidelines for engineers to design safer truck cab IE systems.

References

Bureau of Labor Statistics. (2014). Transportation and material moving: Heavy and tractor-trailer truck drivers injuries, illnesses, and fatalities. Retrieved from: http://www.bls.gov/ooh/transportation-and-material-moving/heavy-and-tractor-trailer-truck-drivers.htm. doi: http://www.bls.gov/iif/oshcdnew.htm, News Release (2014).

Chateauroux, E., Wang, X., & Roybin, C. (2012). Analysis of truck cabin egress motion. International *Journal of Human Factors Modelling and Simulation*, *3*(2), 169-186. doi:10.1504/IJHFMS.2012.051095.

Day, L., & Rechnitzer, G. (2004). Safe tractor access platforms: From guidance material to implementation. *Journal of Agricultural Safety and Health*, *10*(3), 197-209.

Fathallah, F. A., & Cotnam, J. P. (2000). Maximum forces sustained during various methods of exiting commercial tractors, trailers and trucks. *Applied Ergonomics, 31*(1), 25-33.

Federal Motor Carrier Safety Administration. (2007). Step, Handhold, and Deck Requirements for Commercial Vehicles. 49 CFR 399 Subpart L.

Foster, R. J., De Asha, A. R., Reeves, N. D., Maganaris, C. N., & Buckley, J. G. (2014). Stair-specific algorithms for identification of touch-down and foot-off when descending or ascending a non-instrumented staircase. *Gait & Posture*, *39*(2), 816-821. doi: 10.1016/j.gaitpost.2013.11.005.

Giguère, D., & Marchand, D. (2005). Perceived safety and biomechanical stress to the lower limbs when stepping down from fire fighting vehicles. *Applied Ergonomics*, *36*(1), 107-119.

Guan, J., Hsiao, H., Bradtmiller, B., Kau, T.-Y., Reed, M. R., Jahns, S. K., . . . Piamonte, D. P. T. (2012). US truck driver anthropometric study and multivariate anthropometric models for cab designs. *Human Factors: The Journal of the Human Factors and Ergonomics Society*. doi:10.1177/0018720812442685.

Helmkamp, J. C., Lincoln, J. E., Sestito, J., Wood, E., Birdsey, J., & Kiefer, M. (2013). Risk factors, health behaviors, and injury among adults employed in the transportation, warehousing, and utilities super sector. *American Journal of Industrial Medicine*, *56*(5), 556-568. doi: 10.1002/ajim.22148.

International Organization for Standardization. (2006). ISO 2867:2006: Earth-moving machinery -- access systems.

Jones, D., & Switzer-McIntyre, S. (2003). Falls from trucks: A descriptive study based on a workers compensation database. *Work*, *20*(3), 179-184.

Lee, T. Y., Gerberich, S. G., Gibson, R. W., Carr, W. P., Shutske, J., & Renier, C. M. (1996). A population-based study of tractor-related injuries: Regional Rural Injury Study-I (RRIS-I). *Journal of Occupational and Environmental Medicine*, *38*(8), 782-793.

Lin, L. J., & Cohen, H. H. (1997). Accidents in the trucking industry. *International Journal of Industrial Ergonomics*, *20*(4), 287-300. doi: http://dx.doi.org/10.1016/S0169-8141(96)00060-1

Monnier, G., Chateauroux, E., Wang, X., & Roybin, C. (2009). Inverse dynamic reconstruction of truck cabin ingress/egress motions. *SAE International Journal of Passenger Cars-Mechanical Systems, 2*(1), 1593-1599.

Patenaude, S., Marchand, D., Samperi, S., & Belanger, M. (2001). The effect of the descent technique and truck cabin layout on the landing impact forces. *Applied Ergonomics, 32*(6), 573-582.

Reed, M. P. (2010). Truck Ergonomics: Field and Laboratory Research. University of Michigan Transportation Research Institute (UMTRI) Truck Ergo Overview. Retrieved from: http://umtri.umich.edu/content/UMTRI_Truck_Ergo_Overview_2010_03.pdf

Reed, M. P., Ebert-Hamilton, S. M., & Hoffman, S. G. (2010a). Hand positions and forces during truck ingress. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 54, No. 15, pp. 1097-1100). SAGE Publications.

Reed, M. P., Hoffman, S. G., & Ebert-Hamilton, S. M. (2010b). The influence of heavy truck egress tactics on ground reaction force. *Research and Practice for Fall Injury Control in the Workplace,* pp. 192-195.

Reed, M. P., Ebert, S. M., & Hoffman, S. G. (2010c). Modeling foot trajectories for heavy truck ingress simulation. In *Proceedings of the Applied Human Factors and Ergonomics Conference,* Miami, FL.

Society of Automotive Engineers. (2003). SAE J185:200305: Access systems for off-road machines.

Shorti, R., Merryweather, A., Thiese, M., Kapellusch, J., Garg, A., & Hegmann, K. (2014). Fall risk factors for commercial truck drivers. *Journal of Ergonomics*, *9*(3), 1-9. doi: 10.4172/2165-7556.S3-009.

Spielholz, P., Cullen, J., Smith, C., Howard, N., Silverstein, B., & Bonauto, D. (2008). Assessment of perceived injury risks and priorities among truck drivers and trucking companies in Washington State. *Journal of Safety Research*, *39*(6), 569-576. doi: 10.1016/j.jsr.2008.09.005.

Telonio, A., Blanchet, S., Maganaris, C. N., Baltzopoulos, V., Villeneuve, S., & McFadyen, B. J. (2014). The division of visual attention affects the transition point from level walking to stair descent in healthy, active older adults. *Experimental Gerontology*, *50*, 26-33. doi: 10.1016/j.exger.2013.11.007.

The Maintenance Council. (1989). RP-404B: The maintenance council (TMC) recommended practice 404B – Truck and Truck Tractor Access Systems.

Turner, L. M., & Reed, D. B. (2011). Exercise among commercial truck drivers. *American Board for Occupational Health Nurses (ABOHN) Journal*, *59*(10), 429-436. doi: 10.3928/08910162-20110916-01.

Williams, A. F., & Goins, S. E. (1981). Fatal falls and jumps from motor vehicles. *American Journal of Public Health*, *71*(3), 275-279.

CHAPTER 2

RISK FACTORS FOR COMMERCIAL TRUCK DRIVERS

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Fall Risk Factors for Commercial Truck Drivers

Shorti RM[1], Merryweather AS[1], Thiese MS[2], Kapellusch J[3], Garg A[3] and Hegmann KT[2]

[1]*Department of Mechanical Engineering, The University of Utah, USA*
[2]*Department of Family and Preventive Medicine The University of Utah, USA*
[3]*Occupational Science and Technology The University of Wisconsin-Milwaukee, USA*

Abstract

Background: Fall related injuries are common in the commercial trucking industry. Falls from three specific locations constitute 83% of reported falls: the back of truck/trailer, cargo handling and truck cab. Nearly one quarter of all injuries in truck drivers resulting in days away from work occur from mounting and dismounting a vehicle.

Purpose: This study aims to identify risk factors associated with falls and near falls among a population of commercial truck drivers.

Methods: Data from a large cross sectional study of 797 commercial truck drivers were analyzed. Questions about health and behavior were correlated with self-reported data regarding falls from mounting and dismounting activities. Self-reported factors believed to have contributed to a fall are also analyzed.

Results: Falls were reported by many truck drivers in this large, cross sectional study. Two thirds of drivers experiencing falls in the 12-month period prior to enrollment indicated that an environmental factor, e.g., ice, snow, mud influenced their fall and the majority of the falls occurred around the cab. The average BMI in this study population was 33.2 kg/m^2 (SD=5.5), thus most drivers were obese. Self-reported health status and BMI were associated with higher odds of lifetime reported falls during both mounting and dismounting the cab. Other factors that were associated with falls included feeling mentally and physically exhausted.

Conclusions: This study's findings suggest that truck, environmental conditions and personal factors are all significantly associated with reported falls during mounting and dismounting.

Keywords: Truck driver falls; Fall risk factors; BMI; Cross-sectional survey

Introduction

Heavy and tractor-trailer truck drivers, also referred to as commercial truck drivers including short and long haul, constitute 1.6 million US workers [1]. Truck drivers experience falls while mounting and dismounting vehicle cabs that may result in serious injuries. According to the US Bureau of Labor Statistic (BLS), truck drivers experienced 41,840 injuries and illnesses in 2013 that resulted in lost workdays [1]. The median lost workdays among truck drivers was 19 days, which was highest among all reported occupations [1]. More than a third of the cases (40%) resulted in a median of 29 days away from work, implying high severity [1]. Slips, trips, and falls among truck drivers was the second leading event or exposure accounting for 30% of the cases, only preceded by overexertion and bodily reaction at 36% [1].

Falls while mounting and dismounting trucks account for nearly 25% of all injuries in commercial trucking [2]. A three year study of commercial truck drivers from one large US fleet reported direct costs due to slips and falls on and around trucks annually exceeded $20M (US) [3]. Reed [3] also noted that 50% of those falls occurred while dismounting the vehicle.

In several related industries, data suggest that mounting/dismounting large vehicles may be hazardous. Among firefighters, 16% of all compensable injuries are related to emergency vehicles, of which 37% involved stepping down from the vehicle [4]. In the agricultural sector, a large proportion of injuries are also associated with mounting and dismounting tractors [1,5].

Spielholz et al. conducted a self-reported survey of perceived injury risks among trucking companies in Washington state and found that worker behavior frequently contributes to musculoskeletal and slip/trip/fall injuries [6]. Nearly a quarter of drivers identified slippery conditions as an environmental factor. In another study, one-half of the participants reported that they could not see where they placed their feet during dismounting; other problems included steps that were contaminated by ice/snow, water or mud [7]. These findings suggest the need for systematic interventions to control the risks of work-related slip, trip, or fall injuries in the trucking industry [6].

Helmkamp et al. conducted a Survey of Occupational Injuries and Illnesses (SOII) that utilized data from two independent sources – the National Health Interview Survey (NHIS) and the Bureau of Labor Statistics (BLS). They reported that in the trucking, warehouse, and utilities (TWU) sector, overexertion (28%), contact with objects (21%) and falls (21%) are the most common events contributing to higher injury rates.

Important factors influencing trips and falls include driver fatigue, environmental factors, step and handhold configurations, technique, coordination, and physique [3]. Understanding the relationship between commercial truck operators' health and physical behavior during mounting/dismounting is an important step in mitigating injuries from fatal and non-fatal falls among truck drivers. In a recent study conducted by Turner and Reed [8] , a high prevalence of obesity was found in a sample of 300 commercial truck drivers, with 93.3% of

***Corresponding author:** Shorti RM, Department of Mechanical Engineering, The University of Utah, USA, Tel: 801-687-2671; E-mail: rami.shorti@utah.edu

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study participants having a body mass index (BMI) of 25 or higher. Results from Patenaude et al. [7] show that truck driver's weight influences the ground impact force during the descent from the cab, which may be problematic due to an imbalance between lower limb strength and driver's weight.

This cross sectional study of commercial truck drivers was designed to measure health status indicators, chronic illness risk factors, fall risk factors, self-reported falls and crash data. The goal of this article was to identify potential factors associated with mounting and dismounting cabs that are associated with falls. Data from the questionnaire also include possible interactions between these factors to better understand truck driver safety and other health factors associated with falls.

Methods

Study recruitment strategy

Recruitment of truck drivers for this cross sectional study was conducted through a variety of methods including: industry newsletters, meeting with trucking companies, flyers at trucking shows, and direct contacts with potential participants at truck stops and trucking shows. The latter two methods yielded the most enrollees. The majority of drivers were enrolled at truck shows at six nationwide locations (IL, IA, KY, TX, NV, and UT). Drivers were also recruited at three truck stops in Utah and Wisconsin. A few additional recruits were enrolled distance-based (on-line). The inclusion criteria were that subjects had a current United States Commercial Driver's License (CDL), at least 1 year of driving experience, and the ability to read English.

Data collection

The study was approved by the University of Utah and University of Wisconsin at Milwaukee Institutional Review Boards (IRB# 22252 and #07.02.297 respectively). After obtaining informed consent, drivers completed a computerized laptop-administered questionnaire (Filemaker® Pro version 9, Santa Clara, California, USA). The enrollment process included measured Height, Weight, Neck/Waist/Hip circumferences, blood pressure and pulse. Laboratory measures included total cholesterol, low density lipoprotein, high density lipoprotein, triglycerides, non-fasting glucose, and hemoglobin A1C.

The computerized questionnaire was comprised of 864 items covering many domains. These domains included: (a) fall history with corresponding self-reported factors and conditions, (b) demographics (e.g., age, gender, and history of maximum body weight), (c) frequencies and durations of hobbies and outside of work activities, (d) medical history including diseases (e.g., diabetes mellitus, high blood pressure, high cholesterol, and musculoskeletal disorders) (e) psychosocial questions (e.g., depression, job satisfaction, family problems, supervisory and coworker support), (f) occupational specific questions (e.g. miles driven, history of crashes, near-miss events in the past year, manual loading/unloading, securing loads, etc.), and (g) other questions (e.g., sleeping patterns, smoking, alcohol consumption). Computerization was used to improve quality control, including assuring data capture and eliminating out of range answers.

Data on falls were self-reported by drivers and included: (1) lifetime number of falls when (a) mounting a truck or (b) dismounting a truck, (2) falls within the past 12 months when (a) mounting a truck or (b) dismounting a truck, (3) specific factors that drivers felt contributed to causing the fall their most recent fall, (4) lost time due to a fall, and (5) seeing a health care provider because of a fall. Variables analyzed in this article (Table 3) were specifically asked regarding their fall, these variables include environmental factors involved and season, location, and time of fall reflecting the driver's self-attribution to the fall incident. While other variables, including ratings of physical or mental exhaustion, manual material handling, job physically demand, low back pain reporting, and health status reporting are global questions, not specifically related to a fall incidence.

The environmental factor is a dichotomous variable, that includes ice, snow, rain, mud, and/or heat (weather), indicated by the driver to have contributed to a fall within the last 12 months. Footwear is a categorical variable with four levels (athletic, cowboy, work boots, or other). The location of a fall is a self-reported categorical variable that includes cab, trailer, box, away, and other categories. Season of the year is a categorical variable that includes four levels (fall, spring, summer, and winter). Manual loading is a dichotomous variable reported by the truck drivers to have usually manually loaded or unloaded a truck. Additionally, time of fall is a categorical variable (morning, afternoon, evening, and night). BMI is a categorical variable categorized into five levels based on the following criteria: underweight ($BMI<18.5$), normal weight ($18.5 \leq BMI<25$), overweight ($25 \leq BMI<30$), obese ($30 \leq BMI<35$), and morbidly obese ($35 \leq BMI$). The Heath status was a four level self-scoring system from the drivers' health rating as excellent, good, fair, or poor. Finally, feeling mental exhaustion and feeling physical exhaustion ratings include four levels (never, seldom, often, and always).

Statistical methods

Hypotheses: (1) Truck driver health and wellness as measured through self-reported questionnaires are significantly correlated with reported falls during mounting and dismounting.

(2) Truck, environmental, and driver personal factors, such as location around the truck, frequency and time of cab access, footwear, and environmental factors such as ice, rain, and mud are significantly correlated with reported falls during mounting and dismounting.

Statistical analyses were performed using SPSS 19.0 (SPSS; IL, USA; www.spss.com). The self-reported 12-month and lifetime fall counts (outcome variables) were dichotomized to represent driver self-reports of having ever fallen or not. Univariate logistic regression was used to explore possible predictors of falls. Statistical significance was determined *a priori* at $\alpha=0.05$. Finally, potential factors (Tables 2 and 3) were chosen *a priori* out of the items included in the questionnaire based on previously published data relating these variables to potential relationship(s) with balance, strength, slips, and/or falls.

Results

A total of 797 participants (14.1% female, 85.9% male) were included in these analyses. The mean age was 47.2 years (range 21–75) and the mean (standard deviation) height and weight were 177.4 (9.0) cm and 103.5 (24.2) kg respectively. Table 1 provides details of the population's demographics, including means and standard deviations of the count of self-reported 12-month and count of lifetime falls.

Table 2 summarizes results from the logistic regression analysis of potential truck drivers' personal factors related to falls. Table 2 includes the total number of driver self-reported ever falling, organized by either mounting or dismounting falls within 12-month or lifetime durations, along with respective odds ratio. Results indicate that, compared to male truck drivers. Compared to males, females have protective odds of falling while mounting the cab for both 12-month (OR, 0.43, 95% CI 0.22 to 0.84) and lifetime reports (OR, 0.46, 95% CI 0.3 to 0.71).

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Description		All Drivers	12-month Falls		Lifetime Falls	
			Dismount	Mount	Dismount	Mount
		N (% of total)	N (% of total)	N (% of total)	N (% of total)	N (% of total)
Gender	Male	685 (85.9)	156 (22.8)	129 (18.8)	382 (55.8)	317 (46.3)
	Female	112 (14.1)	18 (16.1)	10 (8.9)	57 (50.9)	32 (28.6)
Age Range (yrs)	20-29	26 (3.3)	8 (30.8)	5 (19.2)	12 (46.2)	8 (30.8)
	30-39	95 (11.9)	25 (26.3)	21 (22.1)	54 (56.8)	45 (47.4)
	40-49	219 (27.5)	41 (18.7)	38 (17.4)	114 (52.1)	91 (41.6)
	50-59	294 (36.9)	70 (23.8)	55 (18.7)	163 (55.4)	132 (44.9)
	60-69	142 (17.8)	27 (19)	18 (12.7)	85 (59.9)	67 (47.2)
	70-79	21 (2.6)	3 (14.3)	2 (9.5)	11 (52.4)	6 (28.6)
Hand Dominance	Left-handed	96 (12)	25 (26)	19 (19.8)	53 (55.2)	39 (40.6)
	Right-handed	669 (83.9)	139 (20.8)	110 (16.4)	366 (54.7)	292 (43.6)
	Use both hands equally	32 (4)	10 (31.3)	10 (31.3)	20 (62.5)	18 (56.3)
Race	White	685 (85.9)	155 (22.6)	120 (17.5)	388 (56.6)	303 (44.2)
	Hispanic	48 (6)	12 (25)	12 (25)	21 (43.8)	19 (39.6)
	Black	37 (4.6)	4 (10.8)	3 (8.1)	19 (51.4)	15 (40.5)
	Other	24 (3)	3 (12.5)	4 (16.7)	9 (37.5)	10 (41.7)
	Decline	3 (0.4)	0 (0)	0 (0)	2 (66.7)	2 (66.7)
Haul Type	Short	227 (28.5)	53 (23.3)	41 (18.1)	131 (57.7)	111 (48.9)
	Long	531 (66.6)	112 (21.1)	90 (16.9)	286 (53.9)	224 (42.2)
	Both	26 (3.3)	9 (34.6)	7 (26.9)	17 (65.4)	12 (46.2)
	Other	13 (1.6)	0 (0)	1 (7.7)	5 (38.5)	2 (15.4)
Shift Work	Day Shift	288 (36.1)	63 (21.9)	53 (18.4)	155 (53.8)	125 (43.4)
	Night Shift	62 (7.8)	14 (22.6)	10 (16.1)	36 (58.1)	25 (40.3)
	Swing Shift	249 (31.2)	47 (18.9)	37 (14.9)	131 (52.6)	107 (43)
	Variable Shift	198 (24.8)	50 (25.3)	39 (19.7)	117 (59.1)	92 (46.5)
Career Mileage	1/4 Million Miles	94 (11.8)	24 (25.5)	14 (14.9)	37 (39.4)	25 (26.6)
	1/2 Million Miles	65 (8.2)	10 (15.4)	9 (13.8)	30 (46.2)	22 (33.8)
	3/4 Million Miles	63 (7.9)	13 (20.6)	12 (19)	36 (57.1)	27 (42.9)
	1 Million Miles	141 (17.7)	34 (24.1)	26 (18.4)	83 (58.9)	59 (41.8)
	2 Million Miles	125 (15.7)	22 (17.6)	18 (14.4)	67 (53.6)	58 (46.4)
	3 Million Miles	112 (14.1)	36 (32.1)	26 (23.2)	77 (68.8)	63 (56.3)
	4 Million Miles	54 (6.8)	9 (16.7)	11 (20.4)	37 (68.5)	31 (57.4)
	5 Million Miles or more	45 (5.6)	8 (17.8)	7 (15.6)	24 (53.3)	25 (55.6)
	Unknown	98 (12.3)	18 (18.4)	16 (16.3)	48 (49)	39 (39.8)

Table 1: Demographic Characteristics.

Although not statistically significant, similar results are seen with dismounting falls. While, analyses conducted on truck driver BMI associations with falls were not statistically significant, results in Table 2 shows that being overweight, obese, or morbidly obese have higher odds of lifetime falls when compared to the normal weighted truck driver category. Interestingly, in comparing drivers' fall reports for different truck driver reported health status, a consistent (statistically non-significant) trend was found indicating that improving the health status decreases the likelihood of falls both mounting and discounting a truck cab. Finally, experiencing low back pain was significantly associated with falls for 12-month fall reports during dismounting a truck cab ($p<0.05$) with odds ratio of 1.62, and lifetime fall reports ($p<0.05$) with odds ratio of 1.58 during dismounting a truck cab. Similarly, individuals experiencing LBP are at increased odds of falling while mounting a cab as well (Table 2).

A summary of results from the logistic regression analysis of truck driver's job related professional factors are presented in Table 3. This Table summarizes self-reported odds ratio of reported 12-month and lifetime reported falls. Table 3 describes select questions related to driver physical exertion on the job as well as factors that are suspected to contribute to a fall event based on non-parametric tests (Table 3). Professional job demands variables considered included reports of mental exhaustion, physical exhaustion, driving-related low back pain (LBP) (Table 3). These variables were considered because of potential relationship(s) with balance and strength.

The logistic regression results conducted between the haul type and reported falls were not statistically significant (Table 3). However, long haul truck drivers showed reduced odds of falls when compared to short haul. Additionally, drivers performing both haul (long and short) have higher odds of falls when compared to the short haul truck driver category (Table 3).

Reports of "always" feeling mentally exhausted was found to [significantly] increase the likelihood of falls for 12-months reported falls dismounting (OR, 2.52, , 95% CI 1.28 to 4.99) and mounting a truck cab (OR, 3.42, 95% CI 1.66 to 7.03), as well as lifetime reported falls dismounting (OR, 5.12, , 95% CI 2.46 to 10.66) and mounting a truck cab (OR, 7.25, $p<0.00$, 95% CI 3.46 to 15.18). Furthermore, a trend of increased odds of falls is seen between the different categories when compared to the "never" group (Table 3). Similarly, reports of "always"

Description		12-month Falls		Lifetime Falls	
		Dismount	**Mount**	**Dismount**	**Mount**
		OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Gender	Male	(Reference)	(Reference)	(Reference)	(Reference)
	Female	0.65 (0.38 to 1.11)	0.43 (0.22 to 0.84)*	0.81 (0.55 to 1.21)	0.46 (0.3 to 0.71)**
Age Range (yrs)	20-29	2.67 (0.61 to 11.7)	2.14 (0.37 to 12.41)	0.7 (0.22 to 2.26)	1.04 (0.29 to 3.69)
	30-39	2.14 (0.58 to 7.9)	2.55 (0.55 to 11.9)	1.08 (0.41 to 2.84)	2.1 (0.74 to 5.93)
	40-49	1.38 (0.39 to 4.91)	1.89 (0.42 to 8.49)	0.89 (0.35 to 2.23)	1.66 (0.61 to 4.48)
	50-59	1.87 (0.54 to 6.55)	2.07 (0.47 to 9.19)	1.03 (0.42 to 2.57)	1.91 (0.72 to 5.12)
	60-69	1.41 (0.39 to 5.13)	1.31 (0.28 to 6.11)	1.22 (0.48 to 3.13)	2.08 (0.76 to 5.73)
	70-79	(Reference)	(Reference)	(Reference)	(Reference)
Hand Dominance	Left-handed	1.34 (0.82 to 2.2)	1.25 (0.73 to 2.15)	1.04 (0.67 to 1.6)	0.9 (0.58 to 1.39)
	Right-handed	(Reference)	(Reference)	(Reference)	(Reference)
	Use both hands equally	1 (0.8 to 3.75)	1 (1.065)*	1 (0.66 to 2.85)	1 (0.81 to 3.38)
Race	White	(Reference)	(Reference)	(Reference)	(Reference)
	Hispanic	1.14 (0.58 to 2.24)	1.57 (0.79 to 3.1)	0.59 (0.33 to 1.06)	0.82 (0.45 to 1.49)
	Black	0.41 (0.14 to 1.19)	0.41 (0.13 to 1.37)	0.8 (0.41 to 1.55)	0.86 (0.44 to 1.68)
	Other	0.49 (0.14 to 1.66)	0.94 (0.32 to 2.8)	0.45 (0.2 to 1.05)	0.9 (0.39 to 2.04)
BMI Category	Decline	0 (0 to 0)	0 (0 to 0)	1.52 (0.14 to 16.79)	2.51 (0.23 to 27.79)
	Underweight	0.93 (0.1 to 8.84)	0 (0 to 0)	1.5 (0.24 to 9.46)	1 (0.16 to 6.32)
	Normal Weight	(Reference)	(Reference)	(Reference)	(Reference)
	Overweight	1 (0.59 to 2.04)	1 (0.52 to 1.93)	1 (0.66 to 1.85)	1 (0.69 to 1.97)
	Obese	1.1 (0.59 to 1.9)	1 (0.5 to 1.73)	1.11 (0.86 to 2.26)	1.17 (0.77 to 2.06)
	Morbidly Obese	1.06 (0.44 to 1.8)	0.93 (0.33 to 1.53)	1.39 (0.67 to 2.11)	1.26 (0.59 to 1.88)
Health Status	Excellent	0.43 (0.15 to 1.18)	0.37 (0.13 to 1.09)	0.51 (0.2 to 1.3)	0.49 (0.19 to 1.26)*
	Good	0.46 (0.2 to 1.07)	0.42 (0.17 to 1.01)	1.01 (0.45 to 2.27)	0.76 (0.34 to 1.71)*
	Fair	0.54 (0.23 to 1.29)	0.48 (0.2 to 1.17)	1.08 (0.47 to 2.47)	0.7 (0.31 to 1.6)*
	Poor	(Reference)	(Reference)	(Reference)	(Reference)
Low Back Pain	No	(Reference)	(Reference)	(Reference)	(Reference)
	Yes	1.62 (1.03 to 2.55)*	1.61 (0.99 to 2.62)	1.58 (1.03 to 2.41)*	1.38 (0.92 to 2.08)
Career Mileage	1/4 Million Miles	1.59 (0.65 to 3.88)	0.95 (0.35 to 2.55)	0.57 (0.28 to 1.16)	0.29 (0.14 to 0.61)**
	1/2 Million Miles	0.84 (0.3 to 2.33)	0.87 (0.3 to 2.54)	0.75 (0.35 to 1.61)	0.41 (0.19 to 0.89)*
	3/4 Million Miles	1.2 (0.45 to 3.2)	1.28 (0.46 to 3.55)	1.17 (0.54 to 2.52)	0.6 (0.28 to 1.3)
	1 Million Miles	1.47 (0.62 to 3.46)	1.24(0.5 to 3.08)	1.27 (0.65 to 2.5)	0.58 (0.29 to 1.13)
	2 Million Miles	0.99 (0.4 to 2.41)	0.91 (0.35 to 2.36)	1.03 (0.52 to 2.04)	0.7 (0.35 to 1.4)
	3 Million Miles	2.19 (0.93 to 5.18)	1.64 (0.66 to 4.11)	1.98 (0.97 to 4.04)	1.05 (0.52 to 2.11)
	4 Million Miles	0.93 (0.32 to 2.64)	1.39 (0.49 to 3.94)	1.9 (0.84 to 4.32)	1.08 (0.49 to 2.39)
	5 M. Miles or more	(Reference)	(Reference)	(Reference)	(Reference)
	Unknown	1 (0.41 to 2.61)	1 (0.4 to 2.79)	1 (0.41 to 1.7)	1 (0.26 to 1.08)

*Underweight category excluded from this table (N=2).
**Participants not attributing the fall factor (in bold) as a contributor to the reported fall.

Table 2: Logistic Regression of Potential Personal Factors Related to Falls.

physically exhausted was a significant predictor of self-reported falls for the lifetime period while mounting (OR, 3.97, 95% CI 2.03 to 7.79) and dismounting the cab (OR, 2.7, 95% CI 1.42 to 5.14) (Table 3). Table 3 shows a trend of increase in odds of reported lifetime falls from the "never" (reference) to the "always" category having an odds ratio of 2.7.

Table 3 presents results for the job physically hard variable showing an increased odds of reported falls within individual's rating of "seldom", "often", or "always" when compared to the "never" category. The truck drivers' category rating their job being "often" physically hard, was found to have the highest increase in the likelihood of falls for 12-months reported falls dismounting ($p<0.01$) and mounting a truck cab ($p<0.01$), as well as lifetime reported falls dismounting ($p<0.01$) and mounting a truck cab ($p<0.01$) with all odds ratios reported in Table 3.

Compared to the "never" category, truck drivers experiencing "always" driving-related LBP were 5.75 times more likely to report a fall within 12-month while dismounting (OR, 5.75, 95% CI 2.6 to 12.7) and 5.6 times more likely while mounting a truck cab (OR, 5.6, 95% CI 2.51 to 12.49) and were 5.47 times more likely to report a lifetime fall while dismounting (OR, 5.47 , 95% CI 2.03 to 14.71) and mounting a truck cab (OR, 4.74 , 95% CI 2.03 to 11.07). The results from the logistic regression for the driving-related LBP summarized in Table 3 also shows an increase (a trend) in odds of reporting a fall as individuals experience higher levels of driving-related LBP.

Many truck drivers perform MMH, manually loading or unloading their truck, as part of their job. Compared to the group not performing MMH, the group reporting MMH had a significantly higher odds

Description	12-month Fall Counts		Lifetime Fall Counts	
	Dismount	Mount	Dismount	Mount
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Haul Type				
Short	(Reference)	(Reference)	(Reference)	(Reference)
Long	0.88(0.61 to 1.27)	0.93(0.62 to 1.39)	0.76(0.62 to 1.16)	0.93(0.55 to 1.03)
Both	1.74(0.73 to 4.13)	1.67(0.66 to 4.24)	0.89(0.59 to 3.2)	1.67(0.39 to 2)
Other	0(0 to 0)	0.38(0.05 to 2.99)	0.21(0.16 to 1.68)	0.38(0.04 to 0.97)*
Shift Work				
Day Shift	(Reference)	(Reference)	(Reference)	(Reference)
Night Shift	1.04(0.54 to 2.01)	0.85(0.41 to 1.79)	1.17(0.67 to 2.04)*	0.88(0.5 to 1.53)
Swing Shift	0.83(0.54 to 1.27)	0.77(0.49 to 1.22)	0.95(0.67 to 1.33)*	0.98(0.7 to 1.39)
Variable Shift	1.21(0.79 to 1.85)	1.09(0.69 to 1.73)	1.22(0.85 to 1.76)*	1.12(0.78 to 1.62)
Mental Exhaustion				
Always	2.52(1.28 to 4.99)**	3.42(1.66 to 7.03)**	5.12(2.46 to 10.66)**	7.25(3.46 to 15.18)**
Often	1.49(0.9 to 2.48)	1.82(1.03 to 3.19)*	1.78(1.17 to 2.7)**	1.72(1.12 to 2.63)*
Seldom	1.05(0.65 to 1.69)	1.07(0.62 to 1.84)	1.63(1.12 to 2.38)*	1.24(0.84 to 1.83)
Never	(Reference)	(Reference)	(Reference)	(Reference)
Physical Exhaustion				
Always	2.11(0.98 to 4.52)	1.19(0.55 to 2.56)	3.97(2.03 to 7.79)**	2.7(1.42 to 5.14)**
Often	2.21(1.224.03)**	1.11(0.62 to 1.99)	2.8(1.73 to 4.51)**	1.69(1.05 to 2.71)*
Seldom	1.46(0.842.53)	0.74(0.44 to 1.26)	1.92(1.27 to 2.91)**	1.22(0.8 to 1.85)
Never	(Reference)	(Reference)	(Reference)	(Reference)
Job Physically Hard				
Always	1.72(0.86 to 3.45)	2.28(1.06 to 4.89)*	1.55(0.87 to 2.76)	1.55(0.86 to 2.77)
Often	2.14(1.25 to 3.69)**	2.54(1.37 to 4.7)**	2.44(1.56 to 3.83)**	2.07(1.32 to 3.25)**
Seldom	1.32(0.81 to 2.15)	1.59(0.9 to 2.8)	1.73(1.19 to 2.51)**	1.5(1.02 to 2.2)*
Never	(Reference)	(Reference)	(Reference)	(Reference)
MMH				
No	(Reference)	(Reference)	(Reference)	(Reference)
Yes	1.43(0.98 to 2.09)	1.81(1.21 to 2.7)**	1.94(1.37 to 2.74)**	1.75(1.26 to 2.44)**
Driving-related LBP				
Always	5.75(2.6 to 12.7)**	5.6(2.51 to 12.49)**	5.47(2.03 to 14.71)**	4.74(2.03 to 11.07)**
Often	2.26(1.29 to 3.94)**	1.83(0.99 to 3.4)	2.33(1.39 to 3.91)**	2.53(1.53 to 4.17)**
Seldom	1.46(1 to 2.13)*	1.46(0.97 to 2.2)	1.86(1.37 to 2.52)**	1.79(1.32 to 2.44)**
Never	(Reference)	(Reference)	(Reference)	(Reference)
Footwear				
Work Boots	(Reference)	(Reference)	(Reference)	(Reference)
Athletic Shoes	1(0.47 to 1.08)	1(0.66 to 1.57)	1(0.25 to 0.98)*	1(0.5 to 1.23)
Cowboy Boots	0.71(0.18 to 1.23)	1.02(0.15 to 1.34)	0.5(0.15 to 2.05)	0.79(0.15 to 0.82)*
Other	0.48(0.55 to 4.15)	0.44(0.15 to 1.94)	0.56(0.14 to 9.14)	0.36(0.24 to 2.17)
Location of Fall				
Cab	1.49(0.9 to 2.47)	1.47(0.86 to 2.51)	0.61(0.25 to 1.49)	1.02(0.61 to 1.71)
Trailer	(Reference)	(Reference)	(Reference)	(Reference)
Other	1(0.32 to 6.53)	1(0.05 to 3.98)	1(0.05 to 4.82)	1(0.09 to 1.68)
Season of Fall				
Summer	(Reference)	(Reference)	(Reference)	(Reference)
Fall	1(0.64 to 2.61)	1(0.5 to 2.4)	1(0.21 to 1.6)	1(0.54 to 2.23)
Winter	1.29(0.63 to 1.72)	1.09(0.8 to 2.41)	0.58(0.43 to 2.18)	1.1(1.1 to 3.04)*
Spring	1.04(1.3 to 4.68)**	1.39(1.09 to 4.26)*	0.97(0.41 to 4.06)	1.83(0.86 to 3.42)
Environmental Factors				
No	(Reference)	(Reference)	(Reference)	(Reference)
Yes	7.94(5.14 to 12.26)**	7.81(4.78 to 12.73)**	43.13(28 to 66.42)**	16.58(11.6 to 23.68)**

*representing relationships that are significant to 0.05 level.
**representing relationships that are significant to 0.01 level.

Table 3: Logistic Regression of Potential Professional Factors Related to Falls.

of lifetime reported falls while dismounting (OR, 1.75, 95% CI 1.26 to 2.44) and higher odds that are significant while mounting the cab (OR, 1.94, 95% CI 1.37 to 2.74) as well as [significant] higher odds of reporting falls within the 12-month period while mounting the cab (OR, 1.81, 95% CI 1.21 to 2.7) and higher odds [not significant] while dismounting the cab (OR, 1.43, 95% CI 0.98 to 2.09).

The associations between footwear and reported falls were assessed and results are presented in Table 3. The associations (odds ratios)

Haul Type	Falls from the Cab			
	12 Month		Lifetime	
	Mounting	Dismounting	Mounting	Dismounting
Long Haul	1.1	1.1	5.1	6.0
Short Haul	0.9	1.0	8.7	9.8
Both	1.1	2.1	15.6	19.2
Other	1.0	0.0	30.0	12.5
	Falls from the Trailer			
	12 Month		Lifetime	
	Mounting	Dismounting	Mounting	Dismounting
Long Haul	2.3	2.4	8.7	8.7
Short Haul	0.6	0.6	4.4	5.4
Both	0.0	0.0	1.0	2.5
Other	0.0	0.0	0.0	1.0

Table 4: Comparison of the mean counts falls by location.

between the footwear as reported by the participants show lower odds of reported falls (both 12-month and lifetime while mounting or dismounting) when reporting athletic or cowboy shoes when compared to work boots. Compared to work boots category (the reference category), the odds of reports of lifetime falls dismounting the cab were significantly lower for the athletic category (OR, 0.5, 95% CI 0.25 to 0.98) and also significantly lower for the cowboy boots category (OR, 0.36, 95% CI 0.15 to 0.82).

The majority of falls occurred around the cab (80.6%), while 19.4% occurred on the trailer, and the remaining 2.5% occurred elsewhere (catwalk, box, ground, etc.) Table 4. This is consistent between haul types, as illustrated in Figure 1. Results from the logistic regression do not show a significant relationship between the location of fall and 12-month reports of falls while mounting, (OR, 1.47, 95% CI 0.86 to 2.51), and dismounting, (OR, 1.49, 95% CI 0.9 to 2.47) as well as lifetime reports of falls mounting, (OR, 1.02, 95% CI 0.61 to 1.71), and dismounting the vehicle, (OR, 0.61, 95% CI 0.25 to 1.49).

Of the truck drivers who indicated a fall within the last year while dismounting the truck cab, two thirds (68.8%) indicated that an environmental factor influenced the fall. Similar results were found in fall reports during mounting the truck cab (64.4%). Results of those who indicated that the fall resulted from one or more environmental factors, (ice, snow, mud, rain, sun or heat) are displayed in Figure 2. Of those drivers reporting falls, 53.3% indicated the fall occurring during winter months.

The average number of falls in the past 12 months stratified by haulage type and location indicate that LH drivers experienced more falls from the Trailer (2.3) than the Cab (1.1), while SH reported more falls from the Cab (0.85 and 0.55 respectively). Haulage types listed as Both and Other reported only falls from the cab (1.1 and 1 respectively).

No relationship was found between falls (12-month and lifetime) and the following factors: shiftwork (day, night, or swing), job characteristic (driver, or owner), exercise (whether the drivers did exercise outside of work), vision (whether they wore glasses or not), hand dominance (right handed, left handed, or ambidextrous), age, or feeling rested in the morning.

Discussion

The demographic characteristics of the study sample (Table 2) are consistent with results from another national survey targeting illness and injury data within long haul truck drivers (n=1670), sampled from truck stops across 48 contiguous United States [9]. Falls were reported by many truck drivers in this large, cross sectional study (N=797), having affected 55.4% of drivers dismounting and 44.0% mounting. A better understanding of the interactions between commercial truck operators' health and physical behaviors during mounting/ dismounting is an important step in the efforts to mitigate injuries from falls among these workers. Results from this study are consistent with previous research suggesting falls during dismounting more likely than falls during mounting [10].

Other factors, including whole body vibration (WBV) from prolonged driving has been shown to influence postural stability, which suggests that there is a time dependent increase in postural sway over the course of a driving shift [11]. These specific data were unavailable in this study, however survey data suggest that "Driving time until break" was not significantly correlated with reported falls from dismounting p=0.7, nor was there a correlation with mileage driven in the prior year. Future work is needed to determine if exposure to WBV while driving is associated with risk of falling.

Patenaude et al. [7] reports that, based on the results from interviews, truck driver participants appear to be satisfied with the layout of the cab. On the other hand, half of the study participants reported their inability to see where they placed their feet during truck cab dismount. The risk of fall presented from foot placement uncertainty may be further amplified with the presence of environmental contaminants on the steps. In our study, 68.8% of drivers indicated that environmental

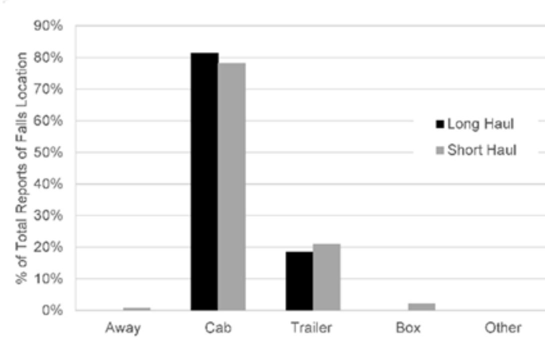

Figure 1: Reported location of falls.

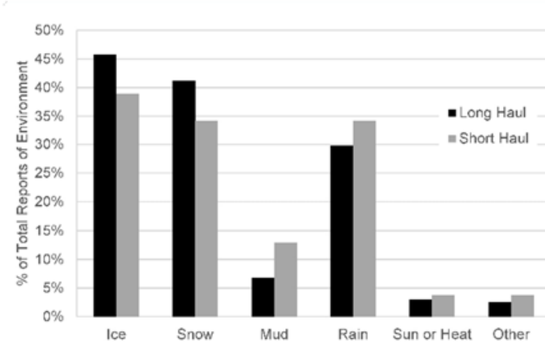

Figure 2: Reported environmental factors influencing falls.

contaminants were factors that influenced their fall. These results suggest that the layout of the cab combined with environmental factors may not be suitable to support dismounting the truck cab safely [7].

Results from this study show being overweight, obese, or morbidly obese have higher odds of lifetime falls when compared to the normal weighted truck driver category. While, these findings were not statistically significant, it trended towards significance. The truck driver population is heavier than the general U.S. population. The average BMI of our study population was 33.2 kg/m^2 (SD=5.5) which is considered obese, and is consistent with other reports (Guan et al. [12] reported a mean of 33.2 kg/m^2 and Sieber et al. [9] reported 33.4 kg/m^2). This is important because results from Patenaude et al. [7] show that truck operator's weight influences the ground impact force during descent from the cab. Lower-limb strength may be inadequate to support the required joint torque caused by this increased reaction force, and represents the imbalance between lower limb strength and a person's weight. Further investigation into lower limb strength of truck drivers and fall risk is needed to understand this relationship.

The effect of fatigue from driving on falls remains understudied. In this study, feelings of mental and physical exhaustions and reports of manual loading and unloading the truck were correlated with fall events. Fatigue may be induced from multiple sources. Although commercial truck drivers' primary task involves driving trucks on roads, driving is not the only task they perform. Truck drivers' tasks include, in many cases, handling of goods that need to be collected, loaded, unloaded, and delivered. These are typical examples of manual material handling (MMH) tasks that require human strength for which many truck drivers are responsible. Thus, some truck drivers may experience fatigue from considerable physical exertions. Mental fatigue may be related to the time demands plus monotony punctuated by hypervigilance.

Finally, physical factors of the truck may have an effect on driver falls. In this study the location of falls was associated with the frequency of falls, with the majority of falls occurring around the cab (80.6%) and 19.4% occurred on the trailer. This implies that future studies should assess cab features that may influence falls. Patenaude et al. [7] reported that half of their study participants reported an inability to see where they placed their feet during truck cab dismount.

Limitations of these findings include the cross-sectional nature of the study that precludes analysis of causal factors. The survey responses are subjective and also subject to recall biases and errors. Finally, the survey questions not including questions targeting the mounting/ dismounting activity limits this study from attributing the falls to a certain physical aspect of the cab or behavioral aspect of the truck driver while accessing the truck cab.

Conclusion

Our findings suggest that several aspects of the truck (trailer or cab), environmental conditions (such as ice, rain, and mud), and driver personal factors (driver health, frequency of cab mounting/ dismounting, footwear) are related to reported falls during mounting and dismounting in the past year as well as over the driver's lifetime. Data also suggest that the proportionally more of falls occurred during dismounting the cab than mounting the cab. Findings suggest that reports of feeling physically exhausted or mentally exhausted were associated with the number of falls.

Future Work

This study provides evidence suggesting that perhaps targeting cab design changes and worker training may help reduce the number of fall injuries to commercial truck drivers. Modifications to truck steps and or choice of footwear that improve the "quality of contact" and provide additional frictional characteristics, provide better visibility to help with targeting, and technology to prevent water, snow and ice build-up could also reduce the chance of a fall while mounting/dismounting truck cabs.

The effect of driving related LBP appears to be another important physical factor that was significantly correlated with falls in this study. Prolonged whole body vibration (WBV) exposure from driving has been shown to impact postural stability [11]. This results from vehicular vibrations that are theorized to lead to back muscle fatigue [13]. The risks of muscle fatigue from MMH may increase among long-distance truck drivers that have also been exposed to vehicle vibrations while driving [14-16]. Future research focused on the effect of fatigue on truck driver fall potential, particularly including objective measures of vibration and back pain is needed [17]. Finally, the current study was focused on the truck driver health and safety in an effort to pinpoint the key factors that influence falls to provide areas of much needed research consideration. A detailed research focused on the truck cab-driver interaction and cab design would be valuable to better understand the factors involved during mounting and dismounting the truck cab. Such research should include key factors most likely to ameliorate the cab access experience such as types of steps/handrail designs, drivers' behavior (facing the cab or facing away) and driver training.

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References

1. Day L, Rechnitzer G (2004) Safe tractor access platforms: from guidance material to implementation. J Agric Saf Health 10: 197-209.
2. Jones D, Switzer-McIntyre S (2003) Falls from trucks: a descriptive study based on a workers compensation database. Work 20: 179-184.
3. Reed MP (2010) Truck Ergonomics: Field and Laboratory Research. UMTRI Truck Ergo Overview [Online].
4. Giguère D, Marchand D (2005) Perceived safety and biomechanical stress to the lower limbs when stepping down from fire fighting vehicles. Appl Ergon 36: 107-119.
5. Lee TY, Gerberich SG, Gibson RW, Carr WP, Shutske J, et al. (1996) A population-based study of tractor-related injuries: Regional Rural Injury Study-I (RRIS-I). J Occup Environ Med 38: 782-793.
6. Spielholz P, Cullen J, Smith C, Howard N, Silverstein B, et al. (2008) Assessment of perceived injury risks and priorities among truck drivers and trucking companies in Washington State. J Safety Res 39: 569-576.
7. Patenaude S, Marchand D, Samperi S, Bélanger M (2001) The effect of the descent technique and truck cabin layout on the landing impact forces. Appl Ergon 32: 573-582.
8. Turner LM, Reed DB (2011) Exercise among commercial truck drivers. AAOHN J 59: 429-436.
9. Sieber WK, Robinson CF, Birdsey J, Chen GX, Hitchcock EM, et al. (2014) Obesity and other risk factors: the National Survey of U.S. Long-Haul Truck Driver Health and Injury. Am J Ind Med 57: 615-626.
10. Nicholson AS, David GC (1985) Slipping, tripping and falling accidents to delivery drivers. Ergonomics 28: 977-991.
11. Ahuja S, Davis J, Wade C (2005) Postural Stability of Commercial Truck Drivers: Impact of Extended Durations of Whole-Body Vibration. Human Factors and Ergonomics Society Annual Meeting Proceedings.
12. Guan J, Hsiao H, Bradtmiller B, Kau TY, Reed MR, et al. (2012) U.S. truck driver anthropometric study and multivariate anthropometric models for cab designs. Hum Factors 54: 849-871.

13. Hansson T, Magnusson M, Broman H (1991) Back muscle fatigue and seated whole body vibrations: an experimental study in man. Clin Biomech (Bristol, Avon) 6: 173-178.

14. Magnusson M, Almqvist M, Broman H, Pope M, Hansson T (1992) Measurement of height loss during whole body vibrations. J Spinal Disord 5: 198-203.

15. Okunribido OO, Magnusson M, Pope MH (2008) The role of whole body vibration, posture and manual materials handling as risk factors for low back pain in occupational drivers. Ergonomics 51: 308-329.

16. Swaen GM, Van Amelsvoort LG, Bültmann U, Kant IJ (2003) Fatigue as a risk factor for being injured in an occupational accident: results from the Maastricht Cohort Study. Occup Environ Med 60 Suppl 1: i88-92.

17. Bible JE, Choemprayong S, O'Neill KR, Devin CJ, Spengler DM (2012) Whole-body vibration: is there a causal relationship to specific imaging findings of the spine? Spine (Phila Pa 1976) 37: E1348-1355.

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CHAPTER 3

EFFECTS OF ANTHROPOMETRY AND CAB CONFIGURATION ON TRUCK DRIVER EGRESS TACTICS AND DRIVER-CAB INTERACTION METRICS

Abstract

A laboratory study of truck driver ingress and egress was conducted at the University of Michigan Transportation Research Institute (UMTRI) with a total of 52 experienced truck drivers representing a wide range of body dimensions and ages. Nine of the drivers (18%) were female. Stature, body weight, and 15 other standard anthropometric dimensions were obtained from each participant.

The objective of this chapter is to provide a description of observed egress behavior; develop an understanding and description of truck driver egress techniques, and define a method of analysis for the egress motions. This chapter will include a detailed description of all study trials from the UMTRI study (52 participants). The data analyzed include three-dimensional reconstructions of truck driver egress motions and quantitative metrics of driver interaction with steps and handholds. Egress behaviors were group based on driver interaction with steps and handholds. The most common group among each of the egress behaviors is analyzed in greater detail in this chapter.

Introduction

Commercial trucks are equipped with steps and handholds to facilitate safe ingress and egress. Truck drivers are commonly instructed to face the truck cab, as well as maintain three points of contact during both ingress and egress. Several studies have observed truck drivers employing alternative egress tactics (Fathallah & Cotnam, 2000). Some previous research on truck cab egress focused on investigating landing impact forces on lower limbs (Fathallah & Cotnam, 2000; Giguère & Marchand, 2005; Patenaude et al., 2001). Other research focused on the initiation of the egress motion. This research indicated a need for assessing the effect of personal factors, such as body dimensions, and architectural parameters, such as the cab step and handhold designs, on egress tactics (Chateauroux et al., 2012).

Digital human models (DHMs) have been applied to investigate cab driver ingress motions to validate the dynamic motion reconstruction method as a discomfort evaluation tool for truck cab access (Monnier et al., 2009). The data from the current study have previously been used to investigate the trajectories of the feet during ingress motions of the truck cab (Reed et al., 2010c), the influence of truck egress tactics on ground reaction forces (Reed et al., 2010b), and the hand positions and forces during truck ingress (Reed et al., 2010a).

Climbing stairs is a common activity with some similarities to truck IE, but has been studied in greater detail (Gates, Lelas, Della Croce, Herr, & Bonato, 2004; Lin, Fok, Schache, & Pandy, 2015; Livingston, Stevenson, & Olney, 1991; Ojha, Kern, Lin, & Winstein, 2009; Reid, Lynn, Musselman, & Costigan, 2007; Schmalz, Blumentritt, & Marx, 2007; Shiomi, 1994; Sinitski, Hansen, & Wilken, 2012). However, stair biomechanics research has focused predominantly on regular stair ascent and descent to assess functional abilities (Kennedy, Boreham, Murphy, Young, & Mutrie, 2007; Loy et al., 1994; Ramstrand & Nilsson, 2009), and as a method to define performance limits in rehabilitation and postsurgical interventions after knee (Hall, Stevermer, & Gillette, 2015; Standifird, Cates, & Zhang, 2014) and stroke surgeries (Modai, Sharon, Bar-Haim, & Hutzler, 2015; Novak & Brouwer, 2013).

Several research efforts have focused on cyclic patterns during stair ambulation of populations with a high fall risk, i.e., older adults, and disabled populations such as transfemoral amputees and knee replacement or knee osteoarthritis patients (Hobara et al., 2013; Laudanski, Brouwer, & Li, 2015; Shiomi, 1994; Song, Yu, Zhang, Sun, & Mao, 2014; Startzell, Owens, Mulfinger, & Cavanagh, 2000; Studenski et al., 1994; Tiedemann, Sherrington, & Lord, 2007; Varnell et al., 2011). These studies evaluated the performance and gait changes of populations with decrements in motor function or proprioceptive acuity, balance problems, or reduced lower-limb function, mainly associated with age and disease.

Although healthy individuals typically ascend and descend well-designed steps by using a step-over-step (SoS) gait pattern, in which each step receives a single foot placement, high fall risk populations were observed to adapt their stair gait and utilize compensatory mechanisms, such as alternative gait patterns, increased handrail use, or sideways motion (Varnell et al., 2011). The step-by-step (SbS) gait pattern, in which individuals place both of their feet on the same step before ascending or descending to a subsequent step, was observed as an alternate stair ambulation pattern in these populations (Reid et al., 2007).

Foot behaviors in stepping are an important focus of IE analysis because alterations of the mechanics of stair stepping have strong effects on the biomechanics of the activity. Therefore, the data from our study analyzed participants' negotiation of a small set of conventionally configured steps in addition to analysis of the IE data.

Methods

Participants

Truck drivers were recruited for the laboratory study through newspaper advertisements and flyers. All participants had at least 5 years of commercial driving experience in tractor-trailer combinations and had driven professionally within the 2 years prior to testing. A total of 52 drivers (10 female, 42 male) were included in the current analyses. The mean age was 46.1 years (range 22–65) and the mean (standard deviation) stature and weight were 178.5 (8.3) cm and 99.1 (23.1) kg, respectively. The mean BMI of this study population was 31.4 kg/m2 (*SD* = 6.3, range 21.6–52.8), which is considered obese. Fifteen other standard anthropometric dimensions were obtained from each participant. Drivers self-identified their race/ethnicity. Sample population used in this research is similar to reported U.S. truck driver population from two large studies of truck drivers. One is a cross-sectional study of U.S. truck drivers (*N*=797, 685 males and 112 females) reporting that most drivers were considered obese having a mean BMI of 33.2 kg/m2 (*SD*=5.5) (Shorti et al., 2014). The other study is an anthropometric study of U.S. truck drivers (*N*=1,950, 1,779 males and 171 females) reported a mean stature (mm) of 1,757 (*SD*=69.11) and mean weight (kg) of 102.8 (*SD*=23.83) (Guan et al., 2012). Selected study participants' characteristics are listed in Table 3.1.

Table 3.1. Total truck driver study participant characteristics

Characteristic	***N***	**Range**	**Mean ± *SD***
Age	52	22.0 – 65.0	46.1 ± 10.8
Stature (cm)	52	157.5 – 197.6	178.6 ± 8.3
Weight (kg)	52	67.6 – 179.1	99.1 ± 23.1
BMI (kg/m^2)	52	21.6 – 52.8	31.4 ± 6.3
Truck Driving Experience	49	1.0 – 44.0	13.8 ± 12.4

Characteristic	***N***	**Percentage***
Gender		
Male	42	80.2
Female	10	19.2
Typical Haul Driven		
Long Haul	23	44.2
Short Haul	19	36.5
Both	6	11.5
No Response	4	7.7
BMI Category		
Normal (18.5<=BMI<25)	7	13.5
Overweight (25<=BMI<30)	14	26.9
Obese (30<=BMI<35)	21	40.4
Morbidly Obese (BMI > 35)	10	19.2
Physical Activity		
Sedentary	6	11.5
Mild	19	36.5
Occasional	14	26.9
Regular	11	21.2

*Note: percentages may not sum to 100 due to rounding

Mockup

A reconfigurable truck cab mockup was constructed with key features of heavy truck cab ingress/egress (IE) systems, as shown in Figure 3.1. The steps can be adjusted vertically and horizontally, simulating the range of step configurations in the current truck fleet based on analysis conducted by UMTRI (Reed, 2010a). Force plates and load cells on the ground, steps, seat, steering wheel, and handholds measured reaction forces. Participants' whole-body motions were recorded using a 13-camera VICON passive-marker optical tracking system, and subjective assessments of ingress/egress difficulty were obtained from all participants.

Participants were instructed to enter and exit the mockup cab using self-selected movement strategies and using specific strategies identified previously in covert field observations. Testing was conducted with both internal and external handholds at the rear of the door opening. The internal handhold was fixed within the cab enclosure and was located 45 mm inside the door opening, 100 mm forward of the rear of the opening, and extended from 1358 to 1794 mm above the ground surface (total usable length of 436 mm). The external handhold, a vertical bar attached to the outside of the mockup immediately rearward of the door opening, was located 113 mm outboard of the sill, 130 mm aft of the door opening, and extended from 1273 to 2207 mm above the ground (total length of 934 mm). The simulated door was constructed with an open aluminum frame and was fixed at a 45-degree angle to the fore-aft axis of the mockup for testing. Additionally, the setup included a diagonal handhold that extended inward and upward from the lower, outboard edge of the door.

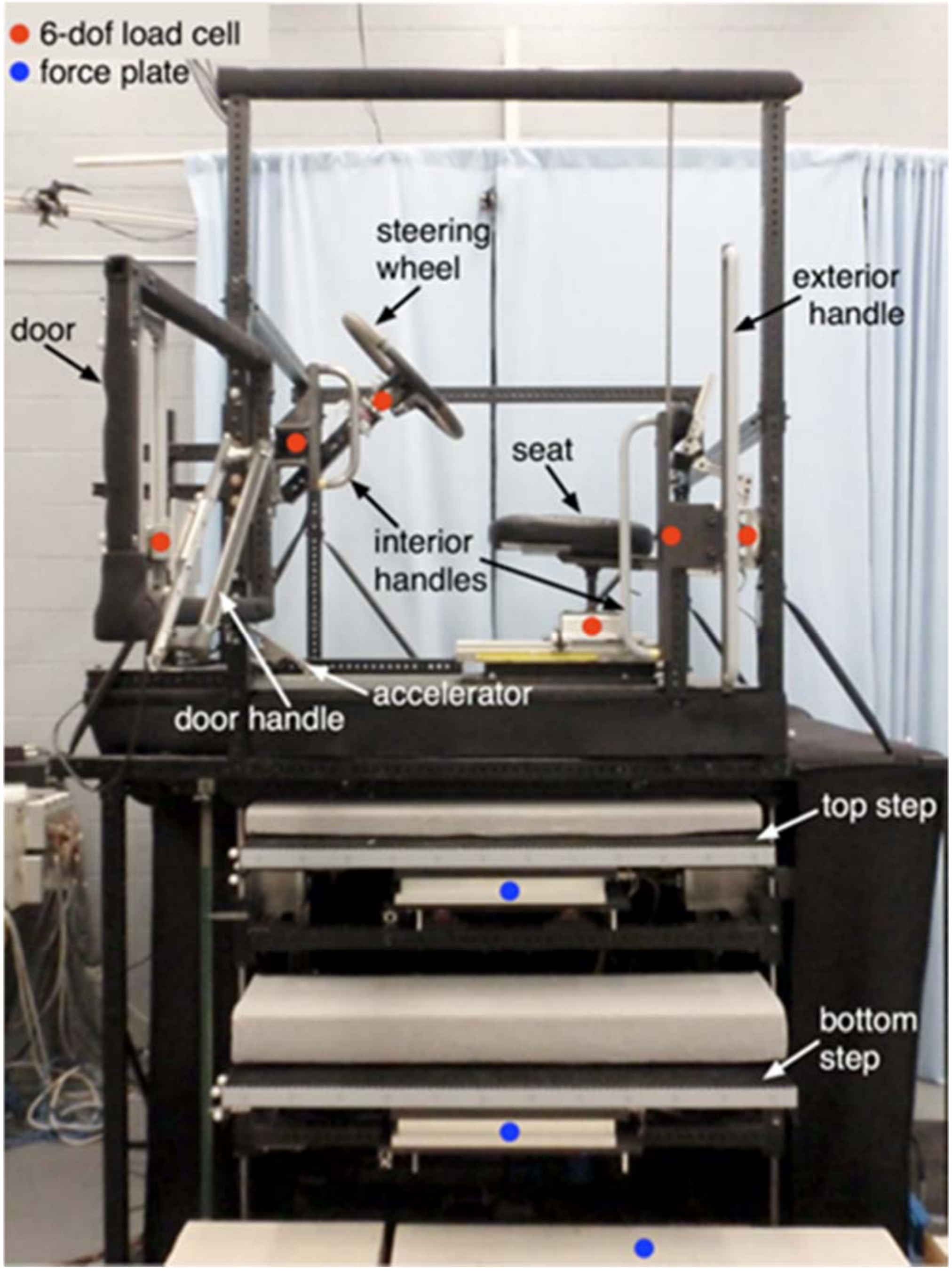


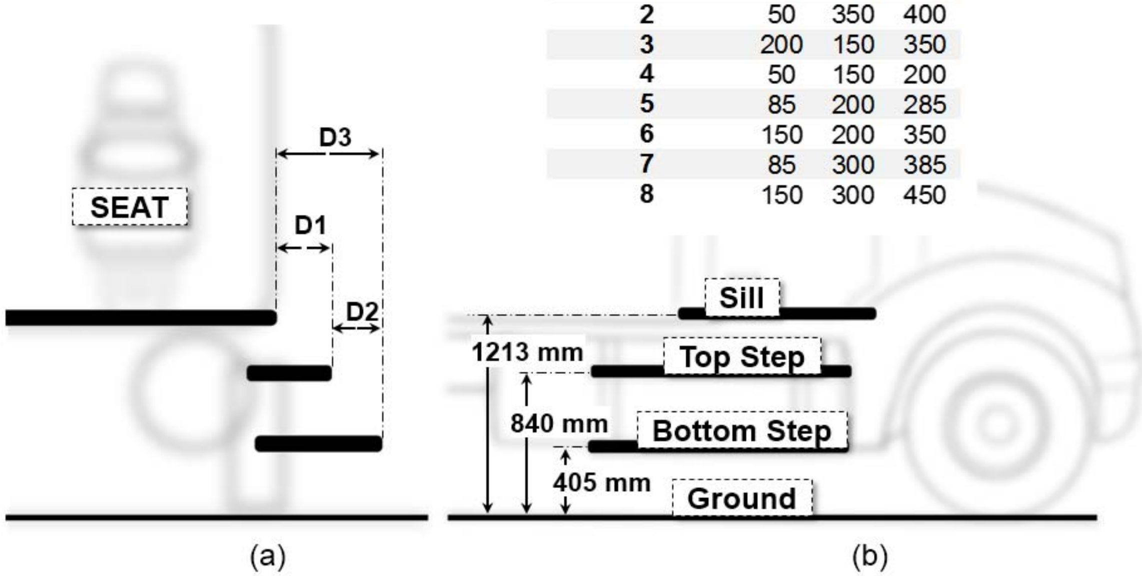
Figure 3.1. Truck cab mockup instrumented to measure reaction forces at the hands and feet. The ground, steps, and seat were instrumented with force plates. Steering wheel and handholds were instrumented using 6-DOF load cells. For clarity, the door is shown opened wider than the 45 degrees used in testing. Reprinted with permissions of University of Michigan Transportation Research Institute (UMTRI) and TruckSteps.org. (www.trucksteps.org)

Cab Step/Handle Configuration

Cab dimensions for the mockup were chosen based on an analysis of dimensional data from 30 trucks (Reed, 2010b). Step and sill heights were fixed. Conditions for this experiment included a set of step and handhold configurations obtained by varying the lateral positions of the steps, and two configurations (internal and external) of the handholds. Drivers entered and exited the cab twice with each combination of the two handhold configurations and the eight different step configurations, for a total of 32 trials per participant. In all trials, participants were able to use a handhold on the door and to use the steering wheel as a handhold. During these trials each driver exited the cab using a self-selected method in the first trial in each condition (undirected trials). In the second trial, the driver was instructed to perform an outward-facing egress if the first trial was inward-facing, and vice-versa (directed trials). The cab mockup illustration along with the dimensions involved are shown in Figure 3.2.

Participant motions were tracked using a VICON passive optical motion tracking system with 13 cameras. A total of 68 retroreflective markers were placed on skin or clothing, as shown in Figure 3.3. The pelvis markers were mounted on a Velcro belt attached to vertical Velcro strips on tight-fitting shorts worn underneath nylon running shorts. The thorax markers were mounted on a snug elastic band under the pectorals. All other markers (except head) were taped to the participant; the wrist and shoe markers were reinforced with duct tape.

Perceived difficulty ratings for each cab configuration were collected following each trial. Participants were asked to rate each configuration relative to their experiences in real-world trucks using an ordinal integer scale from 1 (very easy) to 7 (very difficult).



Step Configuration	D1	D2	D3
1	120	250	370
2	50	350	400
3	200	150	350
4	50	150	200
5	85	200	285
6	150	200	350
7	85	300	385
8	150	300	450

Figure 3.2. The eight step conditions, which were selected to span a large percentage of the step layouts on tractor cabs in the US. D1, the door offset, represents the horizontal offset between the top step and sill, or the bottom of the doorway. D2, the step offset, represents the horizontal offset between the front of both top and bottom steps. D3, the total offset, represents the total represents the horizontal offset between the bottom step and sill, or the bottom of the doorway. (a) Rear view of the step layout. (b) Side view of the step layout.

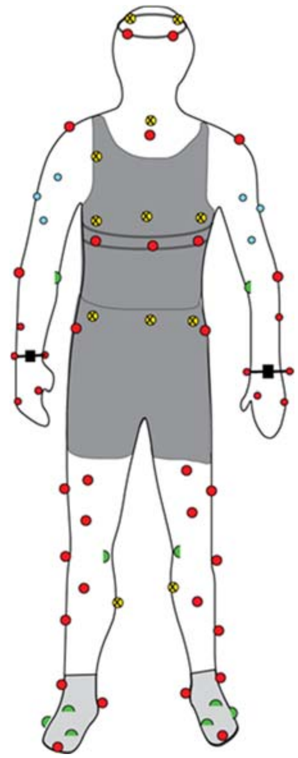


Figure 3.3. Participant marker set placement; yellow markers indicate markers on the back side. Figure provided by the University of Michigan Transportation Research Institute (UMTRI) and TruckStep.org. (www.trucksteps.org)

A score of 4, “average,” would correspond to their experience exiting real-world trucks that they also considered of average difficulty in egress. Participants also rated the acceptability of each experimental cab mockup configuration on an ordinal integer scale from 1 (very unacceptable) to 4 (very unacceptable).

Data Analysis

Data were processed and calculations were performed using Visual3D (v5.02.25, C-Motion, Germantown, MD, USA). Based on recommendations made by Winter (1990), video and analog data were collected at 60Hz and 300 Hz, respectively, and were filtered with a fourth-order low-pass Butterworth filter at 6Hz and 20Hz, respectively. Analyses were also performed based on Winter’s recommendations to select cutoff frequencies. Matlab (R2014a, The Mathworks Inc., Natick, MA, USA) was used to format gait data exported from Visual3D (C-Motion, Germantown, MD, USA) and SPSS (Version 21.0 for Windows, SPSS Science, Chicago, USA) was used to perform the final statistical analyses. BMI was included as a categorical variable with four levels based on the following criteria: normal weight (18.5<=BMI<25, *n*= 7); overweight (25<=BMI<30, *n*=14); obese (30<=BMI<35, *n*=21); and morbidly obese (BMI> 35, *n*=10). The Pearson Chi-squared test of independence was used to explore associations among the variables. A 2-factor (eight step configurations and two egress tactics) repeated measure ANOVA was performed on the egress ratings of difficulty and acceptability. The Chi Square Automatic Interaction Detection (CHAID), a forward sequential tree fitting method for partitioning data, was utilized as a clustering method using the study sample of 1369 egress trials from 52 truck drivers. The dependent, predicted, variable was the categorical foot behaviors.

The independent variables included the BMI, stature, weight, gender, egress tactic, and cab configuration. The cab configuration categorical variable was input into CHAID using four different forms, 8 categories, D1 categories, D2 categories, and D3 categories to allow for discrimination between the sources of variability in foot behaviors based on step characteristics as detailed in Figure 3.2. The tree procedure was selected for this part of the analysis because it makes the results easy to interrupt and this in turn served as the basis for structuring the biomechanical analysis of truck cab egress in Chapters 3 and 4. Statistical significance was chosen a priori at $\alpha = 0.05$.

The following hypotheses were evaluated:

H_1: Truck cab configuration affects driver foot behavior during truck cab egress.

H_2: Truck driver BMI is associated with differences in driver foot behavior during truck cab egress.

H_3: Truck driver egress tactics (FO vs FC) are associated with different foot behaviors.

H_4: Truck driver egress tactics affect driver hand behaviors.

H_5: Truck cab configuration affects driver ratings of difficulty and acceptability.

Systematic Data Analysis Methodology

The main objective during this phase of the research study is to develop an understanding of the driver behaviors to support the investigation of how those behaviors are modified by personal or vehicle characteristics, as well as define a systematic method of analysis for the egress motions.

Driver Egress Behaviors

The egress motions analyzed for this study span the period beginning with the leading foot leaving the sill and ending with initial double limb stance on the floor, i.e., trailing foot's initial contact with the floor. Driver egress tactics can be broadly divided into two major categories: facing the cab, also known as inward-facing (FC) and facing the cab, also known as outward-facing (FO). Subgroups within these categories can be further defined based on other aspects of step/handhold interaction. A graphical representation of the egress trail start, end, and beginning seated positions are included in Figure 3.4.

To better understand and classify foot behaviors, the egress motions were divided into phases based on specific events defined through the foot trajectory and force data based on foot contact with the steps and ground. There were three phases analyzed (Figure 3.5): the first phase (E1) encompasses the transition between the sill and top step, the second phase (E2) is the transition to the bottom step, and the third phase (E3) includes the transition to the ground includes; each phase was defined using beginning and ending events. E1 began once the driver’s leading foot left the sill, and ended when the trailing foot hit the top step. E2 began with the leading foot leaving the top step level, and ended with the trailing foot at the bottom step level. Finally, E3 was defined at the event when the leading foot left the bottom step level, and ended with the trailing foot initial contact on the floor plate, i.e., initial double stance on the floor.

The participant’s foot behaviors were analyzed based on the temporal order of feet used during the three transition phases of the egress motions: E1, E2, and E3. These behaviors are shown in Figure 3.6. The critical element of this classification methodology is the identification of when the leading foot reaches each step and the ground. For

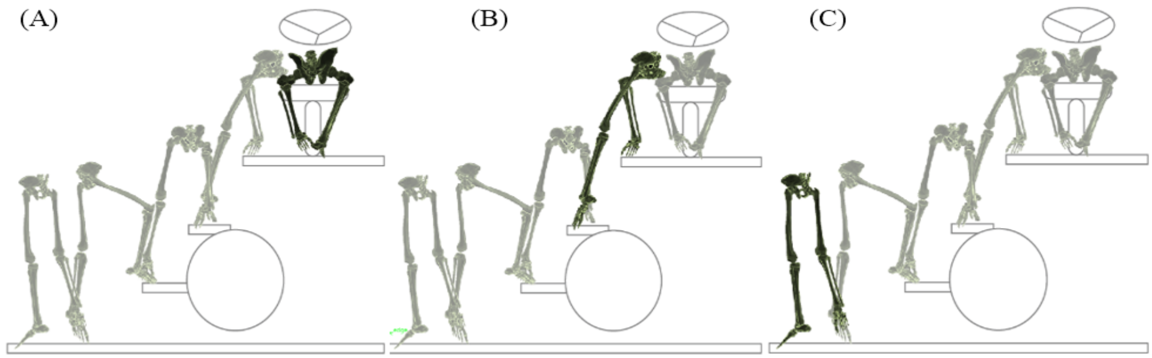


Figure 3.4. Egress motions analyzed for this study illustrated schematically in rear view. (A) Seated starting position of each participant during data collection. (B) Duration of the egress motion analysis began when the leading foot leaving the sill. (C) The egress motion analyzed ended with initial double stance support on the ground.

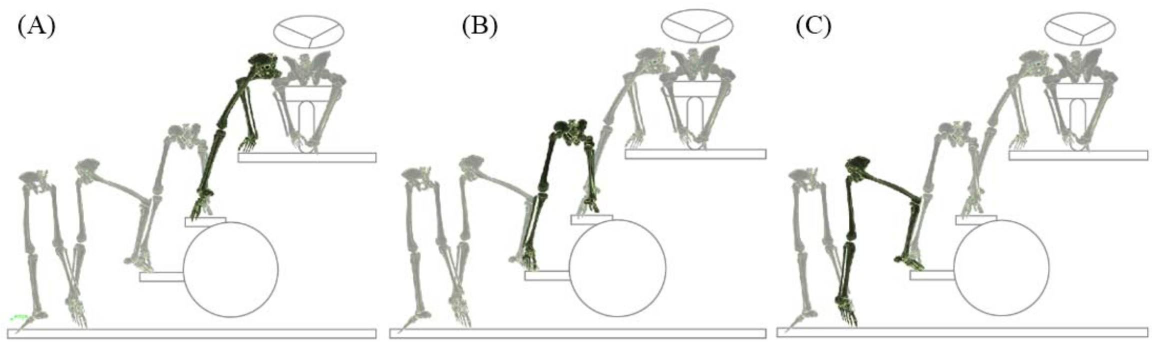


Figure 3.5. Three transition phases of the egress motions analyzed. (A) The transition from the cab sill to top step (E1). (B) The transition between the top step to the bottom step (E2). (C) The transition between the bottom step to the ground (E3).

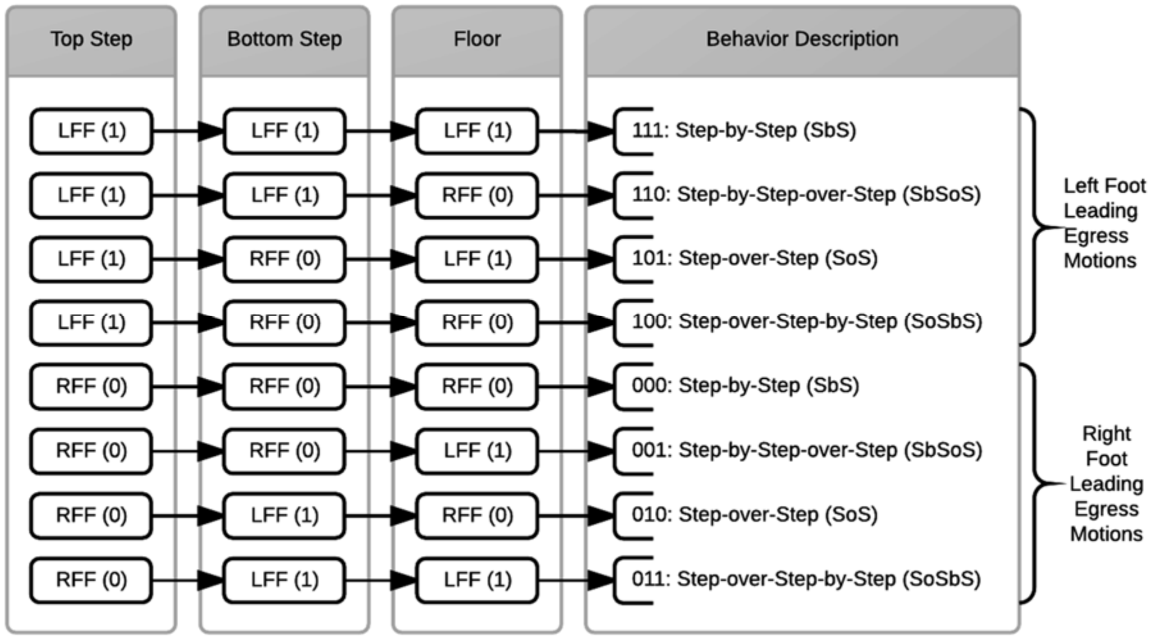


Figure 3.6. Foot behavior classifications and their respective descriptions used in the study analyses. Left foot first (LFF) is leading a given transition with the left foot first. Right foot first (RFF) is leading a given transition with the right foot first.

example, if the left foot reaches each step and the ground first (behavior code 111 in Figure 3.6), then the driver is executing the dual-foot strategy termed step-by-step (SbS), since the right foot follows the left foot to each step and the ground. In contrast, alternating feet, for example right-left-right, defines a step-over-step (SoS) tactic, labeled 101 or 010 in Figure 3.6.

Results

Overall Foot Behavior

A total of 1369 trials were analyzed. The distribution of participant egress behaviors across all trials is summarized in Figure 3.7 as a percentage of total trials. The most common foot behavior performed among all trials was the SoS foot behavior (815 trials, 58.5%), followed by the SoSbS foot behavior (313 trials, 22.86%).

When comparing the distribution of all truck driver foot behaviors over egress tactics, 651 (47.6%) of all trials were facing out and 718 (52.4%) were facing the cab. A summary of the distribution of foot behavior for each egress tactic, shown as a percent of each egress tactic's total, is shown in Figure 3.8. A chi-squared test of independence was performed to examine the association between driver tactics and foot behavior. The driver foot behavior is associated with egress tactic, X(7, N=1369) = 390.198, $p < 0.001$. The majority of the FC trials were performed with the 101 behavior (72.6%), followed by approximately 10% of the trials performing the 110 behavior and the remaining 18% distributed across the other behaviors described in Figure 3.6. A plurality of the FO trials were performed with the 101 behavior (45.2%), followed by approximately 43.2% of the trials performing the 100 behavior and the remaining 11.5% were other behaviors as

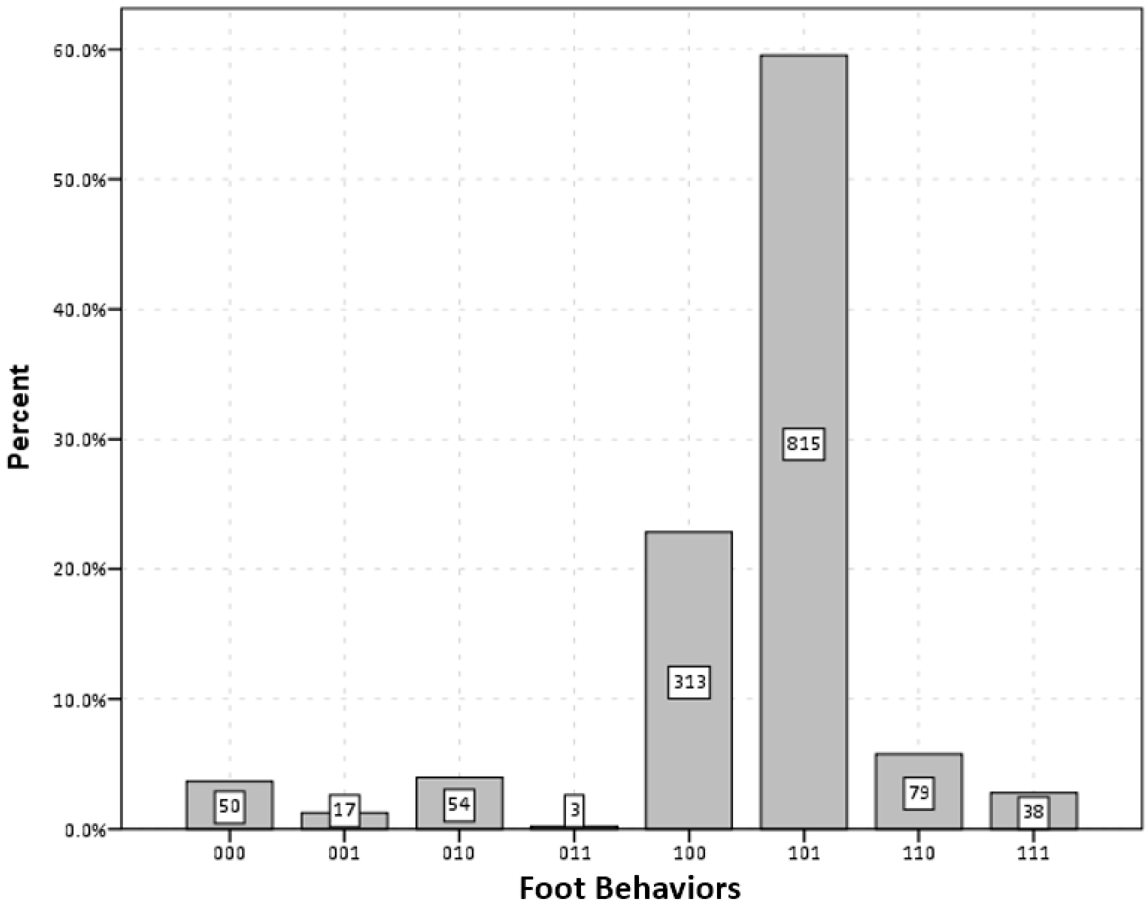


Figure 3.7. The distribution of observed foot behavior over the entire data analyzed (N=1369), with the number of trials observed above the respective foot behavior.

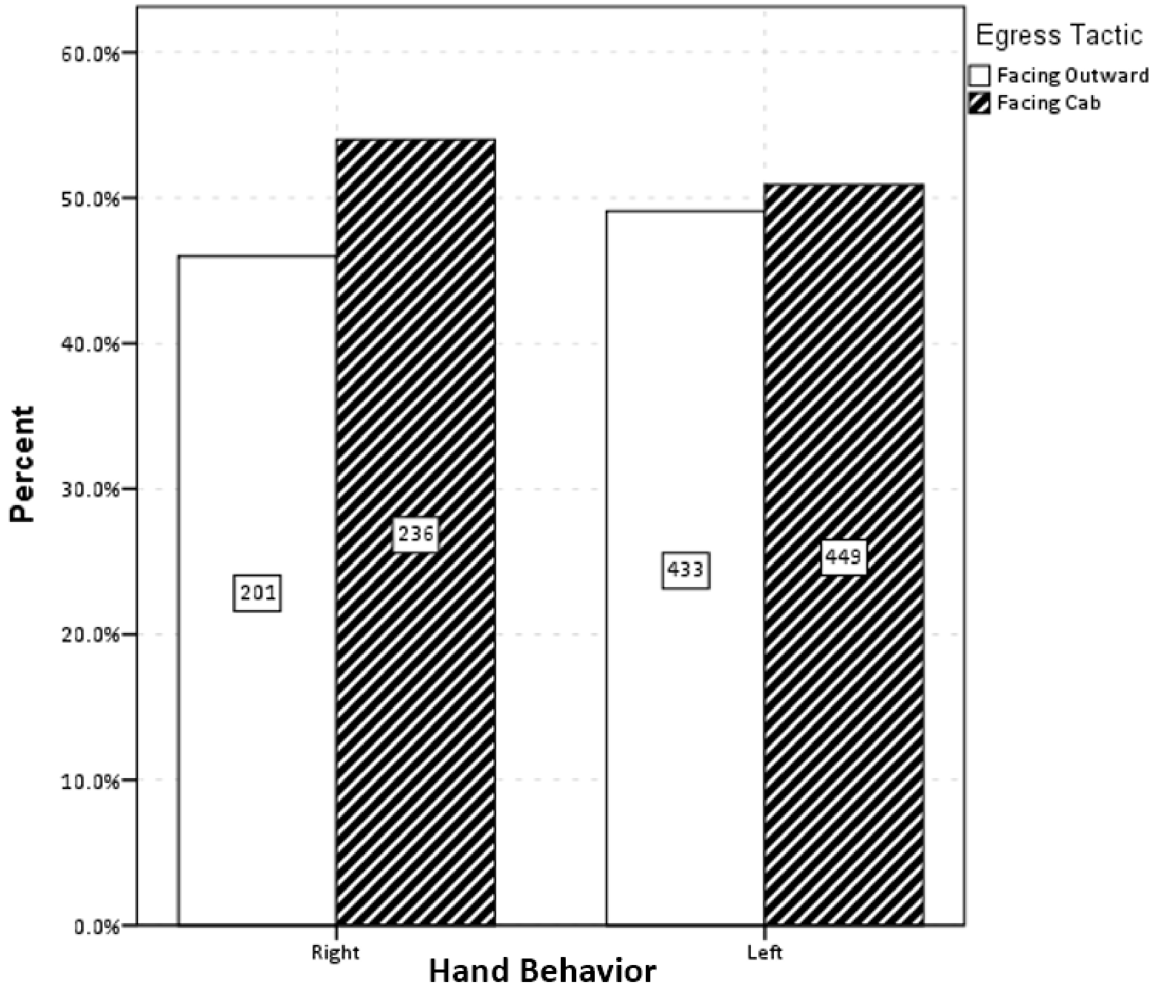


Figure 3.8. Distribution of hand behavior by tactic. Facing the cab vs. facing outward shown as a percentage of each total tactic observed trials.

described above.

The majority of study participants lead with their dominant foot since the SoS foot behavior 101, leading with left foot, was the most common foot behavior observed. Therefore, foot dominance was examined to investigate the effect of foot dominance on the distribution of foot behavior; these results are detailed in Table 3.2. Results showed that leading with the dominant foot (all but 7 participants are right footed) had no effect on the distribution of foot behaviors.

Overall Hand Behavior

Hand behavior was defined using the sequence of use of hands in the initial transition following the sit to transition. Study participants were observed to either lead the egress motions with their right hand first (RHF) or their left hand first (LHF). A majority of the participants 882 (64.4%) led with the left hand, whereas 31.9% (N=437) led with the right hand. The driver did not make hand contact with the mockup in 3.7 % of trials. The distribution of leading hand use was not significantly associated with the facing direction (FO vs. FC), nor with hand dominance (62.5% LHF (N=449), 32.9% (N=236) RHF, 4.6% (N=33) no hand used), as well as FO tactic (66.5% (N=433) LHF, 30.9% (N=201) RHF, 2.6% (N=17) no hand used). The Pearson chi-square test confirmed no significant effect of driver egress tactic on egress hand behavior $X(1, N=1319) = 1.123$, $p = 0.289$. These results are summarized as a percent of each total egress tactic in Figure 3.8.

Table 3.2. Distribution of foot behavior when considering participants' foot dominance.

Foot Behavior	Egress Tactic					
	Facing Outward (FO) (Left-Footed/All)		**Facing the Cab (FC) (Left-Footed/All)**		**Both (FC & FO) (Left-Footed/All)**	
	N	percentage*	*N*	percentage*	*N*	percentage*
000	4/4	0.6/0.6	46/46	7.8/7.1	50/50	4.1/3.7
001	11/11	1.8/1.5	6/6	1/0.9	17/17	1.4/1.2
010	44/49	7.1/6.8	4/5	0.7/0.8	48/54	4/3.9
011	2/3	0.3/0.4	0/0	0/0	2/3	0.2/0.2
100	25/32	4/4.5	248/281	42.2/43.2	273/313	22.6/22.9
101	453/521	72.8/72.6	271/294	46.1/45.2	724/815	59.8/59.5
110	60/70	9.6/9.7	8/9	1.4/1.4	68/79	5.6/5.8
111	23/28	3.7/3.9	5/10	0.9/1.5	28/38	2.3/2.8
Total	586/651	100.0/100.0	626/718	100.0/100.0	1212/1369	100.0/100.0

*Note: percentages may not sum to 100 due to rounding

Egress Style: Hand and Foot Behaviors

In Figure 3.7, the SoS foot behavior was observed to be the leading type of behavior when considering all the study trials (N=1369). Still, when considering hand behavior influence on the distribution of drivers' foot behavior, the SoS foot behavior is observed to be the most common type of foot behavior among both groups; participants leading with the right hand totaled 250 (59.1%) and participants leading with the left hand totaled 521 (57.2%). In other words, the majority of the participants still use the 101 SoS behavior regardless of which hand they used to lead the egress motions (see Figure 3.9).

This is very similar to the percentage of SoS foot behavior (815 trials, 58.5%) of total trials analyzed when not taking into account the hand behavior. The Pearson chi-square test indicated that there was no significant effect of driver egress hand behavior on the egress foot behaviors between the two groups; therefore, leading egress motions with hand first right or left was not affected by tactic, $X(1, N=1084) = 0.589$, $p = 0.443$.

In other words, the majority of the participants still use the 101 SoS behavior regardless of which hand they used to lead the egress motions. This is very similar to the percentage of SoS foot behavior (815 trials, 58.5%) of total trials analyzed when not taking into account the hand behavior. The Pearson chi-square test indicated that there was no significant effect of driver egress hand behavior on the egress foot behaviors between the two groups; therefore, leading egress motions with right or left hand first was not affected by tactic, $X(1, N=1084) = 0.589$, $p = 0.443$.

Further breakdown of the trials by considering hand dominance revealed similar findings. Using the dominant hand (right for most participants, all but 7) to lead the egress motions did not have an effect on the drivers' foot behavior; that is, the SoS 101 behavior.

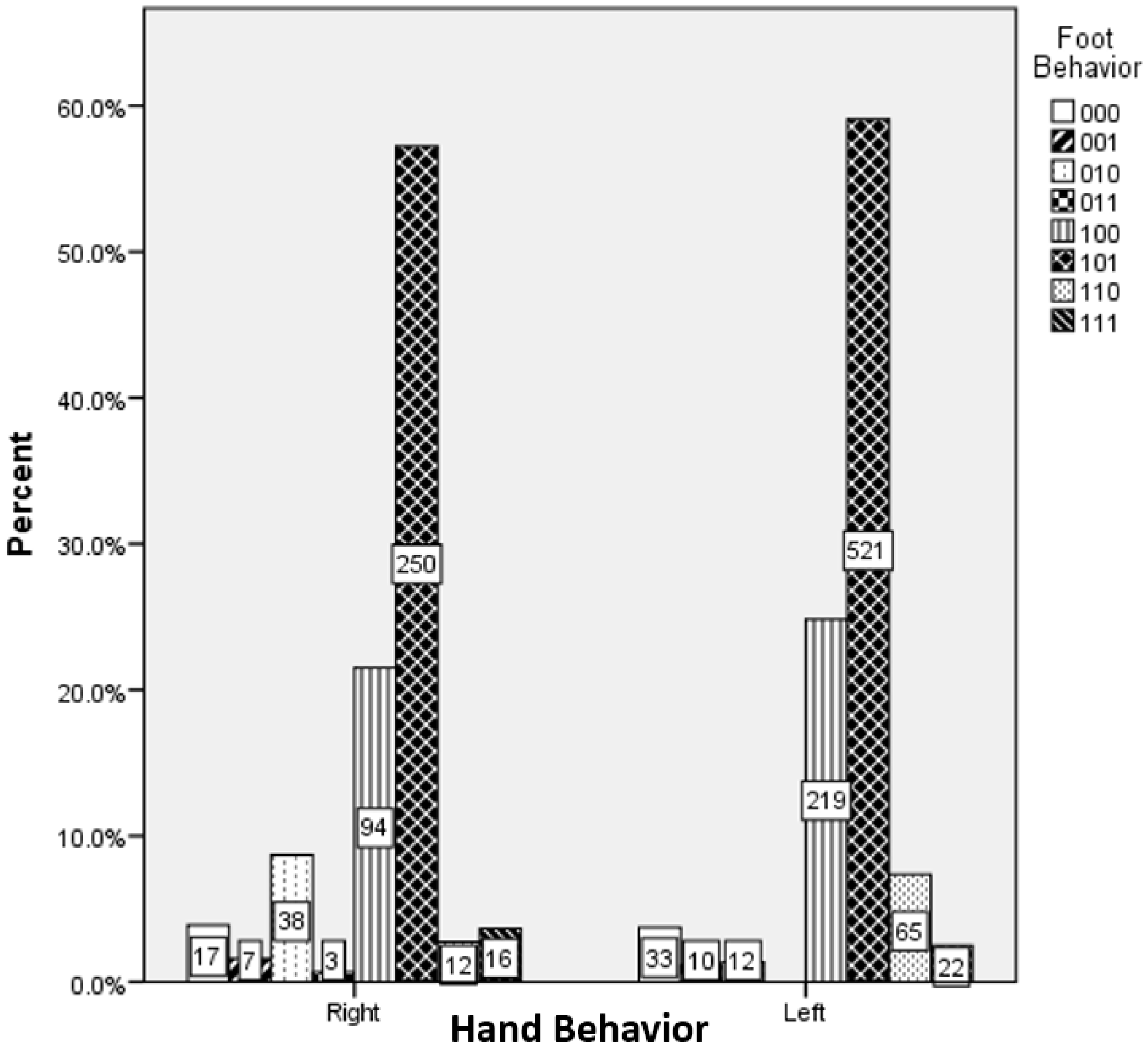


Figure 3.9. The distribution of foot behavior by hand behavior (RHF vs. LHF) shown as a percentage of each total hand behavior.

The same observation is also seen when looking at the distribution clustered by the egress tactic (FC/FO). Figure 3.10 compares the distribution of foot behaviors by overall tactic (FC vs. FO) and leading hand. The Pearson chi-square test indicated that there is no significant effect of driver egress hand behavior on foot behavior for both FC, $X(1, N=526) = 1.699$, $p = 0.192$, and FO egress tactics, FO $X(1, N=558) = 0.013$, $p = 0.909$.

BMI and Step Configuration Effect on Foot Behavior by Tactic

The distribution of drivers' foot behavior broken into egress tactics over all BMI groups is summarized in Table 3.3 and a graphical representation of the distributions are shown in Figure 3.11. Step configuration effect on foot behavior over each tactic was investigated. The Pearson chi-square test indicated that there is no significant effect of cab step configuration on foot behavior for both FC, $X(7, N=553) = 13.283$, $p = 0.066$, and FO egress tactics, $X(7, N=575) = 3.320$, $p = 0.854$. The summary of foot behavior distributions are summarized in Table 3.4, which displays the counts and percentages of total foot behaviors over each step configuration. Driver BMI category was associated with foot behavior for both FC, $X(12, N=700) = 150.368$, $p = 0.000$, and FO, $X(6, N=621) = 117.621$, $p = 0.000$.

Ratings of Difficulty and Acceptability

The participants' ratings of difficulty are summarized for each egress tactic and configuration in Table 3.5. Egress ratings of difficulty summary is shown as counts and percent of total step configuration.

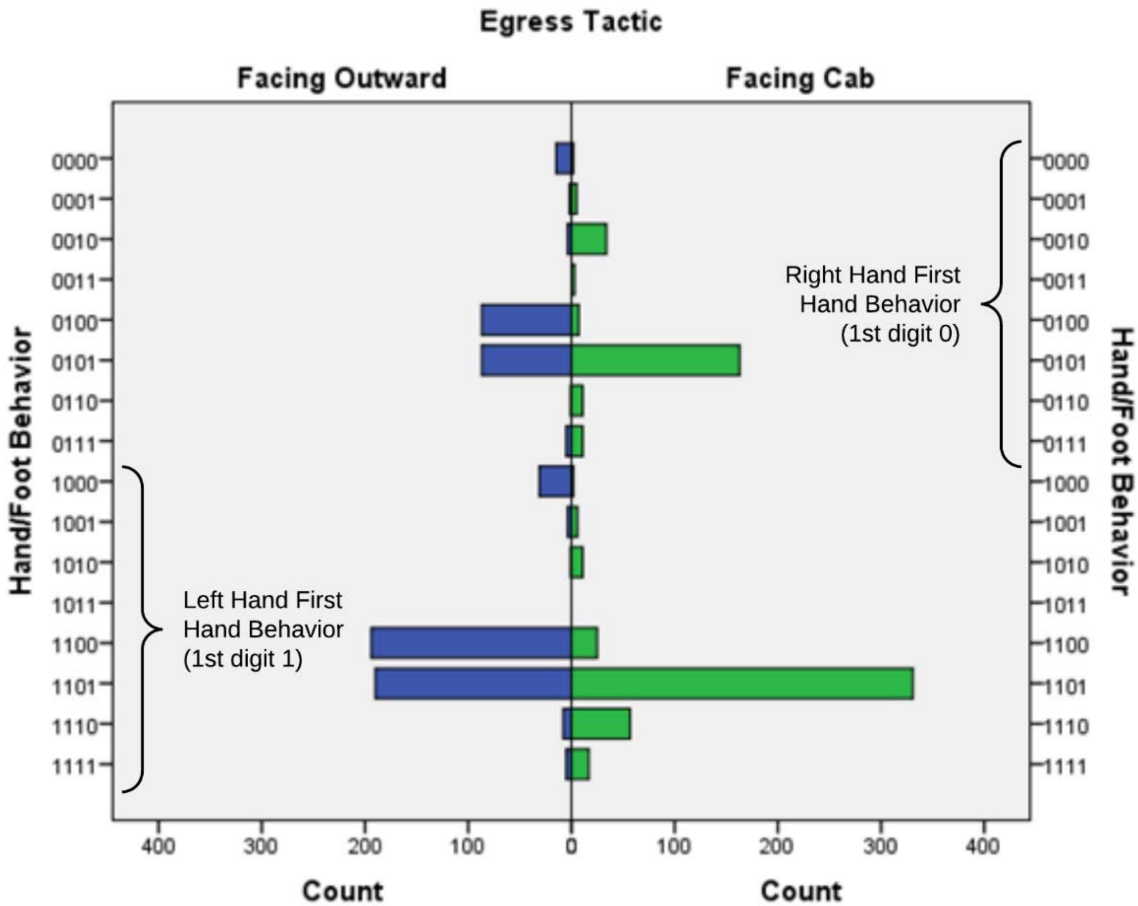


Figure 3.10. Distribution of foot and hand behavior frequencies by tactic. Facing the cab vs. facing outward shown as a percentage of each total tactic and hand behavior observed trials.

Table 3.3. Driver foot behavior distributions over each BMI group for both egress tactics

		BMI (Groups)			
		1	2	3	4
Egress Tactic	**Foot Behavior**	***N* (%)**	***N* (%)**	***N* (%)**	***N* (%)**
FO	**000**	-	16 (7.8)	29 (12.4)	1 (1)
	001	1 (0.9)	4 (2.0)	1 (0.4)	-
	010	1 (0.9)	3 (1.5)	1 (0.4)	-
	011	-	-	-	-
	100	14 (12.2)	84 (41.2)	122 (52.4)	61 (61.6)
	101	98 (85.2)	95 (46.6)	75 (32.2)	26 (26.3)
	110	1 (0.9)	1 (0.5)	1 (0.4)	6 (6.1)
	111	-	1 (0.5)	4 (1.7)	5 (5.1)
FC	**000**	-	-	3 (1.2)	1 (0.9)
	001	-	3 (1.3)	4 (1.5)	4 (3.6)
	010	9 (7.6)	37 (16.1)	1 (0.4)	2 (1.8)
	011	1 (0.8)	1 (0.4)	()	1 (0.9)
	100	3 (2.5)	2 (0.9)	10 (3.8)	17 (15.5)
	101	102 (86.4)	137 (59.6)	221 (85.0)	61 (55.5)
	110	3 (2.5)	42 (18.3)	9 (3.5)	16 (14.5)
	111	-	8 (3.5)	12 (4.6)	8 (7.3)

*Note: percentages may not sum to 100 due to rounding.

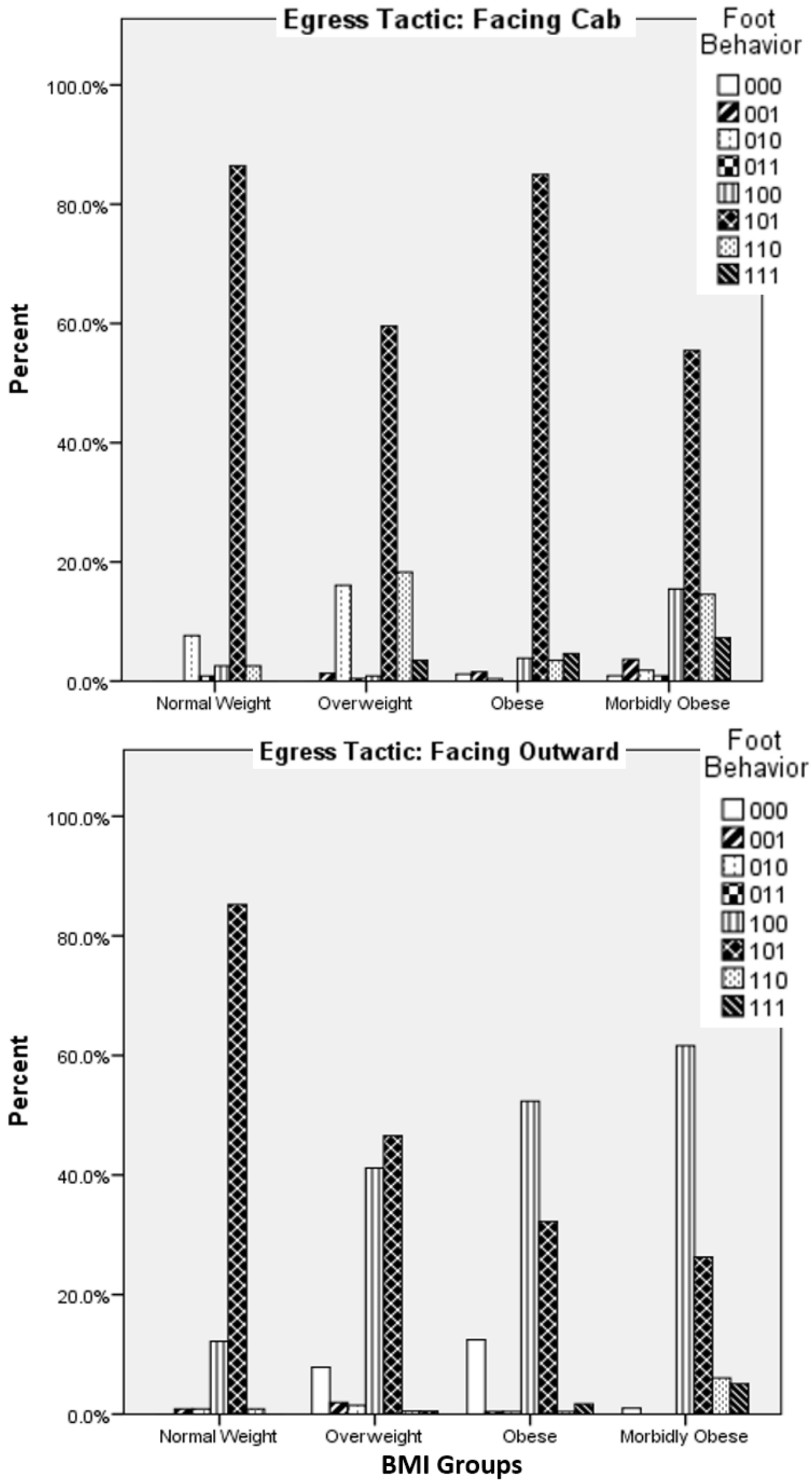


Figure 3.11. The distribution of foot behaviors for all BMI categories analyzed for both egress tactics

Table 3.4. Foot behavior distributions broken by tactic and step configuration

Egress Tactic	Step Configuration	Foot Behavior 000 N (%)	001 N (%)	010 N (%)	011 N (%)	100 N (%)	101 N (%)	110 N (%)	111 N (%)
FO	**1**	9 (7.5)	2 (1.7)	2 (1.7)	0 (0)	51 (42.5)	51 (42.5)	4 (3.3)	1 (0.8)
	2	6 (5.8)	1 (1)	1 (1)	0 (0)	48 (46.6)	45 (43.7)	0 (0)	2 (1.9)
	3	7 (6.2)	1 (0.9)	2 (1.8)	0 (0)	49 (43.4)	50 (44.2)	3 (2.7)	1 (0.9)
	4	10 (10)	1 (1)	0 (0)	0 (0)	43 (43)	42 (42)	1 (1)	3 (3)
	5	6 (11.1)	0 (0)	0 (0)	0 (0)	18 (33.3)	30 (55.6)	0 (0)	0 (0)
	6	2 (3.9)	0 (0)	0 (0)	0 (0)	22 (43.1)	26 (51)	0 (0)	1 (2)
	7	2 (3.7)	0 (0)	0 (0)	0 (0)	26 (48.1)	24 (44.4)	1 (1.9)	1 (1.9)
	8	4 (7.1)	1 (1.8)	0 (0)	0 (0)	24 (42.9)	26 (46.4)	0 (0)	1 (1.8)
FC	**1**	0 (0)	2 (1.5)	8 (6.2)	0 (0)	8 (6.2)	91 (70)	13 (10)	8 (6.2)
	2	0 (0)	3 (2.6)	7 (6.1)	0 (0)	8 (7)	75 (65.8)	15 (13.2)	6 (5.3)
	3	1 (0.9)	3 (2.7)	5 (4.5)	2 (1.8)	7 (6.3)	75 (67.6)	8 (7.2)	10 (9)
	4	0 (0)	2 (2)	5 (4.9)	0 (0)	6 (5.9)	72 (70.6)	15 (14.7)	2 (2)
	5	1 (1.5)	0 (0)	4 (6.2)	1 (1.5)	0 (0)	53 (81.5)	5 (7.7)	1 (1.5)
	6	0 (0)	0 (0)	6 (9.4)	0 (0)	1 (1.6)	51 (79.7)	6 (9.4)	0 (0)
	7	0 (0)	0 (0)	6 (9)	0 (0)	0 (0)	56 (83.6)	4 (6)	1 (1.5)
	8	2 (3.1)	1 (1.5)	8 (12.3)	0 (0)	2 (3.1)	48 (73.8)	4 (6.2)	0 (0)

*Note: percentages may not sum to 100 due to rounding.

Table 3.5. Egress ratings of difficulty summary shown as counts and percent of total step configuration

Step Configuration			**Egress Ratings of Difficulty**													
			1		**2**		**3**		**4**		**5**		**6**		**7**	
#	D1	D2	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
6	150	200	34	29.6	23	20.0	22	19.1	20	17.4	13	11.3	1	0.9	2	1.7
8	150	300	34	28.1	23	19.0	21	17.4	26	21.5	11	9.1	3	2.5	3	2.5
5	85	200	32	26.9	21	17.6	15	12.6	33	27.7	10	8.4	4	3.4	4	3.4
3	200	150	59	26.6	49	22.1	36	16.2	46	20.7	22	9.9	3	1.4	7	3.2
7	85	300	31	25.6	18	14.9	15	12.4	32	26.4	16	13.2	5	4.1	4	3.3
1	120	250	58	23.3	46	18.5	35	14.1	59	23.7	32	12.9	17	6.8	2	0.8
4	50	150	24	12.0	26	13.0	33	16.5	46	23.0	37	18.5	18	9.0	16	8.0
2	50	350	19	8.8	29	13.5	29	13.5	49	22.8	46	21.4	26	12.1	17	7.9

*Note: percentages may not sum to 100 due to rounding

A 2-factor (eight step configurations and two egress tactic) repeated measure ANOVA, N=43, was performed on the egress ratings of difficulty as a continuous measure. Step configuration significantly affected the mean difficulty rating $F(2.866, 25.796) = 4.862$, $p < .01$. However, tactic was not significantly associated with difficulty rating $F(1,9)=1.233$, and no significant interaction effect between tactic and step configuration was observed $F(2.568,23.114)=0.943$. While the main effect of egress tactic was not significant, participants overall had better ratings when facing the cab rather than the facing outward egress tactics, as shown in Figure 3.12.

The participants' ratings of acceptability are summarized in Table 3.6 for each egress tactic and configuration. In Table 3.6, a summary of the egress ratings of acceptability are shown as counts and percent of total step configuration.

A 2-factor (eight step configurations and two egress tactics) repeated measure ANOVA, N=43, was performed on the egress ratings of acceptability. There is a significant main effect of step configuration on ratings, $F(2.441,21.966) = 3.236$, $p = .05$. There is, however, no main effect of tactic on egress ratings of acceptability, $F(1,9)=1.328$, and no significant interaction effect, $F(7,63)=0.576$. While the main effect of egress tactic on ratings of acceptability was not significant, participants overall had better levels of acceptability ratings when facing the cab when compared to facing outward egress tactic, as shown in Figure 3.13.

The FC tactic was associated with greater acceptability across step configurations than the FO tactic. Step configurations 2 and 4 were consistently rated among the most difficult and most unacceptable for both egress tactics. These configurations (see Figure 3.2), lowest sill to top step clearances, suggest that lower clearances are not adequate for a

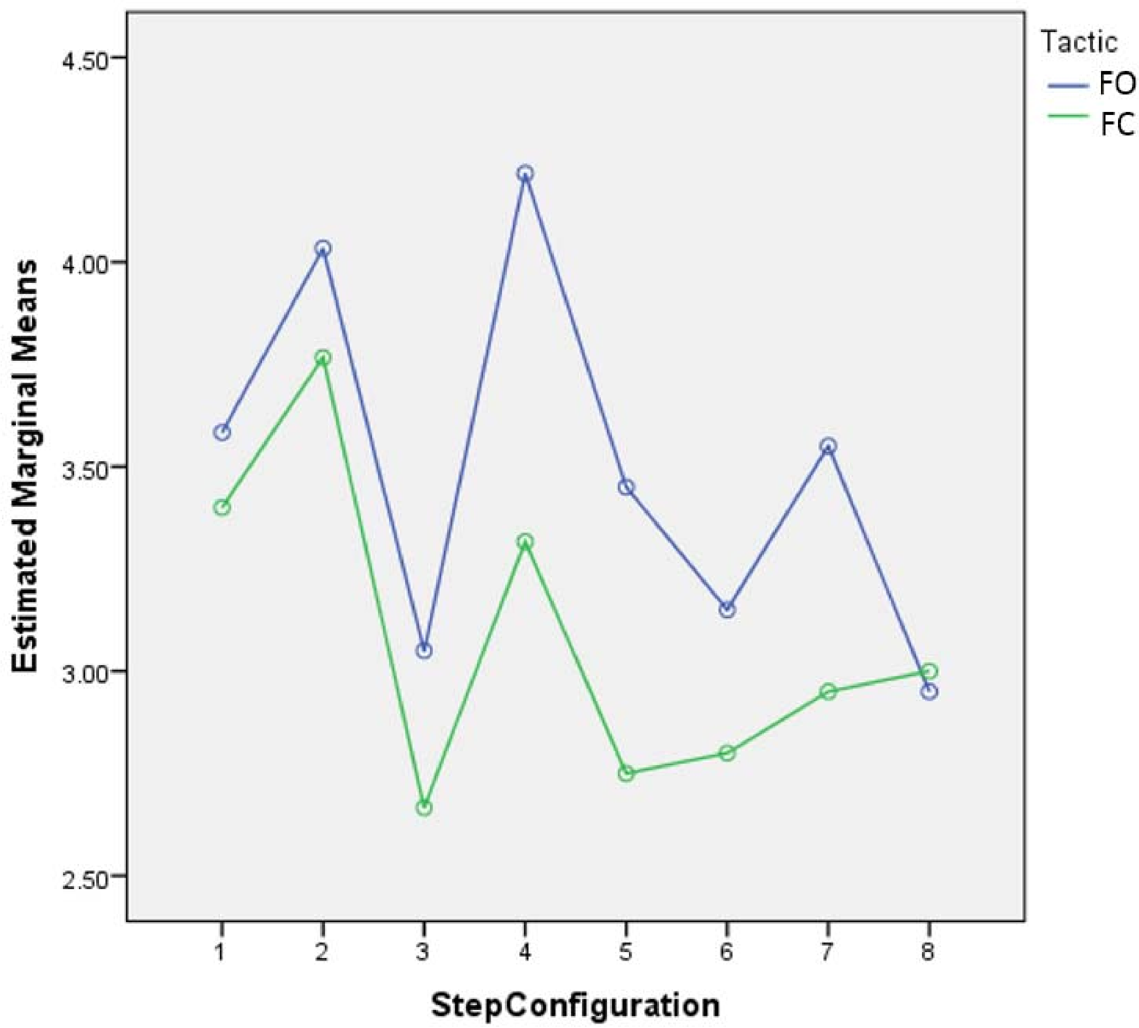


Figure 3.12. Estimated marginal means plot of the egress ratings of difficulty for both egress tactics.

Table 3.6. Egress ratings of acceptability summary shown as counts and percent of total step configuration.

Step Configuration			Egress Ratings of Acceptability							
			1		2		3		4	
#	D1	D2	*N*	%	*N*	%	*N*	%	*N*	%
3	200	150	84	37.8	104	46.8	25	11.3	9	4.1
6	150	200	36	31.3	65	56.5	9	7.8	5	4.3
8	150	300	37	30.6	66	54.5	12	9.9	6	5.0
5	85	200	33	27.7	65	54.6	15	12.6	6	5.0
1	120	250	66	26.6	125	50.4	47	19.0	10	4.0
7	85	300	29	24.0	63	52.1	23	19.0	6	5.0
4	50	150	27	13.5	90	45.0	63	31.5	20	10.0
2	50	350	21	9.8	85	39.5	84	39.1	25	11.6

*Note: percentages may not sum to 100 due to rounding

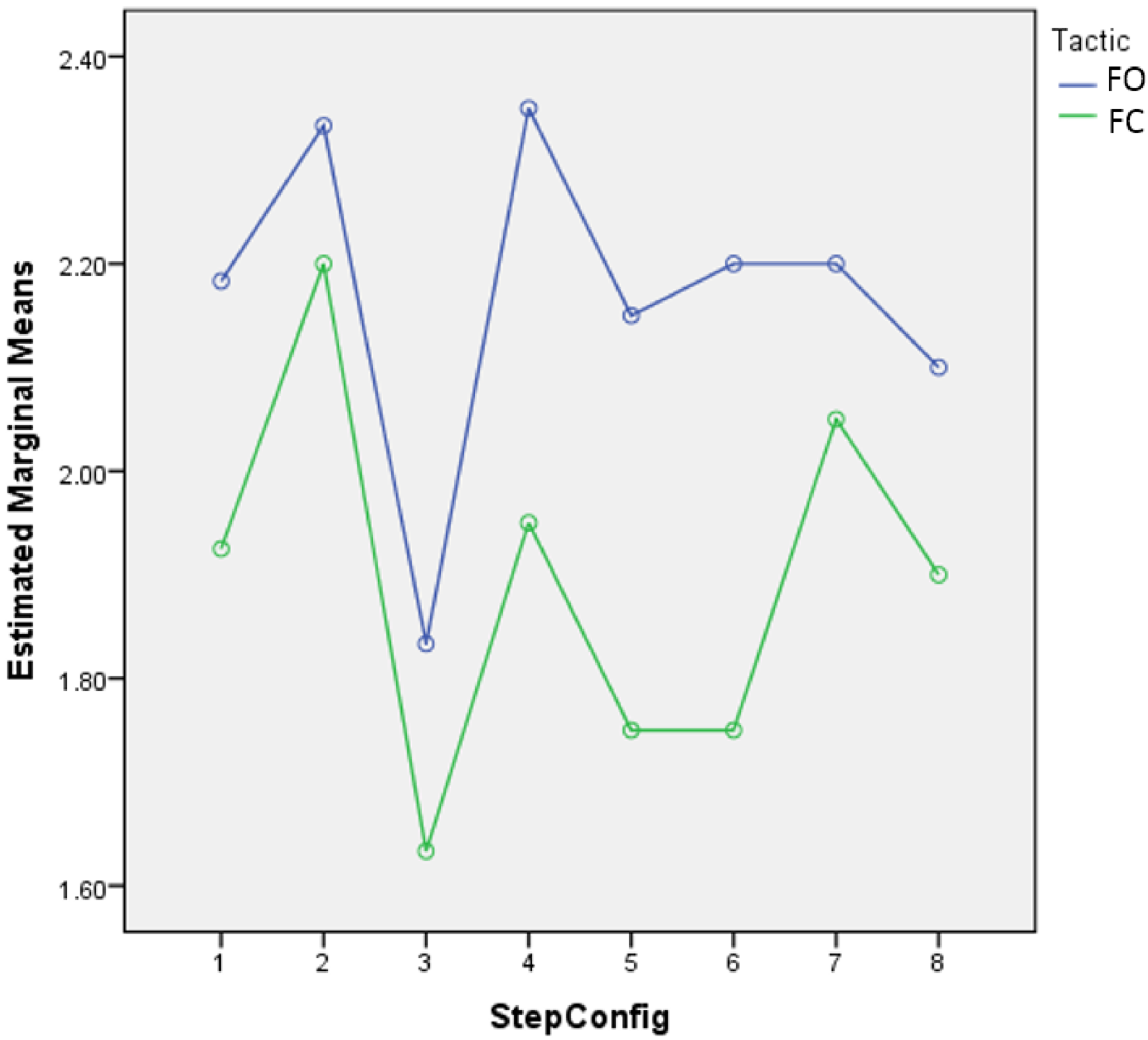


Figure 3.13. Estimated marginal means plot of the egress ratings of acceptability for both egress tactics.

satisfactory driver egress experience.

Results from the CHAID forward sequential tree fitting method showed similar results to the detailed chi-squared and ANOVA tests performed. The overall model has a risk estimate of 0.345 (standard error 0.013), indicating that the foot behaviors predicted by the model (egress tactics, BMI and step configuration) are accurate for 65.5% of the cases. So the "risk" of misclassifying a given egress foot behavior is approximately 34.5%. The tree procedure was selected for this part of the analysis because it makes the results easy to interrupt and this in turn served as the basis for structuring the biomechanical analysis of truck cab egress in Chapters 3 and 4. This analysis shows egress tactic as a lead factor affecting foot behavior during truck cab egress, $X(7, N=1369) = 390.198$, $p = 0.00$. BMI also accounted for alterations in foot behaviors, FO $X(18, N=651) = 154.771$, $p = 0.000$, and FC $X(21, N=718) = 160.941$, $p = 0.000$. Finally, when using the FC egress tactic, foot behavior was modified for those in the obese BMI category by the sill/top step, (<=150) $X(6, N=260 = 19.351, p = 0.025)$, or top/bottom step (<=50), $X(6, N=260 = 19.351$, $p = 0.025$, or overall clearance (<=120), $X(6, N=260 = 19.351, p = 0.025)$.

Discussion

The most common foot behavior among all trials performed was the SoS foot behavior, 58.5%, followed by the SoSbS foot behavior, 22.86%. Driver foot behaviors differed significantly across overall egress tactic (FC vs. FO). However, hand behavior was not associated with foot behavior or overall tactic. There was no effect of truck driver tactics on driver hand behavior during truck cab egress. There was no effect of hand behavior on foot behavior. Driver BMI was associated with driver foot behavior, with results indicating that among the FC group, the morbidly obese group has a shift from the SoS foot behavior to a variety of foot behaviors including, ones that involve leading with the right foot, but still during the SoS foot behavior, was the most among the morbidly obese group as it was for all other groups. In contrast, among the FO tactic, as we increase in BMI groups, the participants shift from using SoS foot behavior into a less demanding SbSoS foot behavior (denoted with 110). This trend is seen across the entire sample. Surprisingly, step configuration was not significantly associated with foot behaviors. Step configuration influenced driver ratings of difficulty and acceptability. Cab configurations 2 and 4 were rated as being more difficult and unacceptable.

Conclusion

The most common truck driver egress foot behavior was SoS. This is consistent with findings from regular stair ambulation biomechanics (Reid et al., 2007), and suggests that SoSbS is likely the compensatory alternative foot behavior adopted by individuals with higher BMI, i.e., the obese and morbidly obese groups. This can also be a compensatory alternative pattern resulting from step designs that do not provide enough clearance for typical step ambulation (SoS), i.e., step configuration 2 and 4 with D1=50 mm sill-top clearances. This implies that BMI significantly affected tactic and influenced foot behaviors to a less demanding foot behavior during egress stair negotiations. Therefore, from these data, it appears that higher BMI groups behavior is indicative of stress compensation as a result of changes in egress tactic, i.e., the facing out tactic.

Foot behavior variance was best explained by egress tactic, BMI, and step configuration. Therefore, consideration of analyses of truck driver IE should take into account common foot behaviors, BMI, and step configuration. Furthermore, egress tactic seems to account for the majority of the variance in foot behavior; thus, further investigation into the effect of egress tactics on other factors related to slips and falls is necessary.

References

Chateauroux, E., Wang, X., & Roybin, C. (2012). Analysis of truck cabin egress motion. *International Journal of Human Factors Modelling and Simulation*, *3*(2), 169-186. doi:10.1504/IJHFMS.2012.051095.

Fathallah, F. A., & Cotnam, J. P. (2000). Maximum forces sustained during various methods of exiting commercial tractors, trailers and trucks. *Applied Ergonomics, 31*(1), 25-33.

Gates, D. H., Lelas, J., Della Croce, U., Herr, H., & Bonato, P. (2004). Characterization of ankle function during stair ambulation. In *Engineering in Medicine and Biology Society, 2004 (IEMBS'04). 26th Annual International Conference of the IEEE* (Vol. 2, pp. 4248-4251). IEEE. doi: 10.1109/IEMBS.2004.1404184.

Giguère, D., & Marchand, D. (2005). Perceived safety and biomechanical stress to the lower limbs when stepping down from fire fighting vehicles. *Applied Ergonomics*, *36*(1), 107-119.

Guan, J., Hsiao, H., Bradtmiller, B., Kau, T.-Y., Reed, M. R., Jahns, S. K., . . . Piamonte, D. P. T. (2012). US truck driver anthropometric study and multivariate anthropometric models for cab designs. *Human Factors: The Journal of the Human Factors and Ergonomics Society*. doi:10.1177/0018720812442685.

Hall, M., Stevermer, C. A., & Gillette, J. C. (2015). Muscle activity amplitudes and co-contraction during stair ambulation following anterior cruciate ligament reconstruction. *Journal of Electromyography and Kinesiology*, *25*(2), 298-304. doi: 10.1016/j.jelekin.2015.01.007.

Hobara, H., Kobayashi, Y., Tominaga, S., Nakamura, T., Yamasaki, N., & Ogata, T. (2013). Factors affecting stair-ascent patterns in unilateral transfemoral amputees. *Prosthetics and Orthotics International*, *37*(3), 222-226. doi: 10.1177/0309364612461166.

Kennedy, R. A., Boreham, C. A., Murphy, M. H., Young, I. S., & Mutrie, N. (2007). Evaluating the effects of a low volume stair climbing programme on measures of health-related fitness in sedentary office workers. *Journal of Sports Science and Medicine*, *6*(4), 448-454.

Laudanski, A., Brouwer, B., & Li, Q. (2015). Activity classification in persons with stroke based on frequency features. *Medical Engineering & Physics*, *37*(2), 180-186. doi: 10.1016/j.medengphy.2014.11.008.

Lin, Y. C., Fok, L. A., Schache, A. G., & Pandy, M. G. (2015). Muscle coordination of support, progression and balance during stair ambulation. *Journal of Biomechanics*, *48*(2), 340-347. doi: 10.1016/j.jbiomech.2014.11.019.

Livingston, L. A., Stevenson, J. M., & Olney, S. J. (1991). Stairclimbing kinematics on stairs of differing dimensions. *Archives of Physical Medicine and Rehabilitation*, *72*(6), 398-402. doi: 10.5555/uri:pii:000399939190174H.

Loy, S. F., Conley, L. M., Sacco, E. R., Vincent, W. J., Holland, G. J., Sletten, E. G., & Trueblood, P. R. (1994). Effects of stairclimbing on VO2max and quadriceps strength in middle-aged females. *Medicine and Science in Sports and Exercise*, *26*(2), 241-247.

Modai, G., Sharon, B., Bar-Haim, S., & Hutzler, Y. (2015). Stair climbing test post-stroke: feasibility, convergent validity and metabolic, cardiac, and respiratory responses. *Topics in Stroke Rehabilitation*, *22*(4), 281-288. doi: 10.1179/1074935714Z.0000000021.

Monnier, G., Chateauroux, E., Wang, X., & Roybin, C. (2009). Inverse dynamic reconstruction of truck cabin ingress/egress motions. *SAE International Journal of Passenger Cars-Mechanical Systems, 2*(1), 1593-1599.

Novak, A. C., & Brouwer, B. (2013). Kinematic and kinetic evaluation of the stance phase of stair ambulation in persons with stroke and healthy adults: A pilot study. *Journal of Applied Biomechanics*, *29*(4), 443-452.

Ojha, H. A., Kern, R. W., Lin, C. H., & Winstein, C. J. (2009). Age affects the attentional demands of stair ambulation: Evidence from a dual-task approach. *Physical Therapy*, *89*(10), 1080-1088. doi: 10.2522/ptj.20080187.

Patenaude, S., Marchand, D., Samperi, S., & Belanger, M. (2001). The effect of the descent technique and truck cabin layout on the landing impact forces. *Applied Ergonomics*, *32*(6), 573-582.

Ramstrand, N., & Nilsson, K. A. (2009). A comparison of foot placement strategies of transtibial amputees and able-bodied subjects during stair ambulation. *Prosthetics and Orthotics International*, *33*(4), 348-355. doi: 10.3109/03093640903074891.

Reed, M. P. (2010a). Ingress/Egress Safety for Truck Drivers. Retrieved March, 02, 2016, from http://trucksteps.org/index.html.

Reed, M. P. (2010b). Ingress/Egress System Dimensions. Retrieved March, 02, 2016, from http://trucksteps.org/dimensions.html.

Reed, M. P., Ebert-Hamilton, S. M., & Hoffman, S. G. (2010a). Hand positions and forces during truck ingress. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 54, No. 15, pp. 1097-1100). SAGE Publications.

Reed, M. P., Hoffman, S. G., & Ebert-Hamilton, S. M. (2010b). The influence of heavy truck egress tactics on ground reaction force. *Research and Practice for Fall Injury Control in the Workplace*, pp. 192-195.

Reed, M. P., Ebert, S. M., & Hoffman, S. G. (2010c). Modeling foot trajectories for heavy truck ingress simulation. In *Proceedings of the Applied Human Factors and Ergonomics Conference,* Miami, FL.

Reid, S. M., Lynn, S. K., Musselman, R. P., & Costigan, P. A. (2007). Knee biomechanics of alternate stair ambulation patterns. *Medicine and Science in Sports and Exercise*, *39*(11), 2005-2011. doi: 10.1249/mss.0b013e31814538c8.

Schmalz, T., Blumentritt, S., & Marx, B. (2007). Biomechanical analysis of stair ambulation in lower limb amputees. *Gait & Posture*, *25*(2), 267-278. doi: 10.1016/j.gaitpost.2006.04.008

Shiomi, T. (1994). Effects of different patterns of stairclimbing on physiological cost and motor efficiency. *Journal of Human Ergology (Tokyo)*, *23*(2), 111-120.

Shorti, R., Merryweather, A., Thiese, M., Kapellusch, J., Garg, A., & Hegmann, K. (2014). Fall risk factors for commercial truck drivers. *Journal of Ergonomics*, *9*(3), 1-9. doi: 10.4172/2165-7556.S3-009.

Sinitski, E. H., Hansen, A. H., & Wilken, J. M. (2012). Biomechanics of the ankle-foot system during stair ambulation: Implications for design of advanced ankle-foot prostheses. *Journal of Biomechanics*, *45*(3), 588-594. doi: 10.1016/j.jbiomech.2011.11.007.

Song, Q., Yu, B., Zhang, C., Sun, W., & Mao, D. (2014). Effects of backpack weight on posture, gait patterns and ground reaction forces of male children with obesity during stair descent. *Research in Sports Medicine*, *22*(2), 172-184. doi: 10.1080/15438627.2014.881823.

Standifird, T. W., Cates, H. E., & Zhang, S. (2014). Stair ambulation biomechanics following total knee arthroplasty: A systematic review. *The Journal of Arthroplasty*, *29*(9), 1857-1862. doi: 10.1016/j.arth.2014.03.040.

Startzell, J. K., Owens, D. A., Mulfinger, L. M., & Cavanagh, P. R. (2000). Stair negotiation in older people: A review. *Journal of the American Geriatrics Society*, *48*(5), 567-580.

Studenski, S., Duncan, P. W., Chandler, J., Samsa, G., Prescott, B., Hogue, C., & Bearon, L. B. (1994). Predicting falls: The role of mobility and nonphysical factors. *Journal of the American Geriatrics Society*, *42*(3), 297-302.

Tiedemann, A. C., Sherrington, C., & Lord, S. R. (2007). Physical and psychological factors associated with stair negotiation performance in older people. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *62*(11), 1259-1265.

Varnell, M. S., Bhowmik-Stoker, M., McCamley, J., Jacofsky, M. C., Campbell, M., & Jacofsky, D. (2011). Difference in stair negotiation ability based on TKA surgical approach. *The Journal of Knee Surgery*, *24*(2), 117-123.

CHAPTER 4

EFFECTS OF EGRESS TACTIC, STEP CONFIGURATION, AND DRIVER CHARACTERISTICS ON DRIVER INTERACTION WITH THE CAB DURING EGRESS AMONG THE MOST COMMON STEP NEGOTIATION PATTERN

Abstract

A laboratory study at UMTRI was conducted with a total of 52 drivers. Nine of the drivers (18%) were female, with a wide range of body dimensions and age. Stature, body weight, and 15 other standard anthropometric dimensions were obtained from each participant. This chapter presents a detailed description of all step-over-step (SoS) trials (*n*=43), which represent a subset of the total experimental study design dataset where the complete study dataset included other foot behaviors.

The objective of this chapter is to provide a description of the observed influence of cab design and driver anthropometric and behavioral factors on driver interaction with steps and handholds during truck cab egress. A more complete definition for the method of analysis for egress motions using points of contact (PoC) variables is established. Three-dimensional reconstruction of truck driver egress motions, and analysis of the driver interaction with handhold and steps are summarized. This chapter will ultimately allow for a better understanding of the effects of egress tactics and cab step configurations on driver

interaction with steps and handholds. In general, during egress, study participants used the aft handhold most frequently, followed by the door handle and then the steering wheel. In summary, driver behaviors was largely influenced by tactics, and BMI.

Introduction

Falls among truck drivers, particularly during cab egress, have been recognized as a leading cause of injuries to truck drivers (BLS, 2014; Jones & Switzer-McIntyre, 2003; Lin & Cohen, 1997; Williams & Goins, 1981). Truck cab access system design (step and handhold layout) and driver behaviors influence the risk of slips, falls, and injury. Understanding the interactions between commercial truck operators' health and physical behaviors with the cab layout and design during mounting/dismounting is an important step in the efforts to mitigate fatal and nonfatal injuries from falls among truck drivers.

Commercial trucks are equipped with steps and handholds to facilitate safe ingress and egress from the truck cab. In the trucking industry, truck drivers are instructed to face the truck cab, as well as maintain three points of contact during ingress and egress. Those instructions are not always followed and alternative egress techniques are employed during cab egress. To enhance the safety of truck drivers, the Federal Motor Carrier Safety Administration (FMCSA), the Technology and Maintenance Council of the American Trucking Associations, and the Society of Automotive Engineers (SAE) along with U.S. military standards provide guidance and recommendations regarding the design and layout of the access systems on heavy trucks and truck tractors. Currently, two major standards are referenced in the design of ingress and egress systems for commercial trucks. ISO 2867:2006 "specifies criteria for access systems (steps, ladders, walkways, platforms, grab rails/handrails, grab handles, guardrails and enclosure entrance and exit openings) as they relate to aiding the operator, maintenance personnel and service personnel in performing their functions on earth-moving machinery" (ISO, 2006). SAE J185:200305 provides "minimum criteria for steps, stairways, ladders, walkways, platforms, handrails, handholds, guardrails, and entrance openings which permit ingress to and egress from operator, inspection, maintenance or service platforms on off-road work machines parked in accordance with the manufacturer's instructions" (SAE, 2003). Although these ISO and SAE requirements for fixed ladders and fixed stairs are not specifically applicable to on-road trucks, they are widely used because no standard specific to heavy trucks is available from ISO or SAE. In addition to these standards, the Federal Motor Carrier Safety Administration, FMCSA Part 399, Subpart L (FMCSA, 2007), and the Technology and Maintenance Council (TMC) of the American Trucking Associations, TMC RP-404B (TMC, 1989), have promulgated recommended step lengths, widths, and spacing for cab-over-engine (COE) highway and heavy truck tractors. Many heavy truck manufacturers reference the FMCSA standard and the TMC RP-404B practice for their heavy truck configurations as well.

Patenaude et al. (2001) reports that, based on the results from interviews, truck driver participants (N=10) appear to be satisfied with the layout of the cab. On the other hand, half of the study participants reported their inability to see where they placed their feet during truck cabin dismount, indicating a failure to meet user needs for safe egress in cab step layout/design. The risk of fall presented from foot placement uncertainty may be further amplified with the presence of contaminants on the steps, such as oil, ice, or mud. In one study composed of two separate industry-wide surveys of 359 trucking companies and 397 commercial truck drivers, nearly a quarter of drivers identified slippery conditions as an environmental factor that led or nearly led to falls (Spielholz et al., 2008). Importantly, 75% of the truckers stated that they use the steering wheel as support during the descent, suggesting that the steering wheel must be considered as part of the IE system (Patenaude et al., 2001). Similar findings that environmental factors, such as rain, snow, and heat, have been reported to be associated with slips or falls (Shorti et al., 2014).

The large range of egress tactics exhibited by truck drivers may be due in part to differences in truck design, as well as personal factors such as BMI (Reed et al., 2010b). Interestingly, Reed et al. (2010b) reported that drivers with higher BMI were more likely to dismount facing the cab, a lower-stress tactic, providing some evidence of risk compensation. In a recent study conducted by Turner and Reed (2011), a high prevalence of obesity was found in a sample of 300 commercial truck drivers, with 93.3% of study participants having a body mass index (BMI) of 25 or higher (Turner & Reed, 2011). These findings are consistent with two large studies of truck drivers. One is a cross-sectional study of U.S. truck drivers (*N*=797, 685 males and 112 females) reporting that most drivers were considered obese with a mean BMI of 33.2 kg/m2 (*SD*=5.5) (Shorti et al., 2014). The other study is an anthropometric study of U.S. truck drivers (*N*=1,950, 1,779 males and 171 females) and reported a mean stature (mm) of 1,757 (*SD*=69.11) and mean weight (kg) of 102.8 (*SD*=23.83) (Guan et al., 2012). Interestingly, this study reports that, compared to truck drivers' weight and physique 25 to 30 years ago, current truck drivers are on average heavier by 12.0 kg and larger in body width and girth, even though they were not reported taller (Guan et al., 2012).

Truck driver behavior when exiting the cab is an important factor for safe cab egress and injury etiology and has been studied by a few researchers. Currently in the trucking industry, truck drivers are trained to maintain three points of contact during ingress and egress of the truck cab. Furthermore, egress while facing toward the cab is also recommended to enable the driver facilitate three points of contact during egress and to reduce the consequences of a slip. This tactic is believed to reduce the probability of loss of balance and the possibility of falling. Several studies concluded that greater forces are sustained when drivers perform egress using the facing outward (FO) tactic (Fathallah & Cotnam, 2000; Giguère & Marchand, 2005; Patenaude et al., 2001; Reed et al., 2010b). Additionally, several studies have reported observing truck drivers ignoring these occupational health and safety recommendations, and instead, employing alternative egress techniques (Fathallah & Cotnam, 2000).

Speed is one motivating factor for truck drivers to adopt alternative egress tactics, e.g., facing outward, and some truck drivers may jump, skipping one or two steps, while using handles only to direct the jump (Patenaude et al., 2001). Patenaude et al. (2001) reported increased compressive forces exerted on the back for outward-facing egress when compared to inward facing. The effects of different tactics, facing outward vs. facing the cab, were not differentiated from the effects of speed in this work. The previous research suggests that truck drivers may adopt ingress/egress tactics that compensate for truck cab design inadequacies, suggesting further research is needed to identify the optimal design that will facilitate safe egress. Moreover, the influence of cab configuration on driver tactic selection has not been reported. It is possible that a truck cab could provide good affordance for low-risk egress but have other features that encourage drivers to adopt more risky tactics.

As discussed earlier, truck drivers tend to use different ingress/egress tactics to compensate for truck cab design inadequacies. Poor cab layout coupled with egress behavior that does not allow for safe descent is likely to increase the probability of injury through slips/falls. Therefore, in order to influence enhanced driver training strategies and design improved truck access systems, it is necessary to consider the truck driver behaviors employed during step negotiations. This requires knowledge of handhold use, the effect of egress tactic, cab layout, and drivers' key personal factors, such as BMI. All of these factors may affect their interaction with the cab during egress stair negotiation, thereby increasing the potential for slips and/or falls. To date, nothing in the literature provides an in-depth analysis of the driver-cab interaction, points of contact, or durations during egress of commercial trucks. Therefore, the goal of this research effort was to investigate if the variability in truck cab layout affects drivers' points of contact (PoC) during egress. Additionally, investigation of how driver tactics, FO vs. FC, affect driver's points of contact (PoC) during egress was performed.

Methods

Participants

This chapter will present a detailed description of all step-over-step (SoS) study trials (n=43), which were a subset of the total experimental study dataset (N=52); the original study included other foot behaviors.

All participants were recruited through newspaper advertisements and flyers. All participants had at least 5 years of commercial driving experience in tractor-trailer combinations and had driven professionally within the 2 years prior to testing. A total of

43 drivers (8 female, 35 male) were included in these analyses. The mean age was 45.3 years (range 22–65) and the mean (standard deviation) stature and weight were 157.5 (8.5) cm and 96.9 (23.3) kg, respectively. The average BMI of this study population was 30.7 kg/m2 (*SD* = 6.4), which is considered obese (range 21.6–52.8). Fifteen other standard anthropometric dimensions were obtained from each participant. Drivers self-identified their race/ethnicity. Select study participants' characteristics are displayed in detail in Table 4.1.

Experimental Mockup Environment Setup

A reconfigurable truck cab mockup was constructed with key features of heavy truck cab ingress/egress (IE) systems, as shown in Figure 3.1. The steps can be adjusted vertically and horizontally, simulating the range of step configurations in the current truck fleet based on analysis conducted by UMTRI (Reed, 2010a). Force plates and load cells on the ground, steps, seat, steering wheel, and handholds measured reaction forces. Participants' whole-body motions were recorded using a 13-camera VICON passive-marker optical tracking system, and subjective assessments of ingress/egress difficulty were obtained from all participants.

Participants were instructed to enter and exit the mockup cab using self-selected movement strategies and using specific strategies identified previously in covert field observations (Reed, 2010b). Testing was conducted with both internal and external handholds at the rear of the door opening. The internal handhold was fixed within the cab enclosure and was located 45 mm inside the door opening, 100 mm forward of the rear of the opening, and extended from 1,358 to 1,794 mm above the ground surface (total usable

Table 4.1. Truck driver characteristics performing the step-over-step foot behavior

Characteristic	***N***	**Range**	**Mean ± *SD***
Age	43	22.0 – 65.0	45.3 ± 11.0
Stature (cm)	43	157.5 – 197.6	178.5 ± 8.5
Weight (kg)	43	67.6 – 179.2	96.9 ± 23.3
BMI (kg/m^2)	43	21.6 – 52.8	30.7 ± 6.4
Truck Driving Experience	41	1.0 – 45.0	14.7 ± 12.9

Characteristic	***N***	**Percentage***
Gender		
Male	35	81.4
Female	8	18.6
Typical Haul Driven		
Long Haul	20	46.6
Short Haul	16	37.2
Both	5	11.6
No Response	2	4.7
BMI Category		
Normal	7	16.3
Overweight	12	27.9
Obese	18	41.9
Morbidly Obese	6	14.0
Physical Activity		
Sedentary	5	11.6
Mild	16	37.2
Occasional	12	27.9
Regular	9	20.9

*Note: percentages may not sum to 100 due to rounding

length of 436 mm). The external handhold, a vertical bar attached to the outside of the mockup immediately rearward of the door opening, was located 113 mm outboard of the sill, 130 mm aft of the door opening, and extended from 1,273 to 2,207 mm above the ground (total length of 934 mm). The simulated door was constructed with an open aluminum frame and was fixed at a 45-degree angle to the fore-aft axis of the mockup for testing. Additionally, the setup included a diagonal handhold that extended inward and upward from the lower, outboard edge of the door.

Cab Step/Handle Configuration

Cab dimensions for the mockup were chosen based on an analysis of dimensional data from 30 trucks (Reed, 2010b). Step and sill heights were fixed, as shown in the top right corner of Figure 3.2. Conditions for this experiment included a set of step and handhold configurations obtained by varying the lateral positions of the steps, and two configurations (internal and external) of the handholds. Drivers entered and exited the cab twice with each combination of the two handhold configurations and the eight different step configurations, for a total of 32 trials per participant. In all trials, participants were able to use a handhold on the door and to use the steering wheel as a handhold. During these trials, each driver exited the cab using a self-selected method in the first trial in each condition (undirected trials). In the second trial, the driver was instructed to perform an outward-facing egress if the first trial was inward-facing, and vice-versa (directed trials). Therefore, the odd trials were undirected and all even trials were directed.

Participant motions were tracked using a VICON passive optical motion tracking system with 13 cameras. A total of 68 retroreflective markers were placed on skin or clothing, as shown in Figure 3.3. The pelvis markers were mounted on a Velcro belt attached to vertical Velcro strips on tight-fitting shorts worn underneath nylon running shorts. The thorax markers were mounted on a snug elastic band under the pectorals. All other markers (except head) were taped to the participant; the wrist and shoe markers were reinforced with duct tape.

Data Analysis and Statistical Methods

Data were processed and calculations were performed using Visual3D (C-Motion, Germantown, MD, USA). Based on recommendations made by Winter (1990), video and analog data were filtered with a fourth-order low-pass Butterworth filter at 6Hz and 20Hz, respectively. Analyses were also performed based on Winter's recommendations to select cutoff frequencies. Matlab (R2014a, The Mathworks Inc., Natick, MA, USA) was used to format gait data exported from Visual3D (C-Motion, Germantown, MD, USA) and SPSS (Version 20 for Windows, SPSS Science, Chicago, USA) was used to perform the final statistical analyses. BMI was included as a categorical variable with four levels based on the following criteria: normal weight ($18.5 <= BMI < 25$, $n = 7$); overweight ($25 <= BMI < 30$, $n=14$); obese ($30 <= BMI < 35$, $n=21$); and morbidly obese ($BMI > 35$, $n=10$). Statistical analyses were performed using SPSS 21.0 (SPSS; IL, USA). Univariate ANOVA were used to explore possible predictors of falls. Tukey's HSD post hoc analysis across each of the egress tactic groups was performed. Statistical significance was chosen a priori at $\alpha = 0.05$.

The following hypotheses were evaluated:

H_1: There is a significant effect of truck cab configuration on driver PoCs during truck cab egress when considering the total egress trial and E1, E2, and E3.

H_2: There is a significant effect of truck cab configuration on driver single hand support during truck cab egress.

H_3: There is a significant effect of truck cab configuration on driver single limb support during truck cab egress.

H_4: There is a significant effect of driver egress tactic on driver PoCs during truck cab egress.

H_5: There is a significant effect of driver egress tactic on driver single hand support during truck cab egress.

H_6: There is a significant effect of driver egress tactic on driver single limb support during truck cab egress.

Systematic Data Analysis Methodology

The main objective of this study is to examine how driver tactics influence driver interaction variables (PoC and Handle use) in order to support the investigation of how those behaviors are modified, by personal or vehicle characteristics, as well as define a systematic method of analysis for the driver egress motions.

Driver Egress Behaviors

The egress motions analyzed for this study span the period beginning with the leading foot leaving the sill and ending with initial double limb stance on the floor, i.e., trailing foot's initial contact with the floor. Driver egress tactics can be broadly divided into two major categories: facing the cab, also known as inward-facing (FC) and facing the cab, also known as outward-facing (FO). Subgroups within these categories can be further defined based on other aspects of step/handhold interaction.

To better understand and classify foot behaviors, the egress motions were divided into phases based on specific events. These events were defined by the foot trajectory and force data based on foot contact with the steps and ground. There were three phases analyzed: the first phase (E1) encompasses the transition between the sill and top step, the second phase (E2) is the transition to the bottom step, and the third phase (E3) includes the transition to the ground. Each phase was defined using beginning and ending events. E1 began once the driver's leading foot left the sill and ended when the trailing foot hit the top step. E2 began with the leading foot leaving the top step level, and ended with the trailing foot at the bottom step level. Finally, E3 began when the leading foot left the bottom step level, and ended with the trailing foot's initial contact with the floor plate, i.e., initial double stance on the floor. A graphical representation is included in Figure 3.4.

The participant's foot behaviors were analyzed based on the temporal order of feet used during the three transition phases of the egress motions: E1, E2, and E3. These behaviors are shown in Figure 3.5. The critical element of this classification methodology is the identification of when the leading foot reaches each step and the ground. For example, if the left foot reaches each step and the ground first (behavior code 111 in Figure 3.6), then the driver is executing the dual-foot strategy termed step-by-step (SbS), since the right foot follows the left foot to each step and the ground. In contrast, alternating feet, for example right-left-right, defines a step-over-step (SoS) tactic, labeled 101 or 010 in Figure 3.6.

Points of Contact Descriptions

In this chapter, the dependent variables focused on the driver interaction with the cab. Those variables included the duration of the interaction as a total time to complete the egress, including the breakdown of the duration of each egress transition. Additionally, the PoC interaction, hand and feet contact with cab steps and handholds, variables detailed in Table 4.2, were also analyzed as a percentage of total egress and as a percentage of each of the egress transitions. Investigating the PoCs variables during each transition would allow for an evaluation of the respective cab elements with which drivers are interacting during those timelines. Those interactions would reveal deficiencies in cab configurations that lead to undesired effects on the dependent variables, such as the ability to maintain PoC and driver tactics during egress.

Results

Handhold utilization differed between egress tactics. These findings are summarized as a percentage of total transition for each egress tactic in Table 4.3. In general, when participants performed the egress and used the FO tactic, they mainly used the aft handhold with their left hand (E1, 460 (70.7%); E2, 564 (86.6%); and E3, 337 (51.8%)) and the door handhold with their right hands (E1, 397 (61.0%); E2, 594 (91.2%); and E3, 329 (50.5%)). Conversely, when the FC tactic was used, the handles were interchanged between hands, right hand mainly using the aft handhold and left hand mainly using the door handhold. The same pattern was observed for all the egress transitions except the initial transition, E1, where the right hand was observed using the steering wheel (46.4%) more often than the right (aft) handhold (15%).

Table 4.2. Points of Contact (PoCs) metrics and associated behavior descriptions and corresponding metric significance during egress using cab steps and handholds.

Metric	Description of associated behavior and significance during egress
PoC	Points of contact with the cab elements, i.e., steps and handholds. During any instance in a given egress trial, this metric implies the utilization of hands and feet to balance or support the body during descent.
1PoC	During egress motion, this metric implies use of one foot to support the body during egress. This PoC behavior is not desirable for safe descent.
2PoC	During egress motion, this metric implies use of either one foot and one hand or two feet to balance or support the body during egress. This PoC behavior is not desirable for safe cad egress.
3PoC	During egress motion, this metric implies use of either two feet and one hand or two hands and one foot to balance or support the body during egress. This PoC behavior is desirable and recommended for safe cab egress.
4PoC	During egress motion, this metric implies use of both feet and hands to support/balance the body during egress before or after motion. This metric maybe also the duration at which the center of mass is lowered in a controlled manner during egress. This metric is likely used as a compensation strategy for adapting to challenging step configurations and behaviors during egress, and trials with high percentages of 4PoC are likely to be associated with longer time durations.
1PoCF	Single limb support, during egress, only one foot used. This metric implies foot used likely for support during dynamic egress. This metric maybe a 1PoC, 2PoC, or 3PoC behavior, implying that it may have a single or double hand support when this behavior is observed. This is a metric is seen in the stair negotiation cycle in the stance and swing phases of descent analogous to the total durations between the beginning of leading foot leg off, through the controlled lowering of that foot, to the beginning of the weight acceptance of the same foot in the stance phase on the following step in addition to the beginning of the leg pull through of the trailing foot in the swing phase to the beginning the weight acceptance of the same foot in the stance phase, right before double support.
2PoCF	Double limb support, two feet used, during egress. This metric implies double limb support used likely for support or balance during dynamic egress. This metric maybe a 2PoC, 3PoC, or 4PoC behavior, implying that it may have a single or double hand support when this behavior is observed. This is a metric is seen in the stair negotiation cycle, i.e., double support, in the stance and swing phases of descent analogous to the durations prior to center of mass transfer between phases (i.e., forward continuance/leg off, controlled lowering, and leg pull through).
1PoCH	Single hand support. During egress, one hand is used. This metric implies hand used likely for balance but could also be used for support in the case when foot forces are not sustained with the supporting leg. This metric is maybe a 2PoC, 3PoC, or 4PoC behavior, implying that it may have a single or double foot support when this behavior is observed. This metric should have similar percentage as 2PoCF to have a safe egress as recommended by the 3PoC rule. Therefore, during egress investigation, either a combination of 1PoCF and 2PoCH or 1PoCF and 2PoCH is used.
2PoCH	Double hand support. During egress, both hands are used. This metric implies hand used likely for support but could also be used for balance. This metric maybe a 2PoC, 3PoC, or 4PoC behavior, implying that it may have a single or double foot support when this behavior is observed. This metric should have similar percentages as 1PoCF to have a safe egress as recommended by the 3PoC rule. Therefore, during egress investigation, either a combination of 1PoCF and 2PoCH or 1PoCF and 2PoCH is used.

*Note: Those variables were also investigated over the three transitions (E1, E2, and E3)

Table 4.3. Details of cab handle utilization during egress broken into the egress transitions (E1, E2, and E3).

Transition	Handle Used	Left Hand				Right Hand			
		FO		FC		FO		FC	
		N	% of Transition	*N*	% of Transition	*N*	% of Transition	*N*	% of Transition
E1	None Used	184	28.3%	70	9.7%	140	21.5%	277	38.6%
	Steering Wheel	7	1.1%	232	32.3%	93	14.3%	333	46.4%
	Aft Handhold	460	70.7%	0	0.0%	0	0.0%	108	15.0%
	Fore Handhold	0	0.0%	101	14.1%	21	3.2%	0	0.0%
	Door Handhold	0	0.0%	315	43.9%	397	61.0%	0	0.0%
	Total	**651**	**100.0%**	**718**	**100.0%**	**651**	**100.0%**	**718**	**100.0%**
E2	None Used	87	13.4%	35	4.9%	41	6.3%	58	8.1%
	Steering Wheel	0	0.0%	200	27.9%	10	1.5%	225	31.3%
	Aft Handhold	564	86.6%	0	0.0%	0	0.0%	435	60.6%
	Fore Handhold	0	0.0%	121	16.9%	6	0.9%	0	0.0%
	Door Handhold	0	0.0%	362	50.4%	594	91.2%	0	0.0%
	Total	**651**	**100.0%**	**718**	**100.0%**	**651**	**100.0%**	**718**	**100.0%**
E3	None Used	314	48.2%	234	32.6%	319	49.0%	183	25.5%
	Steering Wheel	0	0.0%	5	0.7%	0	0.0%	27	3.8%
	Aft Handhold	337	51.8%	0	0.0%	0	0.0%	508	70.8%
	Fore Handhold	0	0.0%	37	5.2%	3	0.5%	0	0.0%
	Door Handhold	0	0.0%	442	61.6%	329	50.5%	0	0.0%
	Total	**651**	**100.0%**	**718**	**100.0%**	**651**	**100.0%**	**718**	**100.0%**

*Note: percentages may not sum to 100 due to rounding

Time to Complete Egress

The time to complete the egress trial was calculated for each participant from the instant the leading foot left the sill to the instant the trailing foot touched the ground, excluding the time it took to move from the seat and get ready for descent. The distribution of the times for all participants is shown in Figure 4.1.

The outliers are primarily participants from the obese and morbidly obese groups, particularly for step configurations 1-4 and the FC condition. Furthermore, the time to complete egress was also calculated for the three transitions, E1, E2, and E3. When examining the distribution of cases over the egress transitions, the effect is most noticeable in the E1 phase, when participants are turning in preparation for the descent. Those distributions are displayed for FO and FC egress tactics in Figure 4.2.

A 2 X 8 (egress tactic X step configuration) factorial analysis of variance tested the effects of driver egress tactics and truck step configuration on egress times, total egress, E1, E2, and E3 times. Results indicated a significant main effect for the egress tactic factor on total egress time, $F(1,799) = 101.980$, $p < .001$; E1 egress time, $F(1,799)= 89.495$; E2 egress time, $F(1,799) = 75.143$, $p < .001$; and E3 egress time, $F(1,799) = 253.155$, $p < .001$. Those who exited with the FO tactic did so in a faster time when compared to those who exited the cab using the FC tactic. Step configuration also affected total egress time, $F(7,799) = 6.745$, $p < .001$; E1 egress time, $F(7,799) = 5.148$, $p < .001$; E2 egress time, $F(7,799) = 6.685$, $p < .001$; and E3 egress time, $F(7,799) = 3.556$, $p < .01$.

Within the FC tactic group, step configuration affected egress phase durations ($F(7,513) = 6.430$, $p < .001$, E1 egress time, $F(7, 513) = 4.893$, $p < .001$, E2 egress time, $F(7, 513) = 5.309$, $p < .001$, and E3 egress time, $F(7, 513) = 3.986$, $p < .001$). However,

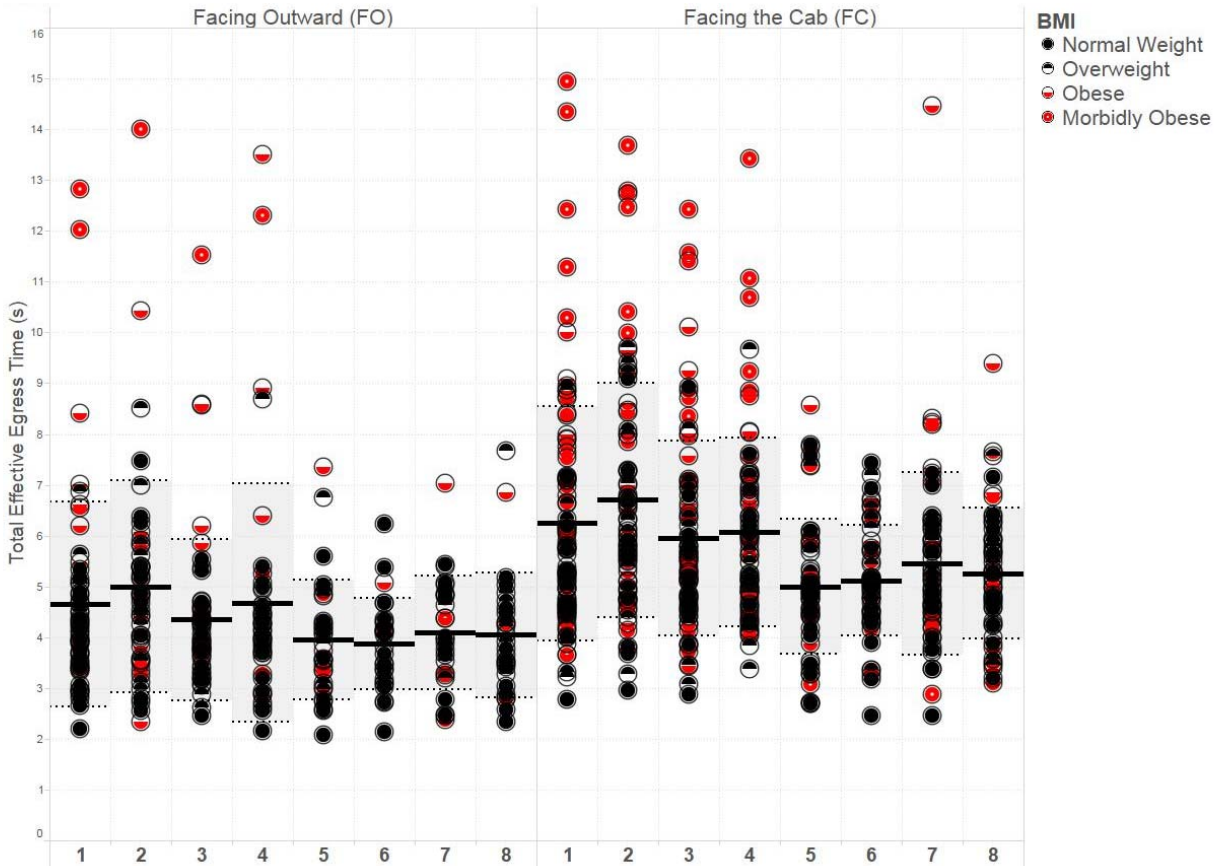


Figure 4.1. The distribution of the time to complete each egress trial for all participants. The two egress tactics are shown, facing outward on the left and facing the cab on the right. The average is the thick line, and the standard deviation is the highlighted area capped with a dashed line. The participants' BMI groups are identified (see the legend).

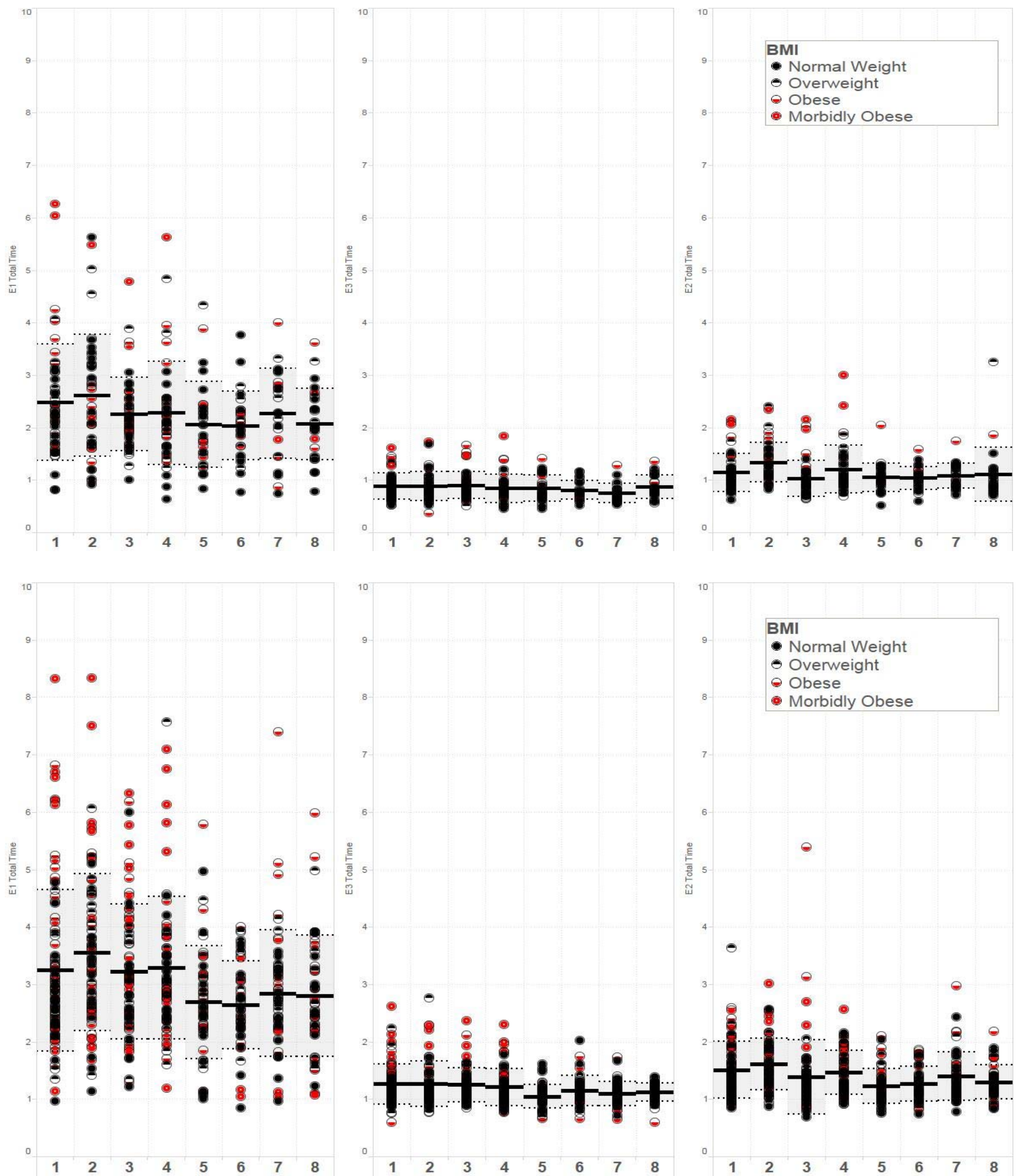


Figure 4.2. The distribution of the time to complete each egress trial for all participants. The two egress tactics are shown, facing outward on the top and facing the cab on the bottom. Each graph is displaying the three egress transitions E1, 2, and 3, left to right. The average is the thick line, and the standard deviation is the highlighted area capped with a dashed line. The participants' BMI groups are identified (see the legend).

within the FO tactic group, no effect of step configuration on total egress time was observed ($F(7,286) = 1.904$, $p = 0.069$, E1 egress time, $F(7, 286) = 1.915$, $p = 0.067$, E3 egress time, $F(7, 286) = 1.049$, $p = 0.379$), except that E2 duration differed somewhat ($F(7, 286) = 3.004$, $p < 0.01$). Descriptive statistics, means, and standard deviations are summarized in Table 4.4, including the statistically significant configurations post hoc comparisons results. Finally, no significant interaction effects between the egress tactic and the step configuration on the egress times were observed.

1 Point of Contact (1PoC)

The effects of driver egress tactic and truck cab configuration on the 1PoC variables (overall egress, E1, E2, and E3) were tested using a two-way ANOVA (egress tactic X cab configuration) factorial analysis. While results indicated no significant main effect of egress tactic on overall egress for 1PoC ($F(1,799) = 0.884$, $p = 0.347$), there were significant effects on 1PoC during all three transitions: E1 1PoC ($F(1,799) = 89.358$, $p < .001$); E2 1PoC ($F(1,799) = 7.090$, $p < .001$); and E3 1PoC ($F(1,799) = 70.858$, $p < .001$).

Those who exited with the FO tactic showed an overall larger percentage of 1PoC compared to those who exited the cab using the FC tactic during the E1 and E2 transitions. However, the E3 transition showed the opposite with the FC technique having larger percentages of time to egress, as shown in Table 4.5. Furthermore, there was no significant main effect of the cab configuration factor on the overall egress 1PoC variable ($F(7,799) = 1.176$, $p = 0.314$; E1 1PoC variable, E2, $F(7,799) = 0.545$, $p = 0.800$; or E3 1PoC variable, $F(7,799) = 1.417$, $p = 0.1950$; however, there was a significant effect on E2 1PoC ($F(7,799) = 2.631$, $p < 0.05$). Univariate analyses on each of the egress tactic groups showed a

Table 4.4. Descriptive statistics, means and standard deviations, and univariate analysis results for all egress times for both egress tactics, FC and FO.

Step Configuration	Egress Total Duration Mean (*SD*)		E1 Duration Mean (*SD*)		E2 Duration Mean (*SD*)		E3 Duration Mean (*SD*)	
	FO	**FC†****	**FO**	**FC†****	**FO†****	**FC†****	**FO**	**FC†****
1	4.65(2.0)	6.14(2.2)[b]	2.49(1.1)	3.21(1.4)[b]	1.15(0.3)[b]	1.49(0.5)[b]	0.87(0.3)	1.23(0.3)[b]
2	5.00(2.1)[a]	6.67(2.3)[a]	2.61(1.1)[a]	3.55(1.4)[a]	1.31(0.4)[a]	1.60(0.4)[a]	0.87(0.3)	1.23(0.4)[b]
3	4.33(1.6)	5.95(1.9)[b]	2.24(0.7)	3.22(1.2)[b]	1.02(0.3)**	1.36(0.6)*	0.89(0.2)[a]	1.24(0.3)[a]
4	4.63(2.3)	6.04(1.8)[b]	2.28(1.0)	3.30(1.2)[b]	1.19(0.5)[b]	1.44(0.4)*	0.84(0.3)	1.19(0.3)[b]
5	3.96(1.2)	4.99(1.3)**	2.07(0.8)	2.68(1.0)**	1.06(0.3)[b]	1.22(0.3)**	0.83(0.2)	1.05(0.2)*
6	3.87(0.9)	5.12(1.1)**	2.04(0.7)	2.66(0.8)**	1.03(0.2)*	1.28(0.3)**	0.80(0.2)	1.13(0.2)[b]
7	4.10(1.1)	5.44(1.8)**	2.27(0.8)	2.84(1.1)*	1.08(0.2)[b]	1.38(0.4)[b]	0.75(0.2)	1.09(0.2)[b]
8	4.05(1.2)	5.26(1.3)**	2.07(0.7)	2.82(1.0)*	1.11(0.5)[b]	1.31(0.3)**	0.86(.2)	1.13(0.2)[b]

[a] baseline category, based on the highest mean rank result of the Kruskal-Wallis rank test
[b] not statistically significant from baseline category, using Tukey's HSD post hoc analysis
† significant effect of the step configuration for the egress tactic group on variable
* 0.05 significance level
** 0.01 significance level

Table 4.5. Descriptive statistics, means and standard deviations, and univariate analysis results for all 1PoCs during all egress trials—E1, E2, and E3—for both egress tactics, FC and FO.

Step Configuration	% Time in 1PoC Average (*SD*)		% Time in 1PoC_E1 Average (*SD*)		% Time in 1PoC_E2 Average (*SD*)		% Time in 1PoC_E3 Average (*SD*)	
	FO	**FC†***	**FO**	**FC**	**FO**	**FC**	**FO**	**FC†***
1	5.2(8.4)	5.2(5.1)[b]	4.4(10.7)	0.5(3.0)	2.1(10.0)	0.4(2.6)	10.2(20.1)	21.1(18.7)[b]
2	6.5(9.3)	4.4(4.2)[b]	6.6(13.5)	0.7(3.3)[a]	1.1(5.0)	0.0(0.0)	11.3(20.3)	21.1(19.7)[b]
3	8.2(12.0)[a]	5.1(5.5)[b]	6.5(10.4)[a]	0.3(2.7)	5.9(20.2)[a]	0.3(1.8)[a]	14.3(24.3)	20.8(19.6)[b]
4	5.8(9.8)	3.7(4.3)*	6.0(11.1)	0.1(0.8)	2.5(12.0)	0.3(2.9)	8.7(17.3)	16.5(18.1)**
5	4.0(6.4)	5.3(4.2)[b]	4.6(12.4)	0.2(1.4)	0.0(0.0)	0.0(0.0)	7.8(15.6)	24.2(18.1)[b]
6	5.9(8.7)	5.7(5.3)[b]	4.9(11.5)	0.0(0.0)	0.4(2.1)	0.3(2.0)	11.3(20.8)	24.1(19.3)[b]
7	4.0(5.7)	5.6(4.3)[b]	4.4(9.4)	0.2(1.3)	0.0(0.0)	0.1(0.9)	7.6(14.8)	25.4(18.6)[b]
8	5.9(8.5)	6.7(4.1)[a]	4.9(11.6)	0.0(0.0)	0.1(0.3)	0.2(1.1)	13.7(20.9)[a]	29.4(17.2)[a]

[a] baseline category, based on the highest mean rank results of the Kruskal-Wallis rank test
[b] not statistically significant from baseline category, using Tukey's HSD post hoc analysis
† significant effect of the cab configuration for the egress tactic group on variable
* 0.05 significance level
** 0.01 significance level

statistically significant effect of cab configuration when facing the cab for 1PoC ($F(7,513) = 2.194$, $p < .05$; and E3 1PoC, $F(7, 513) = 2.490$, $p < .05$), but no effect on the E1 1PoC ($F(7, 513) = 0.528$, $p = 0.872$; or E2 1PoC, $F(7, 513) = 0.446$, $p = 0.873$). Furthermore, no statistically significant effect of cab configuration for the FO group on egress 1PoC ($F(7,286) = 0.869$, $p = 0.531$; E1 1PoC, $F(7, 286) = 0.275$, $p = 0.963$; E2 1PoC, $F(7, 286) = 1.492$, $p = 0.170$; or E3 1PoC, $F(7, 286) = 0.557$, $p = 0.791$) was found. Descriptive statistics, means, and standard deviations are summarized in Table 4.5, including the statistically significant configurations post hoc comparison results. Finally, no significant interaction effects between the egress tactic and the step configuration on the 1PoC variables were found.

2 Points of Contact (2PoC)

Those who exited with the FO tactic showed a higher percentage of 2PoC compared to those who exited the cab using the FC tactic, which is consistent when considering overall egress duration compared to examining all three transitions. These findings were shown to be statistically significant following a 2 X 8 ANOVA (egress tactic X cab configuration) to test the effects of the driver egress tactic and truck cab configuration on the 2PoC variables (overall, E1, E2, and E3). Results indicated that the egress tactic factor had a significant main effect on overall 2PoC ($F(1,799) = 309.542$, $p < .001$; E1 2PoC, $F(1,799) = 185.633$, $p < .001$; E2 2PoC, $F(1,799) = 47.764$, $p < .001$; and E3 2PoC, $F(1,799) = 305.272$, $p < .001$). There was also a significant main effect of the cab configuration on the 2PoC variable ($F(7,799) = 4.052$, $p < .001$) and the E2 2PoC variable ($F(7,799) = 2.107$, $p < 0.05$). However, the step configuration had no effect on the E1 2PoC variable ($F(7,799) = 2.004$, $p = 0.052$), or the E3 2PoC variable ($F(7,799) = 0.746$, $p = 0.633$). Univariate analyses on each of the egress tactic groups showed a statistically significant effect of cab configuration when facing the cab on the 2PoC ($F(7,513) = 2.532$, $p < .05$), E1 2PoC ($F(7, 513) = 1.265$, $p = 0.266$), E2 2PoC ($F(7, 513) = 1.750$, $p = 0.095$), and E3 2PoC ($F(7, 513) = 0.303$, $p = 0.953$). However, there was no statistically significant effect of cab configuration for the FO groups on 2PoC ($F(7,286) = 2.013$, $p = 0.053$), E1 2PoC ($F(7, 286) = 1.685$, $p = 0.112$), E2 2PoC ($F(7, 286) = 0.696$, $p = 0.675$), and E3 2PoC ($F(7, 286) = 0.600$, $p = 0.756$). Descriptive statistics, means, and standard deviations are summarized in Table 4.6, including the statistically significant configurations post hoc comparison results. Finally, no significant interaction effects between the egress tactic and the step configuration on the 2PoC variables were found.

3 Points of Contact (3PoC)

A 2 X 8 (egress tactic X cab configuration) factorial analysis of variance tested the effects of the driver egress tactic and truck cab configuration on the 3PoC variables (overall, E1, E2, and E3). Results indicated a main effect for the egress tactic factor that is statistically significant on overall 3PoC ($F(1,799) = 83.945$, $p < .001$), E1 3PoC, $F(1,799) = 70.846$, $p < .001$, and E2 3PoC, $F(1,799) = 39.304$, $p < .001$). However, there was no significant effect of tactic on E3 3PoC ($F(1,799) = 2.506$, $p = 0.114$). Largely, those who exited using the facing the cab (FC) tactic were observed to have higher mean values of maintaining 3PoCs than those who exited the cab facing outward (FO). Results are summarized in Table 4.7.

Additionally, ANOVA results showed a significant main effect of the cab

Table 4.6. Descriptive statistics, means and standard deviations, and univariate analysis results for all 2PoCs during all egress trials—E1, 2, and 3— for both egress tactics, FC and FO.

Step Configuration	% Time in 2PoC Average (*SD*)		% Time in 2PoC_E1 Average (*SD*)		% Time in 2PoC_E2 Average (*SD*)		% Time in 2PoC_E3 Average (*SD*)	
	FO	**FC**[†]*	**FO**	**FC**	**FO**	**FC**	**FO**	**FC**
1	44.6(17.6)	25.0(12.2)[b]	50.3(21.4)[a]	27.3(19.6)	26.2(28.5)	17.1(19.0)	52.9(16.8)	29.0(17.5)
2	37.9(15.5)	22.4(11.9)[b]	42.6(20.3)	26.2(18.7)	20.5(24.7)	10.9(16.9)	52.3(19.7)	28.9(18.6)
3	44.6(15.1)	23.3(12.5)[b]	50.3(17.7)	23.7(19.1)	26.4(27.2)	16.1(18.9)	52.3(19.3)	28.9(18.8)
4	36.5(15.0)	19.9(11.9)*	39.6(19.5)	21.1(16.0)	22.8(28.2)	10.5(16.6)	49.8(19.2)	28.4(20.0)
5	46.3(16.9)[a]	25.1(13.0)[b]	49.5(23.8)	25.8(19.3)	28.3(31.0)	16.4(18.8)	56.9(16.8)[a]	30.8(16.7)
6	42.9(18.0)	26.0(12.7)[b]	44.4(20.3)	27.7(19.2)	30.4(30.3)	17.2(20.1)	55.2(17.4)	30.0(15.3)
7	44.9(14.4)	26.4(11.4)[b]	45.5(22.0)	28.1(16.9)	32.2(27.8)[a]	17.0(19.4)	56.3(15.8)	31.2(16.4)[b]
8	41.4(12.3)	27.1(10.2)[a]	43.2(15.8)	28.6(17.4)[a]	30.3(28.8)	18.0(19.4)[a]	51.5(18.2)	31.8(15.0)[a]

[a] baseline category, based on the highest mean rank results of the Kruskal-Wallis rank test
[b] not statistically significant from baseline category, using Tukey's HSD post hoc analysis
[†] significant effect of the cab configuration for the egress tactic group on variable
* 0.05 significance level
** 0.01 significance level

Table 4.7. Descriptive statistics, means and standard deviations, and univariate analysis results for all 3PoCs during all egress trials—E1, 2, and 3—for both egress tactics, FC and FO.

Step Configuration	% Time in 3PoC Average (*SD*)		% Time in 3PoC_E1 Average (*SD*)		% Time in 3PoC_E2 Average (*SD*)		% Time in 3PoC_E3 Average (*SD*)	
	FO	**FC[†]****	**FO**	**FC**	**FO**	**FC[†]***	**FO**	**FC[†]***
1	38.1(14.2)	47.8(12.5)*	34.2(18.8)	48.1(19.3)	51.7(20.9)	55.6(15.9)[b]	34.6(16.6)	38.5(17.3)[b]
2	41.6(12.5)	51.1(11.5)[b]	37.7(18.0)	52.2(18.3)	54.1(16.7)[a]	61.6(13.8)[b]	35.4(18.4)	36(15.3)[b]
3	36.9(13.4)	50.3(12.4)[b]	34.2(16.0)	52.3(19.7)	47.6(22.7)	57.4(14.7)[b]	31.4(20.3)	38.6(17.0)[b]
4	44.4(12.5)[a]	54.7(12.3)[a]	42.8(19.7)	55.2(17.6)[a]	51.2(18.8)	62.6(14.7)[a]	38.4(16.7)[a]	42.3(16.4)[a]
5	39.8(13.0)	49.4(13.9)[b]	38.0(20.3)	51.4(19.8)	50.8(18.1)	57.2(16.3)[b]	32.8(13.6)	35.9(17.2)[b]
6	40.8(13.6)	48.2(13.2)[b]	42.0(19.6)	50.7(19.7)	48.4(17.4)	57.0(16.0)[b]	32.4(16.3)	34.0(15.7)[b]
7	41.4(11.5)	47.8(11.7)*	42.2(19.8)	49.7(16.9)	46.5(14.1)	57.6(16.7)[b]	35.2(12.6)	34.0(17.2)[b]
8	43.4(9.3)	46.9(12.3)*	43.5(13.5)[a]	49.7(18.9)	50.3(16.5)	55.5(16.6)[b]	34.7(16.2)	31.7(17.4)*

[a] baseline category, based on the highest mean rank results of the Kruskal-Wallis rank test
[b] not statistically significant from baseline category, using Tukey's HSD post hoc analysis
[†] significant effect of the cab configuration for the egress tactic group on variable
* 0.05 significance level
** 0.01 significance level

configuration on 3PoC ($F(7,799) = 2.880$, $p < .01$), but no significant effect when considering each egress transition's percentage in 3PoC (E1 3PoC ($F(7,799) = 1.782$, $p = 0.088$); E2 3PoC ($F(7,799) = 1.639$, $p = 0.121$); and E3 3PoC ($F(7,799) = 1.775$, $p = 0.089$)). Univariate analyses on each of the egress tactic groups showed a statistically significant effect of cab configuration when facing the cab on the 3PoCs ($F(7,513) = 2.740$, $p < .01$; E2 3PoC, $F(7, 513) = 2.034$, $p < 0.05$; and E3 3PoC, $F(7, 513) = 2.491$, $p < 0.05$), but a nonsignificant effect on E1 3PoC ($F(7, 513) = 0.975$, $p = 0.449$), and no statistically significant effect of cab configuration for the FO groups on 3PoC ($F(7,286) = 1.654$, $p = 0.120$; E1 3PoC $F(7, 286) = 1.692$, $p = 0.111$; E2 3PoC, $F(7, 286) = 0.633$, $p = 0.729$; and E3 3PoC, $F(7, 286) = 0.677$, $p = 0.692$). Descriptive statistics, means, and standard deviations are summarized in Table 4.7, including the statistically significant configurations post hoc comparison results. Finally, no significant interaction effects between the egress tactic and the step configuration on the 3PoC variables were found.

4 Points of Contact (4PoC)

In general, mean of percent in 4PoCs of those who exited using the facing the cab (FC) tactic was higher than those who exited the cab facing outward (FO); those results are summarized in Table 4.8. A 2 X 8 (egress tactic X cab configuration) factorial analysis of variance tested the effects of the driver egress tactic and truck cab configuration on the 3PoC variables (overall, E1, E2, and E3). Results indicated a significant main effect for the egress tactic factor on 4PoC ($F(1,799) = 254.613$, $p < .001$; E1 4PoC, $F(1,799) = 231.986$, $p < .001$; E2 4PoC, $F(1,799) = 29.132$, $p < .001$; and E3 4PoC, $F(1,799) = 106.074$, $p < .001$). There was also a significant main effect of the cab configuration on 4PoC when

Table 4.8. Descriptive statistics, means and standard deviations, and univariate analysis results for all 4PoCs during all egress trials—E1, 2, and 3—for both egress tactics, FC and FO.

Step Configuration	**% Time in 4PoC Average (*SD*)**		**% Time in 4PoC_E1 Average (*SD*)**		**% Time in 4PoC_E2 Average (*SD*)**		**% Time in 4PoC_E3 Average (*SD*)**	
	FO	**FC**	**FO**	**FC**	**FO**	**FC**	**FO**	**FC**
1	12.0(10.5)	22.0(8.6)	11.1(10.8)	24.1(12.6)[a]	20.1(14.3)	27.0(11.8)	2.3(8.2)	11.3(14.1)
2	14.1(8.9)[a]	22.1(8.8)[a]	13.2(11.0)[a]	20.9(12.3)	24.2(13.7)	27.5(10.1)	1.0(3.9)	14.1(15.9)[a]
3	10.3(8.5)	21.3(7.6)	9(10.8)	23.7(11.1)	20.1(14.3)	26.2(10.5)[a]	2.0(7.0)	11.7(14.0)
4	13.3(9.9)	21.7(7.5)	11.6(12.5)	23.6(11.8)	23.5(16.0)[a]	26.6(9.9)	3.1(8.4)	12.8(15.0)
5	10.0(7.2)	20.2(6.7)	7.9(8.3)	22.7(11.3)	20.8(15.6)	26.4(9.9)	2.5(6.6)[a]	9.2(13.1)
6	10.4(8.8)	20.1(6.9)	8.7(9.8)	21.6(10.5)	20.7(16.6)	25.5(10.8)	1.1(3.8)	12.0(15.9)
7	9.7(6.8)	20.2(7.0)	8.0(9.0)	22.0(10.1)	21.3(15.8)	25.2(10.8)	0.8(3.8)	9.4(12.2)
8	9.3(6.8)	19.3(6.0)	8.5(8.0)	21.7(10.4)	19.4(15.5)	26.4(11.1)	0.0(0.2)	7.1(11.6)

[a] baseline category, based on the highest mean rank results of the Kruskal-Wallis rank test
[b] not statistically significant from baseline category, using Tukey's HSD post hoc analysis
[†] significant effect of the cab configuration for the egress tactic group on variable
* 0.05 significance level
** 0.01 significance level

considering the overall egress trial (F(7,799) = 2.601, p < .05), but a nonsignificant effect when considering each egress transition (E1 4PoC, F(7,799) = 0.979, p =0.445; E2 4PoC, F(7,799) = 0.750, p =0.629; and E3 4PoC, F(7,799) = 1.119, p =0.349). Univariate analyses on each of the egress tactic groups showed a statistically nonsignificant effect of cab configuration when facing the cab on the 4PoC (F(7,513) =1.166, p =0.320; E1 4PoC, F(7, 513) = 0.746, p =0.633; E2 4PoC, F(7, 513) = 0.297, p =0.955; and E3 4PoC, F(7, 513) = 1.467, p =0.177), and no statistically significant effect of cab configuration for the FO groups on 4PoC (F(7,286) = 1.513, p =0.163; E1 4PoC, F(7, 286) = 1.324, p =0.238; E2 4PoC, F(7, 286) = 0.542, p =802; and E3 4PoC, F(7, 286) = 0.907, p =0.501). Descriptive statistics, means, and standard deviations are summarized in Table 4.8, including the statistically significant configurations post hoc comparison results. Finally, no significant interaction effects between the egress tactic and the step configuration on the 4PoC variables were found.

Single Limb Support (1PoCF)

A 2 X 8 (egress tactic X cab configuration) factorial analysis of variance tested the effects of driver egress tactic and truck cab configuration on the 1PoCF variables (overall, E1, E2, and E3). Results indicated a significant main effect for the egress tactic factor on 1PoCF (F(1,799) = 99.811, p < .001; E1 1PoCF, F(1,799) = 84.579, p < .001; E2 1PoCF, F(1,799) = 37.419, p < .001; and E3 1PoCF, F(1,799) = 67.382, p < .001). Compared to the FO tactic, the FC tactic had a higher percentage of bearing single limb support when considering total egress or when considering each transition. However, there was no significant main effect of the cab configuration on 1PoCF (F(7,799) = 1.585, p =0.136; E1

1PoCF, $F(7,799) = 1.572$, $p = 0.140$; E2 1PoCF, $F(7,799) = 1.383$, $p = 0.209$; or E3 1PoCF, $F(7,799) = 1.002$, $p = 0.428$). Univariate analyses on each of the egress tactic groups showed a statistically significant effect of cab configuration when facing the cab on the 1PoCF ($F(7,513) = 2.265$, $p < .05$; E1 1PoCF, $F(7, 513) = 1.781$, $p = 0.089$; E2 1PoCF, $F(7, 513) = 1.333$, $p = 0.233$; and E3 1PoCF, $F(7, 513) = 1.631$, $p = 0.124$), and no statistically significant effect of cab configuration for the FO groups on 1PoCF ($F(7,286) = 1.043$, $p = 0.401$; E1 1PoCF, $F(7, 286) = 1.164$, $p = 0.323$; E2 1PoCF, $F(7, 286) = 1.921$, $p = 0.066$; and E3 1PoCF, $F(7, 286) = 0.674$, $p = 0.694$). Tukey's HSD post hoc analyses were conducted. The post hoc results, as well as the descriptive statistics, means and standard deviations are summarized in Table 4.9.

Double Hand Support (2PoCH)

Consistent observations, when considering total egress or when considering each transition (see Table 4.10), were realized when comparing egress tactics. The FC tactic had a higher percentage of maintaining two hand PoC. A 2 X 8 (egress tactic X cab configuration) factorial ANOVA tested the effects of the driver egress tactic and truck cab configuration on the 2PoCH variables (overall, E1, E2, and E3). Results indicated a significant main effect for the egress tactic factor on 2PoCH ($F(1,799) = 250.004$, $p < .001$; E1 2PoCH, $F(1,799) = 211.135$, $p < .001$; E2 2PoCH, $F(1,799) = 30.927$, $p < .001$; and E3 2PoCH, $F(1,799) = 100.821$, $p < .001$). However, there was a significant main effect of cab configuration only on 2PoCH ($F(7,799) = 2.624$, $p < .05$) when considering overall egress, but not when each transition was considered (E1 2PoCH, $F(7,799) = 0.462$, $p = 0.862$; E2 2PoCH, $F(7,799) = 1.883$, $p = 0.069$; and E3 2PoCH, $F(7,799) = 1.823$, $p = 0.080$). Univariate analysis on each egress tactic group showed a statistically significant effect of

Table 4.9. Descriptive statistics, means and standard deviations, and univariate analysis results for all 1PoCF during all egress trials—E1, 2, and 3—for both egress tactics, FC and FO.

Step Configuration	% Time in 1PoCF Average (*SD*)		% Time in 1PoCF_E1 Average (*SD*)		% Time in 1PoCF_E2 Average (*SD*)		% Time in 1PoCF_E3 Average (*SD*)	
	FO	FC†*	FO	FC	FO	FC	FO	FC
1	69.8(9.3)	60.6(9.6)[b]	71.7(13.3)	61.2(12.1)	70.1(6.5)	63.5(8.1)	67.7(7.2)	62(8.2)
2	70.7(9.6)	60.9(8.4)[b]	74.4(11.0)[a]	61.7(11.9)	68.7(7.2)	65.9(8.3)	69.3(9.3)[a]	61.4(7.8)
3	70.3(9.7)[a]	63(8.4)[b]	73.1(12.5)	62.8(11.6)	71.5(7.1)[a]	65.4(8.4)	69(8.8)	65(6.7)[a]
4	66(10.5)	61.2(9.0)[b]	68.3(13.4)	59.7(12.7)	67.5(7.4)	66.5(7.6)[a]	66.8(8.5)	63.4(7.3)
5	69.3(6.6)	64.2(7.2)[b]	69.8(10.9)	64.1(11.2)	68.6(7.6)	65.7(6.3)	68.4(6.8)	63(5.4)
6	69(7.1)	64.3(7.3)[a]	69.9(9.5)	65.5(10.3)[a]	67.8(8.4)	64.8(7.2)	66.7(8.8)	63.2(7.6)
7	68.3(10.2)	62.4(7.9)[b]	68.9(16.2)	63(10.7)	67.7(4.5)	63.9(8.9)	67.9(8.0)	63.3(6.4)
8	69.4(7.9)	64.1(6.0)[b]	72.8(12.9)	64.8(9.7)	66.5(9.7)	64.5(6.2)	66.4(6.6)	63.2(7.9)

[a] baseline category, based on the highest mean rank results of the Kruskal-Wallis rank test
[b] not statistically significant from baseline category, using Tukey's HSD post hoc analysis
† significant effect of the cab configuration for the egress tactic group on variable
* 0.05 significance level
** 0.01 significance level

Table 4.10. Descriptive statistics, means and standard deviations, and univariate analysis results for all 2PoCH during all egress trials— E1, 2, and 3—for both egress tactics, FC and FO.

Step Configuration	% Time in 2PoCH Average (*SD*)		% Time in 2PoCH_E1 Average (*SD*)		% Time in 2PoCH_E2 Average (*SD*)		% Time in 2PoCH_E3 Average (*SD*)	
	FO	FC†*	FO	FC	FO	FC	FO	FC
1	36.4(21.8)	54.4(13.9)[b]	34.2(24.2)	58.1(22.3)	63.3(42.0)	73(27.6)	10(18.2)	30(31.1)
2	42.2(19.7)[a]	58.3(13.6)[b]	40.3(24.1)	56.9(20.8)	71.8(37.6)[a]	82.6(25.1)[a]	9.4(15.2)	32.7(29.1)
3	32.6(19.7)	57.5(13.9)[b]	30.4(22.6)	62.5(20.2)	61.1(42.1)	75.2(29.4)	9.4(19.2)	33.1(32.7)
4	40(21.8)	60.6(13.4)[a]	38.3(28.5)	62.4(19.2)[a]	66.5(42.9)	82.3(26.4)	13.7(21.6)[a]	35.7(31.7)[a]
5	34.2(21.8)	55.7(13.8)[b]	31.5(25.3)	61.1(21.1)	61.1(44.8)	75.7(25.8)	9.4(18.2)	24.9(30.4)
6	34.8(22.5)	55.1(14.1)[b]	34.4(22.7)	60.1(21.0)	57.6(44.1)	72.8(28.5)	6.6(15.7)	29(34.7)
7	34.3(21.6)	53(13.0)*	35.9(30.4)	57.4(19.4)	56.9(42.0)	72(28.2)	5.3(14.8)	24.9(29.8)
8	34.5(17.7)	52.5(11.9)*	37.8(17.3)[a]	58.5(19.0)	55.5(43.8)	72.7(27.5)	3.5(11.0)	20.6(27.2)

[a] baseline category, based on the highest mean rank results of the Kruskal-Wallis rank test
[b] not statistically significant from baseline category, using Tukey's HSD post hoc analysis
† significant effect of the cab configuration for the egress tactic group on variable
* 0.05 significance level
** 0.01 significance level

cab configuration in the facing the cab group on the 2PoCH ($F(7,513) = 2.688$, $p < .05$), no significant effect on E1 2PoCH ($F(7, 513) = 0.826$, $p = 0.566$; E2 2PoCH, $F(7, 513) = 1.715$, $p = 0.103$; and E3 2PoCH, $F(7, 513) = 1.591$, $p = 0.136$). In addition, there was no statistically significant effect of cab configuration for the FO groups on 2PoCH ($F(7,286) = 1.052$, $p = 0.395$; E1 2PoCH, $F(7, 286) = 0.794$, $p = 0.592$; E2 2PoCH, $F(7, 286) = 0.592$, $p = 0.763$; and E3 2PoCH, $F(7, 286) = 1.062$, $p = 0.388$). Descriptive statistics, means, and standard deviations are summarized in Table 4.10, including the statistically significant configurations post hoc comparison results. Finally, no significant interaction effects between the egress tactic and the step configuration on the 2PoCH variables were found.

Discussion

In general, during egress, study participants used the aft handhold most frequently, followed by the door handle and then the steering wheel. Different findings for right and left hands were observed. Predominantly, the aft handhold was used in E1 (33.6%), and E2 (41.2%), and the door in E3 (32.2%) for the left hand. Alternatively, with their right hands, study participants mostly used the steering wheel during E1 (31.1%), the door in E2 (43.4%), and the aft handhold during E3 (37.1%). The door was another handle used frequently with the right hand during E1 (29.0%), E2 (43.4%), and E3 (24.0%). For a lower percentage of time, none of the handles were utilized during E2 transition, right hand (8.9%) and left hand (7.2%); this indicates that participants were able to utilize most available handles. Alternatively, the study participants did not utilize any handle for most of the duration of E1 (30.5%) or E3 (36.7%). When exploring the effect of egress tactics on handle utilization, results showed obvious differences. In general, when participants performed the egress and used the FO tactic, they mainly used the aft handhold with their left hand, E1 (70.7%), E2 (86.6%), and E3 (51.8%), and mostly the door with their right hand, E1 (61.0%), E2, (91.2%), and E3, (50.5%). Conversely, when the FC tactic was used, the handles were used interchangeably between hands, right hand mainly using the aft handhold and left hand mainly using the door handle. This held true for all the egress transitions except the initial transition, E1, where the right hand was observed using the steering wheel (46.4%) more often than the aft handhold (15%).

In general, egress tactic influenced driver technique, i.e., interaction with the cab (PoCs), and egress timeline. There was a significant main effect for the egress tactic factor on total egress time variables. Those who exited with the FO tactic did so in a faster time compared to those who exited the cab using the FC tactic. Similarly, those who exited with the FO tactic showed an overall larger percentage of 1PoC and 2PoC compared to those who exited the cab using the FC tactic, and those findings were consistent when considering overall egress duration compared examining all three transitions for these metrics; however, for 1PoC variable, E3 transition showed the opposite effect, and FC technique had larger percentages. Similarly, those who exited using the facing the cab (FC) tactic were observed to have higher mean values of percent in 3PoCs and 4PoCs than those who exited the cab facing outward (FO). When comparing the effect of egress tactics on single limb support and double hand support PoCs, consistently observations were realized. Compared to the FO tactic, the FC tactic had a higher percentage of bearing single limb support, as well as a higher percentage of maintaining two hand PoC. Consistent findings were observed when considering the effect over each of the egress transitions. Those results were statistically significant for all but overall egress 1PoC, and 3PoC over the E3 transition.

Cab configuration also influenced egress tactics and the driver's egress techniques. As for the egress timeline, there was a significant main effect of the cab configuration on total egress time variables. Results showed that the FC egress tactic group generally exhibited a statistically significant effect of cab configuration on the total egress time, E1 egress time, E2 egress time, and E3 egress time. On the other hand, the FO tactic group had a statistically significant effect of cab configuration on E2 egress time only.

When considering driver interaction with the cab (PoCs), ANOVA results showed a main effect of the cab configuration that is significant on overall egress 2PoC, 3PoC, 4PoC, and 2PoCH variables, but not significant on overall egress 1PoC and 1PoCF. When considering the variables over each transition, PoCs dependent variables were all statistically insignificant except for 1PoC and 2PoC, which were statistically significant over the second transition E2.

When considering each of the egress tactics, univariate and Tukey’s HSD post hoc comparisons between step configurations analyses, the facing the cab egress tactic group showed a statistically significant effect of cab configuration on overall 1PoC, 2PoC, 3PoC, 1PoCF, and 2PoCH when taking into account total egress trial. Those findings were also consistent for the three step transitions for 2PoC and 1PoCF, as well as E3 1PoC, E2 3PoC, and E3 3PoC. On the other hand, when considering the facing outward group, no statistically significant effect of cab configuration on driver tactics for any of the PoCs variables, including those over each transition, were found. Lastly, no significant interaction effects between the egress tactic and the step configuration on any of the dependent variables analyzed were observed.

It is interesting to note that the outliers are accounted for by the obese and morbidly obese groups. This is observed among the step configurations 1-4 and the FC condition. Furthermore, the time to complete egress was also calculated for the three transitions, E1, E2, and E3. When examining the distribution of cases over the egress transitions, the effect is most noticeable in the E1 phase, where participants turn in preparation for the descent. Distributions are displayed for FO and FC egress tactics.

Conclusion

Although not statistically significant for the FO group, out of all the driver-cab interaction variables explored in this study, time to finish and 3PoC variables, over all durations, have been shown to be influenced by egress tactic and cab step configuration.

It is recommended in the trucking industry that drivers maintain three points of contact (3PoC) during ingress and egress of the cab. Drivers maintained 3PoC for roughly half the duration of cab egress during the facing the cab egress trial and a third of the time during the facing outward trial. 3PoC could be two limbs and one hand or two hands and one limb support. In examining the single limb support data distribution, it is noted that drivers maintained single limb support (1PoCF) roughly 70% of the duration within the facing the cab egress trial and 65% of the duration during the facing outward egress trial. Therefore, to maintain the 3PoC guideline, it is expected that drivers should maintain similar percentages of double hand support when exiting the cab. Findings from this study show that those percentages were roughly around 35% and 55% for the FO and FC groups, respectively. By inspecting their respective distributions over double hand support, we find that handle locations/utilization were not ideal in the first and last egress transitions.

This implies that drivers should focus on maintaining double hand support during dynamic egress motion, i.e., when transitioning, given that the main foot behavior used is step-over-step (SoS) foot behavior where at least 75% of the duration of the time drivers are at single limb support.

References

Bureau of Labor Statistics. (2014). Transportation and material moving: Heavy and tractor-trailer truck drivers injuries, illnesses, and fatalities. Retrieved from: http://www.bls.gov/ooh/transportation-and-material-moving/heavy-and-tractor-trailer-truck-drivers.htm. doi: http://www.bls.gov/iif/oshcdnew.htm, News Release (2014).

Fathallah, F. A., & Cotnam, J. P. (2000). Maximum forces sustained during various methods of exiting commercial tractors, trailers and trucks. *Applied Ergonomics, 31*(1), 25-33.

Federal Motor Carrier Safety Administration. (2007). Step, Handhold, and Deck Requirements for Commercial Vehicles. 49 CFR 399 Subpart L.

Giguère, D., & Marchand, D. (2005). Perceived safety and biomechanical stress to the lower limbs when stepping down from fire fighting vehicles. *Applied Ergonomics*, *36*(1), 107-119.

Guan, J., Hsiao, H., Bradtmiller, B., Kau, T.-Y., Reed, M. R., Jahns, S. K., . . . Piamonte, D. P. T. (2012). US truck driver anthropometric study and multivariate anthropometric models for cab designs. *Human Factors: The Journal of the Human Factors and Ergonomics Society.* doi:10.1177/0018720812442685.

International Organization for Standardization. (2006). ISO 2867:2006: Earth-moving machinery -- access systems.

Jones, D., & Switzer-McIntyre, S. (2003). Falls from trucks: A descriptive study based on a workers compensation database. *Work*, *20*(3), 179-184.

Lin, L. J., & Cohen, H. H. (1997). Accidents in the trucking industry. *International Journal of Industrial Ergonomics*, *20*(4), 287-300. doi: http://dx.doi.org/10.1016/S0169-8141(96)00060-1

Patenaude, S., Marchand, D., Samperi, S., & Belanger, M. (2001). The effect of the descent technique and truck cabin layout on the landing impact forces. *Applied Ergonomics, 32*(6), 573-582.

Reed, M. P. (2010a). Ingress/Egress Safety for Truck Drivers. Retrieved March, 02, 2016, from http://trucksteps.org/index.html.

Reed, M. P. (2010b). Ingress/Egress System Dimensions. Retrieved March, 02, 2016, from http://trucksteps.org/dimensions.html.

Reed, M. P., Hoffman, S. G., & Ebert-Hamilton, S. M. (2010). The influence of heavy truck egress tactics on ground reaction force. *Research and Practice for Fall Injury Control in the Workplace*, pp. 192-195.

Society of Automotive Engineers. (2003). SAE J185:200305: Access systems for off-road machines.

Shorti, R., Merryweather, A., Thiese, M., Kapellusch, J., Garg, A., & Hegmann, K. (2014). Fall risk factors for commercial truck drivers. *Journal of Ergonomics*, *9*(3), 1-9. doi: 10.4172/2165-7556.S3-009.

Spielholz, P., Cullen, J., Smith, C., Howard, N., Silverstein, B., & Bonauto, D. (2008). Assessment of perceived injury risks and priorities among truck drivers and trucking companies in Washington State. *Journal of Safety Research*, *39*(6), 569-576. doi: 10.1016/j.jsr.2008.09.005.

The Maintenance Council. (1989). RP-404B: The maintenance council (TMC) recommended practice 404B – Truck and Truck Tractor Access Systems.

Turner, L. M., & Reed, D. B. (2011). Exercise among commercial truck drivers. *American Board for Occupational Health Nurses (ABOHN) Journal*, *59*(10), 429-436. doi: 10.3928/08910162-20110916-01.

Williams, A. F., & Goins, S. E. (1981). Fatal falls and jumps from motor vehicles. *American Journal of Public Health*, *71*(3), 275-279.

CHAPTER 5

EFFECTS OF EGRESS TACTIC, STEP CONFIGURATION, AND DRIVER CHARACTERISTICS ON DRIVER BIOMECHANICS DURING CAB STEP NEGOTIATION

Abstract

The objective of this chapter is to provide a description of the observed influence of cab design and driver anthropometric and behavioral factors on driver biomechanics factors during truck cab egress. This chapter examines in detail the most common driver egress behavior identified in Chapter 3. By providing a more detailed description of truck driver biomechanics experienced during interactions with the cab, a better understanding of the influence of the systems involved during cab egress is established. The analysis focuses on three-dimensional reconstruction of truck driver egress motions and analysis of driver interaction with handholds and steps.

A laboratory study at UMTRI was conducted with a total of 52 drivers. Nine of the drivers (18%) were female, with a wide range of body dimensions and age. Stature, body weight, and 15 other standard anthropometric dimensions were obtained from each subject. The analysis of drivers' foot behaviors in Chapter 3 revealed eight main foot behaviors with varying prevalence: step-by-step leading with the left foot (2.8%), step-by-step leading with the right foot (3.7%), step-by-step-over-step leading with the left foot (1.2%),

step-by-step-over-step leading with the right foot (5.8%), step-by-step leading with the left foot (59.5%), step-by-step leading with the right foot (3.9%), step-over-step-by-step leading with the left foot (22.9%), step-over-step-by-step leading with the right foot (0.2%). This chapter includes a detailed description of the most common foot behavior, left foot lead step-over-step (SoS) foot behaviors, with a total of 815 study trials from 43 participants.

In summary, driver biomechanics largely depends on their interaction with the cab, tactics, foot behaviors, and the quality of contact with the steps. Findings from this research indicate the required coefficient of friction is more elevated when negotiating the bottom step; therefore, drivers are at a higher likelihood of slip potential when compared to the top step. Similarly, the loading rates and peak ground reactions forces are higher when drivers are negotiating steps and the ground. Findings from this research indicated that a portion of drivers performed egress facing away from the cab and given the prevalence of high body mass index (BMI) among this population, cab handhold and step configuration should incorporate stability metric calculations to allow such population for proper "footing" and allow for their CoM to be as close to the truck as possible in the event the drivers utilized the FO egress tactic. In summary, driver biomechanics largely depends on their interaction with the cab, tactics, foot behaviors, and the quality of contact with the steps.

Introduction

Earlier research indicates that slips leading to falls are a major cause of driver injury during ingress and egress (Lin & Cohen, 1997). According to BLS 2014 data, incidence rates of falls, slips, or trips are highest among heavy truck drivers (BLS, 2014). Falls to lower level, falls on same level, and slips or trips without falls all together accounted for 35% of the injuries and illnesses to heavy and tractor-trailer truck drivers in 2014. The slips and/or falls issue has been recognized as a leading cause of injuries among truck drivers, particularly during cab egress by several researchers and organizations (BLS, 2014; Jones & Switzer-McIntyre, 2003; Lin & Cohen, 1997; Williams & Goins, 1981).

Currently, the safety measures employed to reduce the likelihood of injury during truck cab access include design considerations, such as the presence of handrails as well as the spacing of steps to facilitate safe ingress and egress of the truck cab. Others include training considerations such as recommendations to face the truck cab as well as maintain three points of contact during ingress and egress. Cab design alone has been reported to be inadequate to facilitate safe egress; Patenaude et al. (2001) reports that half of the study participants (N= 10) reported their inability to see where they placed their feet during truck cab dismount, indicating a deficiency in cab step layout/design to meet user needs for safe egress. The risk of fall presented from foot placement uncertainty may be further amplified with the presence of contaminants on the steps. Consistently, previous results show that the layout of the cab is not adequate to facilitate a descent without risks of injuries (Patenaude et al., 2001). Another factor that suggests that the layout of the cab is inadequate was that 75% of the truckers stated that they use the steering wheel as support during descent (Patenaude et al., 2001).

Current safety recommendations are not always followed by drivers and alternative egress techniques are employed during cab egress, such as facing outward (FO) during egress, a technique that was shown to inhibit higher proportions of points of contact. Furthermore, several studies concluded that greater forces are sustained when drivers perform egress using the FO tactic (Fathallah & Cotnam, 2000; Giguère & Marchand, 2005; Patenaude et al., 2001; Reed et al., 2010b). Truck drivers tend to use different ingress/egress tactics to compensate for truck cab design inadequacies or compensate for personal factors such as BMI (Reed et al., 2010b).

Poor cab layout coupled with egress behavior that does not allow for safe descent is likely to increase the probability of injury from slips/falls, a situation that requires further systematic and detailed research. These investigations involve a detailed understanding of current cab components used during descent, the individuals using the cab, and the factors and behaviors involved as individuals are using the access system. Understanding the interactions between commercial truck operators' health and physical behaviors with the cab layout/design during ingress/egress is an important step in the efforts to mitigate fatal and nonfatal injuries from falls among truck drivers.

The probability of injury or likelihood of slips and/or falls has been investigated previously by studying the coefficient of friction (CoF) of a given surface. There are many equipment configuration factors and individual factors that may contribute to operator falls from a vehicle. The dynamic coefficient of friction and surface condition are factors commonly investigated in gait studies and might applicable here. Other factors include the strength requirements at joints as a function of hand and foot placement.

A detailed description of the foot interaction with the step, including details of relative foot kinematics and associated foot force profiles, is developed in this research. This provides a more accurate definition of etiological risk factors for slipping and loss of contact that may lead to falling while entering or exiting truck cabs. The main hypothesis behind this research is that truck cab configuration, driver anthropometry, and egress tactics are contributing factors to slip/fall potential.

The effect of egress tactic, cab layout, and drivers' personal factors, such as BMI, and slip/fall potential are summarized. To date, no literature provides an in-depth analysis of the driver-cab interaction variables, during egress of truck, such as required coefficient of friction, loading rate, CoM velocity and acceleration, foot clearance, foot rotation angle relative to step, and base of support area on step have been reported. Therefore, the goal of this research effort is to investigate if the variability in truck cab layout affects drivers' biomechanical variables during egress. Additionally, we investigate if driver tactics, FO vs. FC, has an effect on those variables during egress.

Methods

Participants

All participants were recruited through newspaper advertisements and flyers. All participants had at least 5 years of commercial driving experience in tractor-trailer combinations and had driven professionally within the 2 years prior to testing. A total of 43 drivers (8 female, 35 male) were included in these analyses. The mean age was 45.3 years (range 22–65) and the mean (standard deviation) stature and weight were 157.5 (8.5) cm and 96.9 (23.3) kg, respectively. The average BMI of this study population was 30.7 kg/m2 (*SD* = 6.4), which is considered obese (range 21.6–52.8). Fifteen other standard anthropometric dimensions were obtained from each participant. Drivers self-identified their race/ethnicity. Select study participants' characteristics are displayed in detail in Table 4.1.

Experimental Mockup Environment Setup

A reconfigurable truck cab mockup was constructed with key features of heavy truck cab ingress/egress (IE) systems, as shown in Figure 3.2. The steps can be adjusted vertically and horizontally, simulating the range of step configurations in the current truck fleet based on analysis conducted by UMTRI (Reed, 2010a). Force plates and load cells on the ground, steps, seat, steering wheel, and handholds measured reaction forces. Participants' whole-body motions were recorded using a 13-camera VICON passive-marker optical tracking system, and subjective assessments of ingress/egress difficulty were obtained from all participants.

Participants were instructed to enter and exit the mockup cab using self-selected movement strategies and using specific strategies identified previously in covert field observations. Testing was conducted with both internal and external handholds at the rear of the door opening. The internal handhold was fixed within the cab enclosure and was located 45 mm inside the door opening, 100 mm forward of the rear of the opening, and extended from 1358 to 1794 mm above the ground surface (total usable length of 436 mm). The external handhold, a vertical bar attached to the outside of the mockup immediately rearward of the door opening, was located 113 mm outboard of the sill, 130 mm aft of the door opening, and extended from 1273 to 2207 mm above the ground (total length of 934 mm). The simulated door was constructed with an open aluminum frame and was fixed at a 45-degree angle to the fore-aft axis of the mockup for testing. Additionally, the setup included a diagonal handhold that extended inward and upward from the lower, outboard edge of the door.

Cab Step/Handle Configuration

Cab dimensions for the mockup were chosen based on an analysis of dimensional data from 30 trucks (Reed, 2010b). Step and sill heights were fixed, as shown in the top right corner of Figure 3.2. Conditions for this experiment included a set of step and handhold configurations obtained by varying the lateral positions of the steps, and two configurations (internal and external) of the handholds. Drivers entered and exited the cab twice with each combination of the two handhold configurations and the eight different step configurations, for a total of 32 trials per participant. In all trials, participants were able to use a handhold on the door and to use the steering wheel as a handhold. During these trials, each driver exited the cab using a self-selected method in the first trial in each condition (undirected trials). In the second trial, the driver was instructed to perform an outward-facing egress if the first trial was inward-facing, and vice-versa (directed trials). Therefore, the odd trials were undirected and all even trials were directed.

Participant motions were tracked using a VICON passive optical motion tracking system with 13 cameras. A total of 68 retroreflective markers were placed on skin or clothing, as shown in Figure 3.3. The pelvis markers were mounted on a Velcro belt attached to vertical Velcro strips on tight-fitting shorts worn underneath nylon running shorts. The thorax markers were mounted on a snug elastic band under the pectorals. All other markers (except head) were taped to the participant; the wrist and shoe markers were reinforced with duct tape.

Data Analysis and Statistical Methods

Data were processed and calculations were performed using Visual3D (C-Motion, Germantown, MD, USA). Based on recommendations made by Winter (1990), video and analog data were filtered with a fourth-order low-pass Butterworth filter at 6Hz and 20Hz, respectively. Analyses were also performed based on Winter's recommendations to select cutoff frequencies. Matlab (R2014a, The Mathworks Inc., Natick, MA, USA) was used to format gait data exported from Visual3D (C-Motion, Germantown, MD, USA) and SPSS (Version 20 for Windows, SPSS Science, Chicago, USA) was used to perform the final statistical analyses. BMI was included as a categorical variable with four levels based on the following criteria: normal weight ($18.5 <= BMI < 25$, $n = 7$); overweight ($25 <= BMI < 30$, $n=14$); obese ($30 <= BMI < 35$, $n=21$); and morbidly obese ($BMI > 35$, $n=10$). Statistical analyses were performed using SPSS 21.0 (SPSS; IL, USA). A 2X4X7 (egress tactic X BMI X cab configuration) factorial ANOVA design was used to test the effects of driver tactics, BMI, and truck cab step configuration on dependent variables RCoF, LR, FCL, and FRA during the total egress trial as well as over each of the transitions. Tukey's HSD post hoc analysis across each of the egress tactic groups was performed. Statistical significance was chosen a priori at $\alpha = 0.05$.

The following hypotheses were evaluated:

H_1: There is a significant effect of truck cab configuration on driver required coefficient of friction (RCoF) during truck cab egress.

H_2: There is a significant effect of truck cab configuration on driver loading rate (LR) during truck cab egress.

H_3: There is a significant effect of truck cab configuration on driver foot placement clearance (FCL) during truck cab egress.

H_4: There is a significant effect of truck cab configuration on driver foot rotation angle relative to step (FRA) during truck cab egress.

H_5: There is a significant effect of driver egress tactic on driver required coefficient of friction (RCoF) during truck cab egress.

H_6: There is a significant effect of driver egress tactic driver loading rate (LR) during truck cab egress.

H_7: There is a significant effect of driver egress tactic on driver foot placement clearance (FCL) during truck cab egress.

H_8: There is a significant effect of driver egress tactic on driver foot rotation angle relative to step (FRA) during truck cab egress.

Data Analysis Methodology

The main objective of this phase of the research study was to develop an understanding of the effect of driver tactics and cab configuration on driver-cab biomechanics in order to support the investigation of how those behaviors are modified, by personal or vehicle characteristics, as well as define a systematic method of analysis for the driver egress motions.

Driver Egress Behaviors

The egress motions analyzed for this study span the period beginning with the leading foot leaving the sill and ending with initial double limb stance on the floor, i.e., trailing foot's initial contact with the floor. Driver egress tactics can be broadly divided into two major categories: facing the cab, also known as inward-facing (FC) and facing the cab, also known as outward-facing (FO). Subgroups within these categories can be further defined based on other aspects of step/handhold interaction.

To better understand and classify foot behaviors, the egress motions were divided into phases based on specific events. These events were defined by the foot trajectory and force data based on foot contact with the steps and ground. There were three phases analyzed: the first phase (E1) encompasses the transition between the sill and top step, the second phase (E2) is the transition to the bottom step, and the third phase (E3) includes the transition to the ground. Each phase was defined using beginning and ending events. E1 began once the driver's leading foot left the sill and ended when the trailing foot hit the top step. E2 began with the leading foot leaving the top step level and ended with the trailing foot at the bottom step level. Finally, E3 began when the leading foot left the bottom step level and ended with the trailing foot's initial contact with the floor plate, i.e., initial double stance on the floor. A graphical representation is included in Figure 3.4.

The participant's foot behaviors were analyzed based on the temporal order of feet used during the three transition phases of the egress motions: E1, E2, and E3. These behaviors are shown in Figure 3.5. The critical element of this classification methodology is the identification of when the leading foot reaches each step and the ground. For example, if the left foot reaches each step and the ground first (behavior code 111 in Figure 3.6), then the driver is executing the dual-foot strategy termed step-by-step (SbS), since the right foot follows the left foot to each step and the ground. In contrast, alternating feet, for example right-left-right, defines a step-over-step (SoS) tactic, labeled 101 or 010 in Figure 3.6.

Biomechanical Modeling Using Visual3D

A custom biomechanical model of the truck drivers was built using Visual3D software (C-Motion, Germantown, MD, USA). The biomechanical model consisted of a set of segments, comprised of the pelvis, thighs, shanks, feet, trunk, upper arms, forearms, and hands. Each segment was defined by using a set of markers defining boundary conditions and parameters such as the proximal and distal endpoints, and joint center and mediolateral landmarks, as well as tracking and virtual markers that were either tracked or calculated from the dynamic motion trials. Depending on the geometry of the segment, either cones, cylinders, spheres, or ellipsoids can be used to model each segment and develop a total biomechanical model that can be applied and scaled to each subject. The mass, moments of inertia (IXX, IYY, IZZ), and CoM_P for each segment are then calculated for each segment and for the total biomechanical model in 3D space (Hanavana, 1964).

The custom model was applied to each participant trials and was fitted to each participant static trial as well as individual anthropometric inputs, i.e., the height and weight of each participant, to scale the model appropriately. The center of mass position (CoM_P) trajectory was then calculated and visualized for all trials. The CoM position array contains the XYZ trajectory of the position of the center of gravity of a segment resolved in the laboratory coordinate system. The marker, landmark, CoM position, and CoM acceleration trajectories were used in the process of defining key events for the phases defined during each participant trials. The Center of Mass Velocity (CoM_V) was then calculated using the first derivative of each data point of the CoM_P trajectory using Visual3D using the finite difference algorithm method. For a given CoM_P signal:

$CoM_P(t_i)\ ;\ for\ i = 1, 2,3, \dots, n$

The CoM_V first derivative is calculated using the following equation:

$$CoM_V(t_i) = \frac{CoM_P(t_{i+1}) - CoM_P(t_{i-1})}{t_{i+1} - t_{i-1}}$$

Furthermore, the magnitude of each of the XYZ CoM_V trajectory points was calculated using the following equation:

$$CoM_V(x, y, z) = \sqrt{(x^2 + y^2 + z^2)}$$

Similarly, The Center of Mass Acceleration (CoM_A) was calculated using the second derivative of each data point of the CoM_P trajectory using Visual3D using the finite difference algorithm method. For a given CoM_P signal:

$CoM_P(t_i)\ ;\ for\ i = 1, 2,3, \ldots, n$

The CoM_A second derivative is calculated using the following equation:

$$CoM_A(t_i) = \frac{CoM_P(t_{i+1}) - 2CoM_P(t_i) + CoM_P(t_{i-1})}{(t_{i+1} - t_i)^2}$$

Furthermore, the magnitude of each of the XYZ CoM_A trajectory points was calculated using the following equation:

$$CoM_A(x, y, z) = \sqrt{(x^2 + y^2 + z^2)}.$$

SoS Foot Pattern Phases During Cab Egress

All participants started the egress trial from a seated position and ended with a T-pose on the ground level. The egress motions analyzed for this study span the period beginning with the leading foot leaving the sill and ending with initial double limb stance on the floor, i.e., trailing foot's initial contact with the floor. Explicit events, defined through the foot motion trajectory and force data, were established to determine foot interaction with the seat, steps, and ground. Those events defined the beginning and end of each limb interaction with each step and ground and were later used to determine the nature of the motions involved during cab egress and determination of the egress phases. Cab egress motions inside the cab, i.e., sit to stand and egress preparation, as well as egress motions at ground level, i.e., ground gait post initial onset of double stance on the ground, were not analyzed in this research.

During the SoS foot pattern, each foot is on a different step and performing the opposite function of the other foot. For instance, during the sill and top step negotiation, while the trailing foot (TF) is in stance and loading phases on the cab sill, the loading foot (LF) is in swing and unloading phases, respectively. These phases include the LF leg pull through, controlled lowering, and weight acceptance. Once both feet are at the same level, this cycle is repeated with each foot performing the opposite phases that were performed during the previous cycle.

The start of the swing phase during interaction with the sill was defined using the foot motion trajectory with an explicit event marking initial foot departure from the sill. The swing phase during interaction with the seat, steps, and ground were marked using the reaction force data, defined using an explicit event with a threshold of 50N for the respective cab element.

Similarly, the start of the stance phase during interaction steps and ground were marked using the reaction force data, defined using an explicit event with a threshold of 50N for the respective cab element.

At the instant that the loading phase of the leading foot is marked for one foot, the unloading phase is also initiated and marked for the other foot. The loading phase is identified using an explicit event through a pipeline applied to the normal reaction force component with a threshold of 50N. The end of the loading/unloading phases was marked with the end of contact of trailing foot with the previous step. This event typically happens at the same time the leading foot is at approximately the maximum force and marks the beginning of the single stance phase. Moreover, during the loading and unloading phases, the feet are in double stance, two points of contact on the lower limbs, during the entire phase but driver upper limbs maybe at one or two points of contact; therefore, it is expected that variance in peak reaction forces at the limb are due to the variability in handhold use and speed of decent during the loading/unloading phases, i.e., the transition between steps. The SoS foot behavior phases and respective force profiles are shown in Figure 5.1.

Biomechanical Factors

In this chapter, two kinetic dependent variables were investigated, the required coefficient of friction (RCoF), and the loading rate (LR). Both, the LR and the RCoF variables are kinetic metrics used to describe the reaction force (RF) profile. The earlier describes the slope of the initial portion of the vRF and the latter describes the ratio of the vertical to horizontal RF components. Other variables considered in this study include stability related metrics such as foot kinematic parameters that define the orientation and location of the foot during support on the steps, i.e., the foot placement clearance (FCL), foot rotation angle (FRA) that define the foot base of support area over step (BoSAS) during the loading and unloading phases. In addition, driver spatiotemporal parameters, i.e., whole body transfer CoM_A and CoM_V during the cab egress, were considered and analyzed. Those metrics were investigated over the entire egress trial, and within each of the egress transitions.

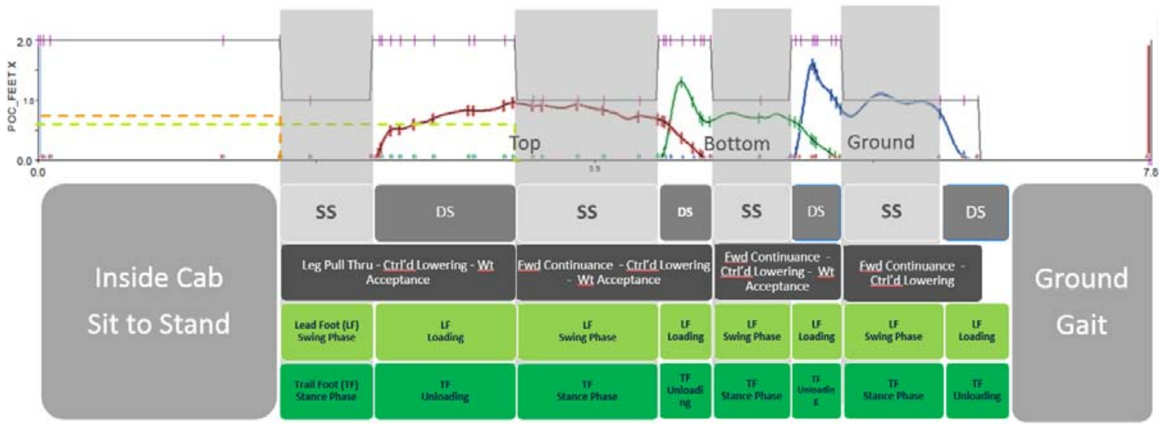


Figure 5.1.The SoS foot behavior phases and respective force profiles.

Reaction Forces

Reaction forces at the steps and ground may be related to the driver's level of risk during cab egress (Fathallah & Cotnam, 2000). Research conducted at the Liberty Mutual Research Center showed that GRFs are influenced by use of handholds, driver tactics, and overall truck cab configuration (Fathallah & Cotnam, 2000). This is consistent with other research findings showing that driver IE tactics (Merryweather, Shorti, Thiese, Caughey, & Hegmann, 2010; Patenaude et al., 2001), anthropometry (Patenaude et al., 2001), and step/handhold configuration (Giguère & Marchand, 2005) affect the resulting peak ground reaction forces at the feet.

Furthermore, during ground contact, the GRF is an indicator of the intensity of stress on the human system (Powers et al., 1999). Injury potential likely increases with increases in GRF, although the nature of the relationship is unknown (Handsaker et al., 2014; Oshkour et al., 2014; Valtonen, Poyhonen, Manninen, Heinonen, & Sipila, 2015). Several kinetic variables that may be related to injury risk have been previous investigated, including peak vGRF (Oesch, Meyer, Jansen, & Kool, 2015; Pickle, Wilken, Aldridge, Neptune, & Silverman, 2014), time to peak vGRF (Matsufuji et al., 2015; Wong, Wang, Wang, & Ko, 2014), and loading rate (Logerstedt, Zeni, & Snyder-Mackler, 2014; Luder et al., 2015). High loading rates, as measured by the rate of increase of GRF, may increase injury risk (Roche et al., 2015; Taddei et al., 2014).

Loading rate (LR), also referred to in the literature as the rate of change of the vertical ground reaction force (van Bergen, van Eekeren, Reilingh, Sierevelt, & van Dijk, 2013), can be calculated in several ways. One approach utilizes the instantaneous rate of change of the normalized vertical ground reaction force, from the first derivative of vGRF, to calculate the LR (van Bergen et al., 2013). Other approaches utilize events to define the duration, with the LR calculated as the slope of the line between events, the first event being the first exceedance of a threshold force level defining initial contact with sensor and the final event being a peak force threshold characteristic of the interaction, such as the first instance when the vGRF reaches BW plus 50N (Tuncer, Hansen, & Amis, 2014), a percentage or multiple of BW (Harrison, Danneskiold-Samsoe, & Bartels, 2013), overall peak vGRF (Alshawabka, Liu, Tyson, & Jones, 2014), or the initial impact peak during contact with plate (Vincent, George, Seay, Vincent, & Hurley, 2014); this peak typically marks the end of the approximately linear region, loading region, on the vRF curve during the initial phase of contact with the sensor. An example of the vertical ground reaction force profile is shown in Figure 5.2.

In this study, the LR was defined as the slope of the initial loading region of the vRF, defined using the contact with plate at 50N to the initial peak as shown in Figure 5.3. The LR normalized to BW was calculated using the following equation:

$$LR = \frac{vRF_{final}}{\left(t_{final} - t_{initial}\right)BW}$$

In this equation, tinitial is the initial time where vRF reaches a threshold of 50N, tfinal is time at end of the linear region marked with the threshold at which the vRF reaches the foremost impact peak, BW is the subject body weight, and vRFfinal is the vRF at tfinal. The units are BW/second. The loading rate was calculated using a pipeline that was applied to each participant trials. This pipeline utilized the respective step events that defined the peak vertical reaction force, tinitial, and tfinal.

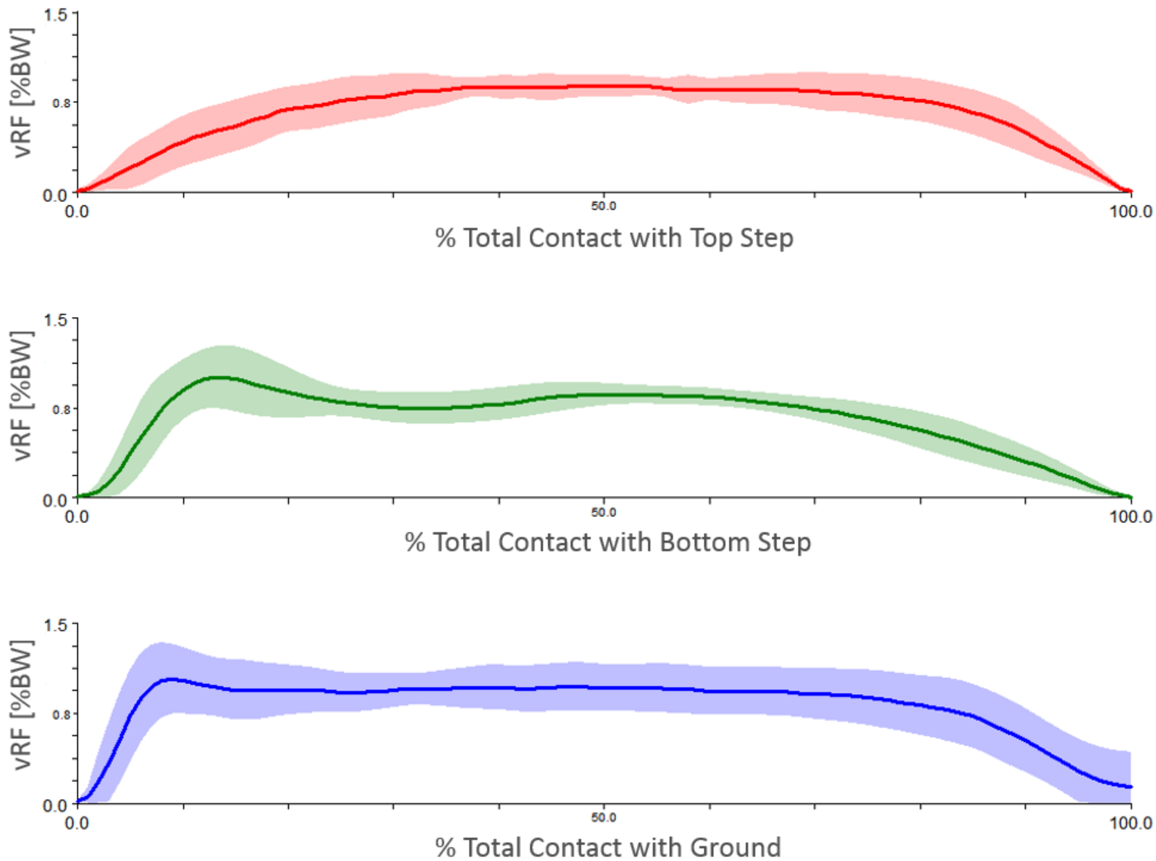


Figure 5.2. Example vRF, as a percent of total subject BW, for top step (top), bottom step (middle), and ground (bottom).

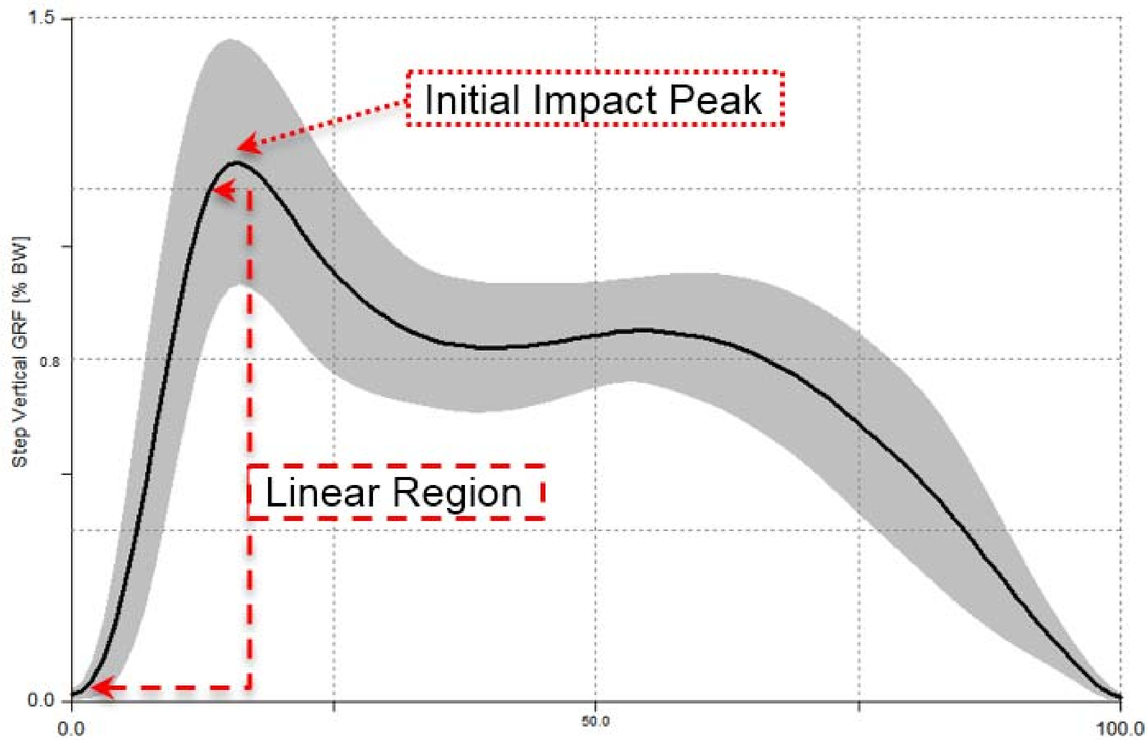


Figure 5.3 Sample profile of vertical ground reaction force (vGRF), normalized to body weight (BW), during total foot contact with step. The loading rate is defined using the loading region marked with dashed lines, and defined as the initial contact with plate at 50N to the initial impact peak.

Required Coefficient of Friction (RCoF)

The horizontal forces on steps and on the ground provide a measure of the risk that has been shown to be an important predictor of slip incidents (Chang, Chang, & Matz, 2012). The dynamic coefficient of friction (DCoF) is commonly used to investigate slips and falls (Burnfield & Powers, 2006; Fong, Hong, & Li, 2005; Gronqvist, Hirvonen, Rajamaki, & Matz, 2003; Hanson, Redfern, & Mazumdar, 1999). Burnfield and Powers (2006) concluded that knowledge of the coefficient of friction (CoF), between a person's shoe and the surface, can be used to predict the probability of a slip event. Similarly, Hanson et al. (1999) showed that the number of slip and fall events increased as the difference between the required CoF and the measured DCoF increased. For level ground surfaces, if CoF remains above 0.25, slips and associated falls may be unlikely (Gronqvist et al., 2003).

The horizontal forces on steps and on the ground provide us with a measure of the friction requirements under the measured loading conditions (Chang et al., 2012). Furthermore, field data indicate that foot slips and slips leading to falls are a leading cause of driver injury during ingress and egress (Lin & Cohen, 1997). Traditionally, for slips on level surfaces, the RCoF represents the minimum coefficient of friction that must be available at the shoe-step interface to prevent slip initiation. RCoF is normally calculated as the ratio of horizontal to vertical (normal) forces on flat, horizontal surfaces that are exerted during normal, non slip events. The rationale for terming this ratio the "required" COF is that a slip would have occurred during the observed event if the COF were lower than this ratio. Critically, this rationale is dependent on the loading behavior that produces the measured forces, that is, the RCOF is the required coefficient of friction given the observed human behavior.

In this study, the RCoF is calculated as a ratio of the horizontal to normal forces between the contacting foot and ground or step and incorporates the vector sum of both the shear, anterior-posterior direction, and transverse, medio-lateral direction, components of the GRFs (see illustration in Figure 5.4) using the following equation (Chang, Chang, & Matz, 2011):

$$\mathrm{RCoF_{mod}}(\mu_R) = \frac{\sqrt{F_S^2 + F_T^2}}{\mathrm{F_N}}$$

While this RCoF metric can be used to predict the probability of a slip event on level surfaces (Burnfield & Powers, 2006; Hanson et al., 1999), the interaction between a driver's foot and the step during truck cab egress may be significantly more complex than that with the ground during walking on level surfaces. Therefore, the horizontal reaction forces were evaluated with their temporal relationship in relation to foot kinematics and trajectories.

Maximum RCOF values were observed at the beginning and end of contact with the step, as shown in Figure 5.5. Nonslip large RCoF values have previously been reported by several researchers investigating slips on level surfaces (Chang et al., 2012; Fino & Lockhart, 2014). Those inflated RCoF values are a result of extremely small vRF that occur during the situation when the body weight is supported by the other limb at that moment, with only a small fraction of the weight supported on the limb with large RCoF values. Therefore, in this present investigation, the RCoF values were considered only over the duration where the respective vRF is above a threshold of 50 N, since those values do not result in slip or noticeable change in CoM trajectory position (Yamaguchi, Yano, Onodera, & Hokkirigawa, 2013).

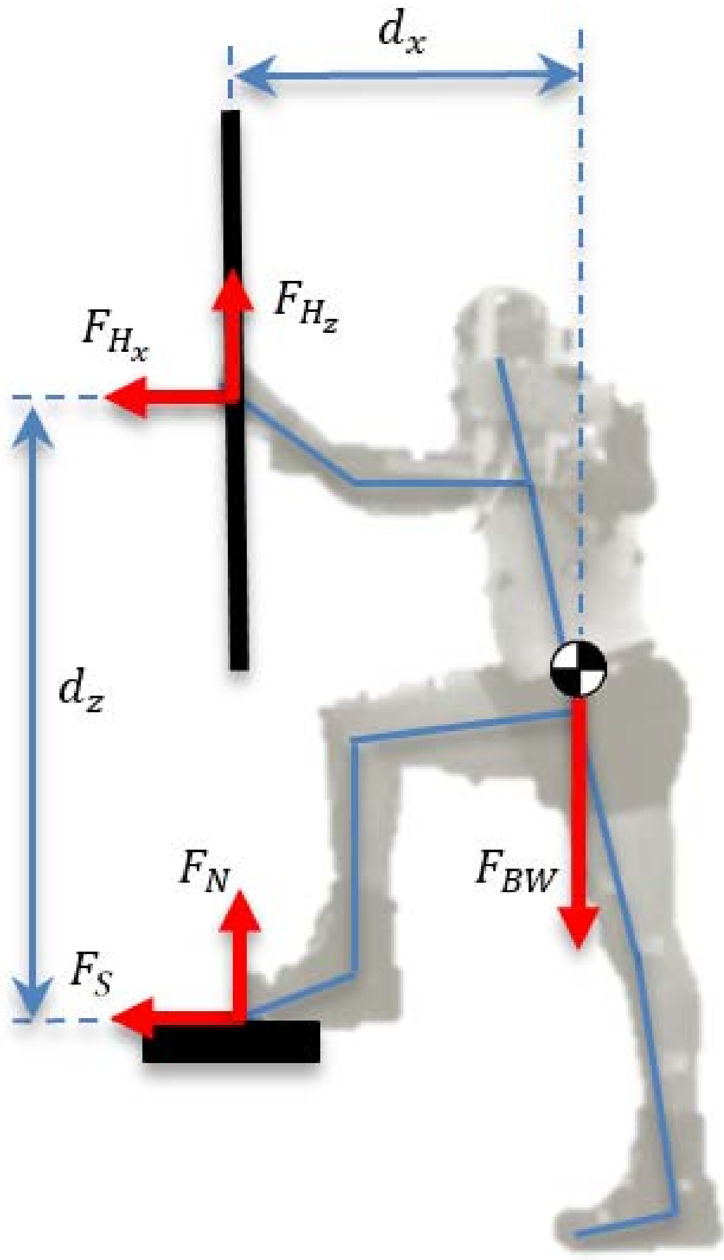


Figure 5.4. A simplified free-body diagram of a driver during ingress.

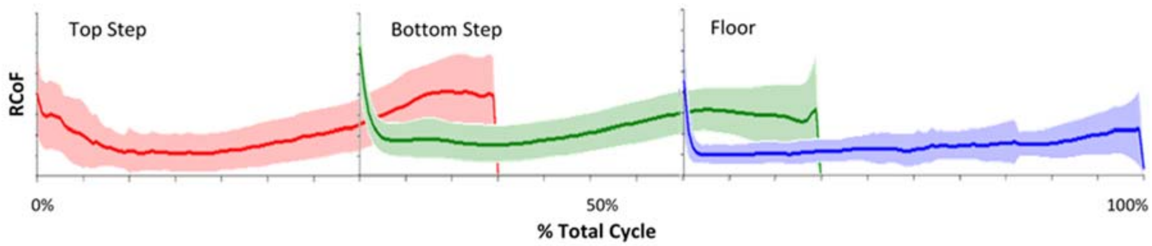


Figure 5.5. Example RCoF calculated for each step shown across total contact with top step (left), bottom step (middle), and ground (right).

While this approach helps eliminate contamination of RCoF values that do result in macroscopic slips, there is an overlap between when the beginning and end of the transitions (shown in Figure 5.5). This is the phase when the leading foot is loading and the trailing foot is unloading. A slip with the trailing foot at this point may not be consequential, and may even help to prevent a trip with the trailing foot. Consequently, the RCoF values were only considered for each limb to the point where the threshold of 50 N on the leading foot is met. This method allows for a continuous RCoF from start to finish of the egress in SoS stair negotiation pattern, as shown in Figure 5.6.

Foot Placement Clearance (FCL)

While the RF is an important measure of risk, foot placement may be an equally important factor. Providing adequate clearance and depth for optimal foot placement is essential to reducing the moment at the ankle in certain situations where a slip or loss of contact could result. This may result in the inability to generate enough moment to support the body. Since increases in BMI and age have been shown to be associated with a gradual decline in muscle strength (Cooper et al., 2011; Hardy et al., 2013), it is important to determine the influence of truck configuration, driver anthropometry, and egress tactics on the factors relating the characteristics of the ground reaction forces to identify situations when they would be minimized.

The foot placement clearance (FCL) is the fraction of the bottom of the foot in contact with the step. FCL was defined as the distance cleared by the foot relative to the front edge of the step during the loading phase of contact with a step (Figure 5.7). For the FC egress tactic, FCL was calculated using a marker placed on the toe and another marker

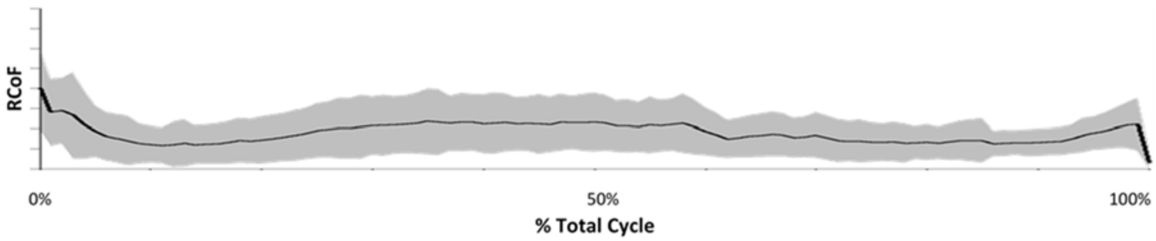


Figure 5.6. Sample RCoF calculated used for total egress cycle. Vertical axis? Label foot contact events from the preceding plot.

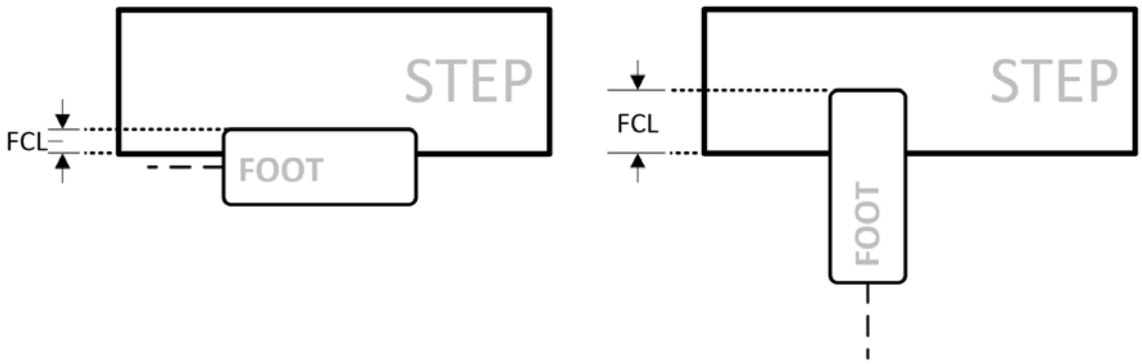


Figure 5.7. Illustration of the step and foot displaying the foot placement clearance relative to step (FCL), when the foot is perpendicular to step (right), and parallel to the step (left).

placed on the front of the step. For the FO egress tactic, the heel marker was used to calculate the FCL. Since the orientation of the foot was not controlled in this study, the sign convention of the FCL as well as the foot rotation angle relative to the step were used to verify the orientation of the foot and calculate the correct FCL.

Foot Rotation Angle Relative to Step (FRA)

Foot kinematics and associated ground/step reaction force profiles provide valuable information about the quality of contact between the foot and the step that can be utilized in biomechanical models to predict slips and loss of contact.

The foot rotation angle relative to step (FRA) was calculated using the lower limb 3D reconstructed model from the captured motions of the egress trials. The foot model was defined using the heel, toe, fifth metatarsal, ankle medial and lateral, mid-forefoot, and ankle joint center markers fitted to the Visual3D built-in foot model to visualize foot trajectories and orientation in 3D space. The foot orientation, specifically the foot rotation, was calculated relative to each step for all subjects. A secondary method was used to verify the foot orientation. This method used the toe and heel markers projected on the step surface to establish a center line that was used to calculate the rotation of the foot relative to the step front edge. The angles were calculated such that a 90° angle implied that the foot was perpendicular to the step and a 0° or 180° angle implied that the foot was parallel to the step. Figure 5.8 shows an illustration of the foot relative to a step used to define FRA in two scenarios. The illustration on the right side shows the foot perpendicular to a step and the illustration on the left side shows the foot parallel to a step.

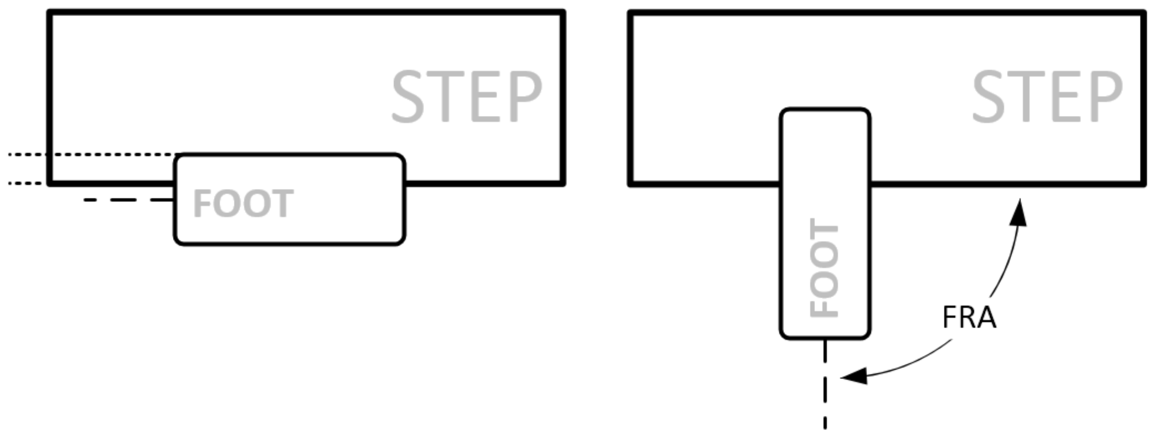


Figure 5.8. Illustration of the step and foot displaying the foot rotation angle relative to step (FRA). On the right, the illustration presents the foot at 90°, perpendicular, relative to the front of the step, and on the left side, the illustration shows the foot at a 0° or 180° angle, parallel, relative to the front of the step.

Base of Support Area on Step (BoSAS)

The base of support area on step (BoSAS) was calculated as a percent of total foot area for each step/foot interaction during egress using the following equation:

$$\%\ \mathrm{BoSAS} = \frac{L_{foot}\ d_{clearance} \cos^2 \theta + W_{foot}\ d_{clearance} \sin^4 \theta}{L_{foot} W_{foot}} 100\%$$

where, θ is the foot angle relative to the step, Lfoot is foot length, Wfoot is foot width, and dclearance is the length of foot overlap on the step. A 90° angle was defined as perpendicular to the step and a 0° or 180° angle was defined as parallel to the step, as shown in Figure 5.9.

This allows for estimation of a given foot area overlap on a step using the foot clearance relative to the front edge of the step, and foot angle relative to the step. This equation was developed to address the need for a simple method to estimate the overlap area since the interpretation of the foot clearance on a given step is not meaningful without taking into account the foot angle relative to the step. To illustrate this point, Figure 5.10 illustrates a calculation of a hypothetical situation where foot length is defined as 10 units and foot width as 4 units yielding a total foot area of 40 units. The graph displays BoSAS calculation as a percentage of total area, vertical axis, shown over a range of angles, 0° to 180° degrees, the horizontal axis, for a series of foot clearances, 1 to 10 units shown as individual lines.

In future studies, BoSAS can be determined using a pressure sensor instrumented within a shoe insole that calculates the relative area from the grid of sensors actuated as a percent of total foot area. In situations where such sensors are not available, simpler methods may be employed that still utilize the concept of percent coverage over the total step, as an indication of available or functional base of support over the step.

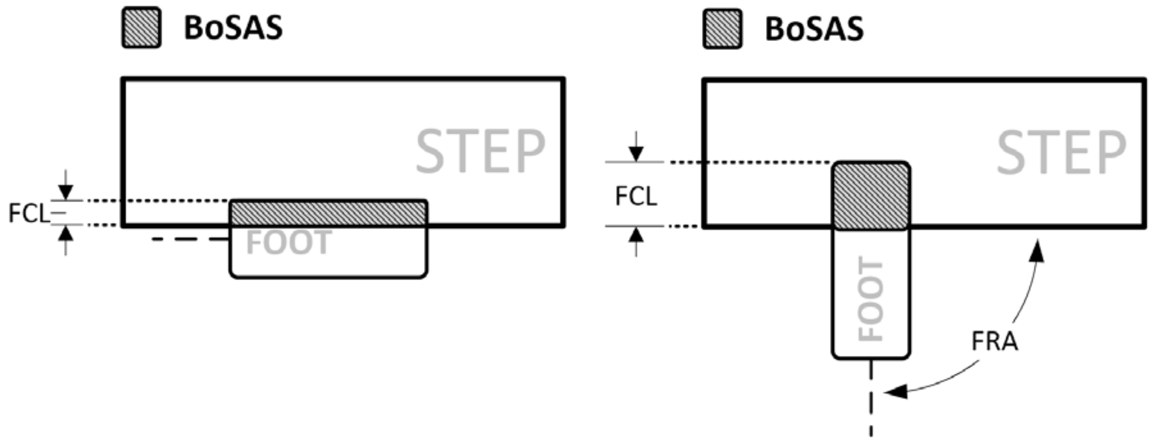


Figure 5.9. Illustration of the step and foot displaying the foot placement clearance relative to step (FCL), foot rotation angle relative to step (FRA), and respective foot base of support area on step (BoSAS), when the foot is perpendicular to step (right), and parallel to the step (left).

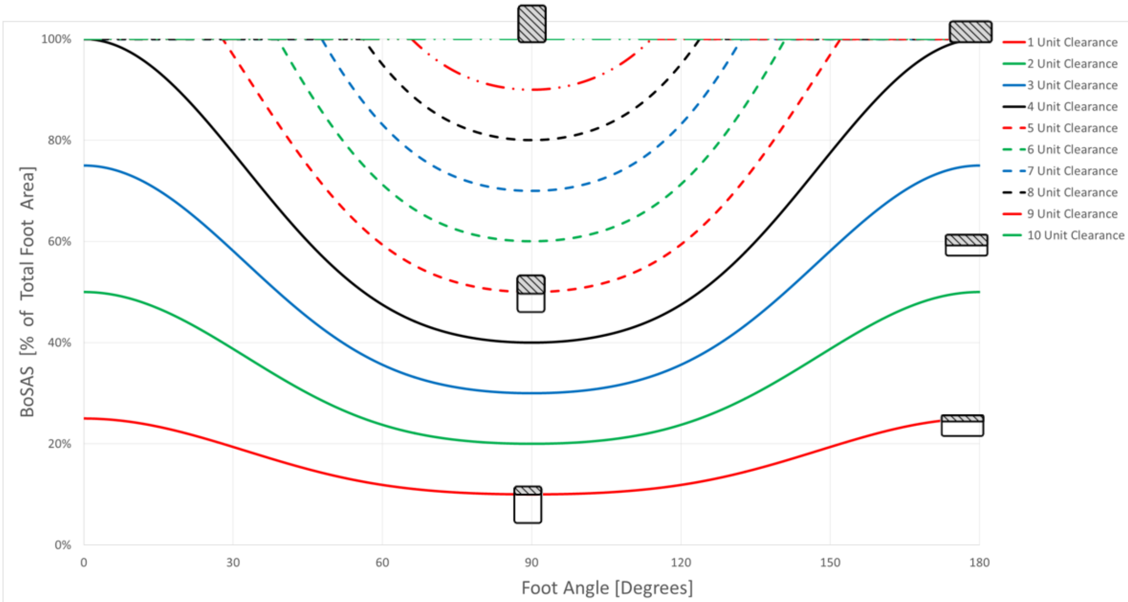


Figure 5.10. Illustration of BoSAS calculation for a hypothetical situation where foot length is defined as 10 units and foot width as 4 units yielding a total foot area of 40 units. The graph displays BoSAS calculation as a percentage of total area, vertical axis, shown over a range of angles, 0° to 180° degrees, the horizontal axis, for a series of foot clearances relative to the front edge of the step, 1 to 10 units shown as individual lines.

Results

Required Coefficient of Friction (RCoF)

Table 5.1 includes a summary of means and standard deviations, and ANOVA results for the RCoF variable during all egress trial, E1, 2, and 3, for both egress tactics, FC and FO. The main effect of tactic was statistically significant, indicating higher peak RCoF for the facing the cab tactic, when compared to the facing outward tactic for the peak RCoF over the entire egress trial (FO: M=0.44, SD=0.11, FC: M=0.45, SD=0.12), $F(1,747)$= 4.876, p<0.05, peak RCoF during E1(FO: M=0.33, SD=0.27, FC: M=0.34, SD=0.14), $F(1,747)$= 4.391, p<0.05, and peak RCoF during E2 (FO: M=0.27, SD=0.1, FC: M=0.40, SD=0.10), $F(1,747)$= 286.835, p<0.001. While this effect was also statistically significant during E3 transition (FO: M=0.40, SD=0.09, FC: M=0.28, SD=0.1), $F(1,747)$= 190.058, p<0.001, the results indicated a lower peak RCoF for the facing the cab tactic when compared to the facing outward tactic during this final transition to the ground. The effect of step configuration within the FO tactic showed no statistically significant effect on peak RCoF during the entire egress trial, $F(7, 262)$= 1.132, p=.343, as well as during each of the egress transitions, E1, $F(7, 262)$= .510, p=.827, E2, $F(7, 262)$= .797, p=.590, E3, $F(7, 262)$= 1.296, p=.253. BMI also had no significant effect on the peak RCoF during the entire egress trial, $F(3, 262)$= 2.154, p=.094, peak RCoF during E1, $F(3, 262)$= 2.333, p=.074, or peak RCoF during E2, $F(3, 262)$= 1.614, p=.186, but a statistically significant effect on peak RCoF during E3 stair negotiation, $F(3, 262)$= 3.536, p<0.05. No interaction effects were observed between step configuration and BMI, on any of the RCoF variables, peak RCoF during E1, $F(21, 262)$= .743, p=.786, peak RCoF during E2, $F(21, 262)$= .767, p=.759, peak RCoF during E3, $F(21, 262)$= .474, p=.977, or peak RCoF during the entire

Table 5.1. Descriptive statistics, means and standard deviations, and univariate analysis results for RCoF variable during all egress trial, E1, 2, and 3, for both egress tactics, FC and FO.

Step Configuration	Peak RCoF Average (*SD*)		Peak RCoF_E1 Average (*SD*)		Peak RCoF_E2 Average (*SD*)		Peak RCoF_E3 Average (*SD*)	
	FO	**FC†****	**FO**	**FC**	**FO**	**FC†****	**FO**	**FC†****
1	0.43(.09)	0.43(.11)[b]	0.34(.09)	0.39(.12)[a]	0.38(.09)[a]	0.35(.10)**	0.32(.10)	0.24(.11)[b]
2	0.45(.10)	0.48(.11)[a]	0.36(.13)	0.40(.13)	0.37(.10)	0.39(.12)[b]	0.34(.11)	0.25(.12)[b]
3	0.43(.09)	0.44(.13)[b]	0.34(.11)	0.39(.12)	0.34(.08)	0.37(.10)**	0.34(.11)	0.26(.13)[b]
4	0.47(.14)	0.48(.11)[b]	0.38(.18)	0.40(.13)	0.39(.08)	0.44(.10)[a]	0.33(.10)	0.23(.10)[a]
5	0.48(.12)[a]	0.46(.11)[b]	0.37(.16)	0.39(.13)	0.39(.11)	0.41(.10)[b]	0.32(.10)	0.22(.09)[b]
6	0.41(.09)	0.4(.09)**	0.31(.09)	0.35(.10)	0.37(.10)	0.36(.08)**	0.32(.09)	0.21(.10)*
7	0.43(.08)	0.45(.13)[b]	0.34(.10)[a]	0.36(.12)	0.39(.09)	0.42(.12)[b]	0.34(.08)[a]	0.21(.09)[b]
8	0.41(.11)	0.41(.11)*	0.37(.14)	0.37(.13)	0.31(.06)	0.32(.09)**	0.30(.09)	0.23(.09)**

[a] baseline category, based on the highest mean rank results of the Kruskal-Wallis rank test
[b] not statistically significant from baseline category, using Tukey's HSD post hoc analysis
† significant effect of the cab configuration for the egress tactic group on variable
* 0.05 significance level
** 0.01 significance level

egress trial, $F(21, 262)= .636$, $p=.890$.

When considering the FC tactic, step configuration influence was statistically significant on peak RCoF when considering the step negotiation during the entire egress trial, $F(7, 485)= 2.263$, $p<0.05$, as well as each of the transitions, E2, $F(7, 485)= 7.425$, $p<0.001$, and E3, $F(7, 485)= 2.861$, $p<0.01$, but the influence of step configuration was not statistically significant on peak RCoF during the transition E1, $F(7, 485)= .585$, $p=.768$. Furthermore, the effect of BMI on the FC egress tactic was analyzed and showed a statistically significant effect on peak RCoF when considering the entire egress trial, $F(3, 485)= 8.252$, $p<0.001$, as well as during each of the transitions E1, $F(3, 485)= 9.927$, $p<0.001$, E2, $F(3, 485)= 16.279$, $p<0.001$, and E3, $F(3, 485)= 5.766$, $p=0.001$. Finally, similar to the FO tactic, there was no interaction effect between the step configuration and BMI on peak RCoF when considering the entire egress trial, $F(21, 485)= .896$, $p=.597$, the E1 transition, $F(21, 485)= .925$, $p=.559$, E3 transition, $F(21, 485)= .911$, $p=.576$, and E3 transition, $F(21, 485)= .736$, $p=.796$.

Loading Rate (LR)

There was no main effect of egress tactic on top step loading rate (LR), (FO: $M=2.90$, $SD=1.94$, FC: $M=2.60$, $SD=2.07$), $F(1, 743)=0.442$, $p=.506$; however, the effect was statistically significant on both bottom step loading rate, (FO: $M=6.27$, $SD=3.06$, FC: $M=4.65$, $SD=1.78$), $F(1, 743)= 48.239$, $p<0.001$, and ground loading rate, (FO: $M=10.60$, $SD=3.18$, FC: $M=6.71$, $SD=2.46$), $F(1, 743)= 216.272$, $p<0.001$. Table 5.2 includes a summary of means and standard deviations, and ANOVA results for the LR variable during all egress trial, E1, 2, and 3, for both egress tactics, FC and FO.

Table 5.2. Descriptive statistics, means and standard deviations, and univariate analysis results for Peak Loading Rate (LR) variable during all egress trial interaction with Top Step. Bottom Step, and Ground for both egress tactics, FC and FO.

Step Configuration	Peak Top Step LR Average (*SD*)		Peak Bottom Step LR Average (*SD*)		Peak Ground LR Average (*SD*)	
	FO	**FC†****	**FO†****	**FC†****	**FO**	**FC†***
1	2.91(1.93)	2.38(2.03)[b]	5.97(3.00)**	4.6(1.77)**	10.63(3.06)	6.57(2.48)[b]
2	2.91(2.03)	2.18(1.97)*	4.61(2.64)**	3.87(1.57)**	11(2.92)	6.29(2.67)[b]
3	2.63(1.44)	2.33(1.56)[b]	8.13(3.23)[a]	5.86(2.17)[a]	10.02(2.95)	6.52(2.02)[b]
4	2.41(1.44)	2.31(1.56)*	5.48(2.76)**	4.1(1.58)**	9.99(2.94)	6.31(2.38)[b]
5	3.18(1.84)	3.38(2.69)[a]	7.03(2.65)[b]	4.7(1.34)**	11.08(3.63)	7.04(2.59)[b]
6	2.83(1.98)	3.04(1.94)[b]	6.96(2.74)[b]	4.85(1.48)*	10.77(3.59)	7.38(2.74)[b]
7	3.72(3.27)	2.83(2.50)[b]	5.63(2.49)**	4.62(1.57)**	10.67(3.47)	6.88(2.30)[b]
8	3.18(1.70)[a]	2.98(2.19)[b]	6.51(3.23)[b]	4.7(1.75)**	11.19(3.49)[a]	7.26(2.41)[a]

[a] baseline category, based on the highest mean rank results of the Kruskal-Wallis rank test
[b] not statistically significant from baseline category, using Tukey's HSD post hoc analysis
† significant effect of the cab configuration for the egress tactic group on variable
* 0.05 significance level
** 0.01 significance level

For drivers with FO egress tactic, the effect of step configuration on loading rate was significantly different during interaction with bottom step, $F(7, 260)= 4.918$, $p<0.001$, but not different for the top step, $F(7, 260)= 1.009$, $p=.425$, or ground, $F(7, 260)= .383$, $p=.912$. Moreover, for the FO egress tactic, BMI had an effect on the loading rate during interaction with all steps, top step, $F(3, 260)= 10.808$, $p<0.001$, bottom step, $F(3, 260)= 11.235$, $p<0.001$, and ground, $F(3, 260)= 10.509$, $p<0.001$. However, there was no interaction between step configuration and BMI during interaction with steps, top step, $F(21, 260)= .531$, $p=.956$, bottom step, $F(21, 260)= .930$, $p=.552$, and ground, $F(21, 260)= .372$, $p=.995$.

In comparison with FO egress tactic, step configuration had a statistically significant effect on top step loading rate, $F(7, 483)= 5.045$, $p<0.001$, bottom step loading rate, $F(7, 483)= 7.639$, $p<0.001$, and ground loading rate, $F(7, 483)= 2.178$, $p<0.05$, among truck drivers descending using the FC egress tactic. Likewise, the loading rates, among FC group, during interaction with all steps, top step, $F(3, 483)= 16.476$, $p<0.001$, bottom step, $F(3, 483)= 7.003$, $p<0.001$, and ground, $F(3, 483)= 11.322$, $p<0.001$, were different across BMI groups. Similar to the FO egress tactic, however, there was no interaction effect between step configuration and BMI during interaction with bottom step, $F(21, 483)= 1.530$, $p=.063$, and ground, $F(21, 483)= .831$, $p=.682$, but the interaction effect was significant for the top step, $F(21, 483)= 1.618$, $p=.041$.

Foot Rotation Angle Relative to Step (FRA)

There was a significant main effect of egress tactic on drivers' left foot rotation angle relative to the top step (FO: $M=135.43$, $SD=23.19$, FC: $M=29.19$, $SD=15.35$), $F(1,$

747)= 4025.991, *p*<0.001, as well as on drivers' right foot angle during bottom step negotiation (FO: *M*=98.99, *SD*=38.76, FC: *M*=74.89, *SD*=18.97), *F*(1, 747)= 105.538, *p*<0.001.

For drivers with FO egress tactic, there was no significant effect of cab configuration on right foot angle relative to bottom step, *F*(7, 262)= 712.249, *p*=0.866, and a trend towards significance on the left foot angle relative to top step, *F*(7, 262)= 1063.631, *p*=0.054; however, drivers with FC egress tactics showed a significant effect of step configuration on right foot angle relative to bottom step, *F*(7, 485)= 2.675, *p*=0.01, but no effect on left foot angle relative to top step, *F*(7, 485)=0. 321, *p*=0.945. Table 5.3 includes a summary of means and standard deviations, and ANOVA results for the right and left FRA variable during all egress trial, E1, 2, and 3, for both egress tactics, FC and FO.

Among FO egress tactic, BMI effect was statistically significant on left foot angle during stair negotiation with the top step, *F*(3, 262)= 3.864, *p*=0.01, and not significant for the right foot, *F*(3, 262)= 1.366, *p*=0.253. In comparison, drivers using the FC egress tactic showed an effect of BMI on right foot angle relative to bottom step, *F*(3, 485)= 5.138, *p*<0.01, but no significant effect on left foot angle during interaction with top step, *F*(3, 485)=0. 287, *p*=0.835. Finally, there was no interaction effect on left or right foot angles relative to steps for both FO egress tactic group, left foot, *F*(21, 262)=0.494, *p*=0.971 and right foot, *F*(21, 262)= 0.466, *p*=0.980, or FC egress tactic, left foot, *F*(21, 485)=0.805, *p*=0.715, and right foot, *F*(21, 485)= 0.492, *p*=0.973.

Table 5.3. Descriptive statistics, means and standard deviations, and univariate analysis results for left and right feet rotation angles (FRA), relative to top and bottom steps, respectively, for both egress tactics, FC and FO.

Step Configuration	**Left Foot Angle Average (*SD*)**		**Right Foot Angle Average (*SD*)**	
	FO	**FC**	**FO**	**FC†****
1	134.23(26.42)	30.46(16.28)	99.06(41.14)	76.25(21.80)[b]
2	143.14(18.30)[a]	28.31(18.18)	98.59(37.55)	78.03(16.84)[b]
3	131.54(23.83)	28.08(11.84)	88.71(36.10)	80.73(18.55)[a]
4	133.77(24.55)	29.04(17.64)	101.05(34.72)	80.08(18.69)[b]
5	133.19(24.22)	29.81(13.69)	104.31(38.93)	71.95(14.59)[b]
6	133.04(21.82)	30.25(12.26)[a]	96.43(43.50)	70.52(18.24)[b]
7	138.34(21.40)	29.46(18.26)	107.53(39.12)[a]	68.4(18.28)**
8	136.84(21.73)	28.03(10.74)	104.56(42.28)	65.78(17.30)**

[a] baseline category, based on the highest mean rank results of the Kruskal-Wallis rank test
[b] not statistically significant from baseline category, using Tukey's HSD post hoc analysis
[†] significant effect of the cab configuration for the egress tactic group on variable
* 0.05 significance level
** 0.01 significance level

Foot Placement Clearance (FCL)

Table 5.4 includes a summary of means and standard deviations, and ANOVA results for the right and left FCL variable during all egress trial, E1, 2, and 3, for both egress tactics, FC and FO. There was a main effect of egress tactic on foot clearance relative to front of the step for both left and right feet during negotiation with top (FO: M=0.10, SD=0.03, FC: M=0.06, SD=0.03), $F(1, 747)$= 170.396, p<0.001, and bottom steps (FO: M=0.08, SD=0.05, FC: M=0.07, SD=0.03), $F(1, 747)$= 16.262, p<0.001, respectively.

In considering the effect of cab configuration among FO egress tactic, the foot clearance was not different for the top step, $F(7, 262)$= 1.294, p=0.253, but was significantly different for the bottom step, $F(7, 262)$= 95.969, p<0.001. Moreover, BMI had an effect on foot clearance that was statistically significant for both top, $F(3, 262)$= 3.639, p<0.05, and bottom step, $F(3, 262)$= 3.284, p<0.05. There was no interaction between the cab configuration and BMI for both top step, $F(21, 262)$= 0.892, p=0.602, and bottom step, $F(21, 262)$= 1.092, p=.357.

For the FC group, however, no effect of cab configuration was found on top step foot clearance, $F(7, 485)$= 1.515, p=0.160, but a difference that was statistically significant on the bottom step foot clearance, $F(7, 485)$= 114.849, p<0.001. BMI had no effect on foot clearances during stair negotiations of top step, $F(3, 485)$= 1.036, p=.376, and bottom step, $F(3, 485)$= 1.351, p=.257. Finally, no interaction effect between step configuration and BMI was found for either feet with the top step, $F(21, 485)$= 1.110, p=0.333, or bottom step, $F(21, 485)$=0.681, p=0.853.

Table 5.4. Descriptive statistics, means and standard deviations, and univariate analysis results for left and right feet clearances during interaction with top and bottom steps, respectively, for both egress tactics, FC and FO.

Step Configuration	**Top Step Clearance Average (*SD*)**		**Bottom Step Clearance Average (*SD*)**	
	FO	**FC**	**FO†****	**FC†****
1	0.11(.03)[a]	0.07(.04)	0.07(.02)**	0.06(.01)**
2	0.1(.02)	0.06(.02)	0.06(.03)**	0.06(.02)**
3	0.1(.03)	0.06(.05)	0.17(.03)[a]	0.14(.03)[a]
4	0.08(.03)	0.05(.03)	0.06(.02)**	0.05(.02)**
5	0.1(.02)	0.06(.03)	0.06(.02)**	0.06(.01)**
6	0.1(.03)	0.05(.03)	0.06(.02)**	0.07(.01)**
7	0.1(.02)	0.06(.03)	0.06(.02)**	0.06(.02)**
8	0.1(.02)	0.07(.03)[a]	0.07(.02)**	0.06(.02)**

[a] baseline category, based on the highest mean rank results of the Kruskal-Wallis rank test
[b] not statistically significant from baseline category, using Tukey's HSD post hoc analysis
† significant effect of the cab configuration for the egress tactic group on variable
* 0.05 significance level
** 0.01 significance level

Foot Base of Support on Step (BoSAS)

The main effect of egress tactic was significant for both left foot base of support area over the top step (FO: M=57.04%, SD=20.49%, FC: M=44.21%, SD=23.56%), $F(1, 747)= 59.564$, $p<0.001$, and right foot base of support area over bottom step (FO: M=37.62%, SD=20.69%, FC: M=28.08%, SD=13.67%), $F(1, 747)= 65.295$, $p<0.001$.

When considering the FO egress tactic, cab configuration appeared to have a significant effect on both left foot and right foot base of support area over the top, $F(7, 262)= 2.505$, $p<0.01$, and bottom, $F(7, 262)= 60.377$, $p<0.001$, steps respectively. Furthermore, BMI had an effect on the left foot base of support, $F(3, 262)= 10.394$, $p<0.001$, but not the right foot, $F(3, 262)= 2.025$, $p=.111$. Finally, there was no interaction effect on left foot BoS area, $F(21, 262)=0.661$, $p=.869$, or right foot BoS area, $F(21, 262)= 0.786$, $p=.737$.

On the other hand, among the FC egress tactic, cab configuration had an effect on left foot BoS area, $F(7, 485)= 2.175$ $p<0.05$, and right foot BoS area, $F(7, 485)= 71.646$, $p<0.001$. Similarly, BMI had a significant effect on both left foot, $F(3, 485)= 3.541$, $p<0.05$, and right foot BoS area, $F(3, 485)= 2.898$, $p<0.05$. Finally, no interaction effect was found between the step configuration and BMI for left foot, $F(21, 485)=0.886$, $p=.610$, or right foot BoS area, $F(21, 485)=0.619$, $p=.906$. Table 5.5 includes a summary of means and standard deviations, and ANOVA results for the right and left foot base of support on step during interaction with top and bottom steps, respectively, for both egress tactics, FC and FO.

Table 5.5. Descriptive statistics, means and standard deviations, and univariate analysis results for left and right foot base of support on step during interaction with top and bottom steps, respectively, for both egress tactics, FC and FO.

Step Configuration	**% Total Left Foot Area Average (*SD*)**		**% Total Right Foot Area Average (*SD*)**	
	FO	**FC**	**FO[†]****	**FC[†]****
1	63.49(21.27)	47.59(24.81)	34.72(11.88)	25.4(6.83)
2	64.11(21.89)[a]	47.52(21.37)[a]	26.66(10.36)	22.28(7.23)
3	53.56(19.43)	40.23(23.43)	74.33(15.07)[a]	51.85(14.25)[a]
4	48.98(20.88)	39.96(24.55)	25.41(8.96)	19.69(6.76)
5	53.71(18.03)	45.44(23.83)	27.57(10.95)	23.49(7.03)
6	55.12(18.78)	38.11(23.37)	31.63(11.22)	27.53(6.83)
7	58.94(16.06)	46.5(22.95)	31.34(14.64)	24.59(13.45)
8	55.89(20.52)	47.63(22.16)	34.82(11.12)	27.76(8.91)

[a] baseline category, based on the highest mean rank results of the Kruskal-Wallis rank test
[b] not statistically significant from baseline category, using Tukey's HSD post hoc analysis
[†] significant effect of the cab configuration for the egress tactic group on variable
* 0.05 significance level
** 0.01 significance level

Discussion

Generally, participants utilizing the FC egress tactic had a significantly higher peak RCoF when compared to the facing outward tactic for the peak RCoF. This observation was the case when considering the peak RCoF over the entire egress trial (FO: M=0.44, SD=0.11, FC: M=0.45, SD=0.12) as well as when taking into account the egress transitions for peak RCoF during E1 (FO: M=0.33, SD=0.27, FC: M=0.34, SD=0.14), and peak RCoF during E2 (FO: M=0.27, SD=0.1, FC: M=0.40, SD=0.10), but peak RCoF during E3 transition to the ground indicated a lower peak RCoF for the facing the cab tactic when compared to the facing outward tactic (FO: M=0.40, SD=0.09, FC: M=0.28, SD=0.1). Lower coefficient of friction situations are typically regarded as slippery and hypothesized to induce accidents during stair negotiations (Chen et al., 2014). In a situation where the available coefficient of friction (ACoF) matches the required coefficient of frictional demands of a cab egress tactic, it suggests that FO cab tactic has higher slip potential in situations where there is snow or slippery conditions on the ground following a cab egress, since it requires a surface with higher ACoF, i.e., rougher interface between foot and surface condition. On the other hand, FC egress tactic requires a higher quality of contact and ACoF between the driver shoes and steps during egress and transition between the sill and top step as well as top to bottom steps.

Overall, loading rates increased on each subsequent step during the cab egress, with the ground loading rate being highest. Drivers descending the cab while facing the cab had lower loading rates on the bottom step (M=4.65, SD=1.78) and ground (M=6.71, SD=2.46) when compared to the facing out tactic (bottom: M=6.27, SD=3.06, ground: M=10.60, SD=3.18). The same pattern is seen, between both tactics, when negotiating the top step but the difference is not statistically significant (FO: M=2.90, SD=1.94, FC: M=2.60, SD=2.07). This similarity is due to the transitioning time that was described in Chapter 3, which can introduce more variance between subjects, and therefore yields nonsignificant differences.

Both CoMV and CoMA were affected by egress tactic; those who exited utilizing the FO tactic (CoMV: M=0.65, SD=0.17 and CoMA: M=5.22, SD=1.54) did so with higher peaks of CoMV and CoMA than those exiting using the FC tactic (CoMV: M=0.52, SD=0.12 and CoMA: M=6.19, SD=1.58). These results were consistent when the peak CoMV and CoMA are investigated during each of the three transitions except for that CoMA was higher for the FC tactic for the first transition, E1, (FO: M=2.39, SD=1.39, FC: M=2.52, SD=1.46), and the second transition, E2, (FO: M=4.09, SD=1.39, FC: M=4.42, SD=1.61). These findings demonstrate that FO egress tactic will allow for a much faster descent from the cab, which is a favorable choice for a driver, which helps explain why truck drivers use the FO technique as an alternative cab egress tactic.

Subjects using different egress tactics rotate their feet differently relative to the step when approaching the top step. When using the FO egress tactic, the active foot on the top step (left foot) is rotated on average slightly to the right side of the subject (M=135.43, SD=23.19), but closer to perpendicular relative to the step front edge, with the proximal end of the foot closest to the cab. On the other hand, when using the FC technique, the foot is oriented on average to the left side of the subject (M=29.19, SD=15.35), closer to parallel relative to the step front edge, with the distal end of the foot closest to the cab. The fact that when using the FC tactic, the foot is closer to parallel, confirms that there are cab design elements, i.e., step depth, which force a more parallel foot posture relative to the step to allow for a proper base of support during transitions. Furthermore, egress tactic had an effect on the foot orientation, FRA, relative to the bottom step (FO: *M*=98.99, *SD*=38.76, FC: *M*=74.89, *SD*=18.97). This implies that the egress tactic is affecting their ability to situate their feet, prior to loading one's limb, to allow proper support on step. Facing the cab tactic allows for less foot clearance relative to front of the top step (FO: *M*=0.10, *SD*=0.03, FC: *M*=0.06, *SD*=0.03), and bottom step (FO: *M*=0.08, *SD*=0.05, FC: *M*=0.07, *SD*=0.03). This finding further emphasizes the need to analyze the foot angles relative to the step in conjunction with foot clearance. The more foot clearance allowed the more the base of support area over the step, which translates into a more stable egress. This is true when both feet compared are oriented in the same manner, but data above showed that when comparing tactics, foot orientation is significantly different. Therefore, since FC egress tactic had forced a relatively parallel foot, the clearance averages will be lower, but still implying a "good" total base of support on step. It is interesting to note that loading on the foot for facing the cab tactic is on the distal end of the foot while facing out foot loading is on the proximal end of the loading; proximal loading has higher mechanical advantage with respect to loading relative to the ankle joint.

Finally, egress tactic FO showed a higher percentage of foot base of support area over both top (FO: *M*=57.04%, *SD*=20.49%, FC: *M*=44.21%, *SD*=23.56%), and bottom steps (FO: *M*=37.62%, *SD*=20.69%, FC: *M*=28.08%, *SD*=13.67%), when compared to FC tactic.

Cab configuration was shown to affect drivers' biomechanical factors involved during egress motions. Results showed that there was an effect of cab configuration on LR when negotiating bottom step. This is an important finding that provides insight into how changes in step depths affect how stress is transferred through the limbs and, in this case, is driven by how fast the descent process is happening (since the LR is time dependent). This finding is consistent with the result that cab configuration differences account for changes in peak CoMV during each three transition. As the loading rate increases in a given trial, it is expected that the time it took for the loading phase of the transition process from one step to another is expedited as well as the total body CoM location change over time, i.e., CoMV, as does the impact-stress translation through the driver's limb.

Additionally, while cab configuration differences did not show statistically significant effects on top step FRA, there was still an indication towards significance. Bottom step FCL, on the other hand, was significantly different between cab configurations. Finally, both left and right feet base of support area over the top and bottom steps, respectively, were different between cab configurations, providing further evidence that changes in cab design elements is affecting how the foot is oriented and situated on the step during cab descent.

Cab configuration within the FO egress tactic did not have an effect on RCoF, LR when negotiating top step and ground, peak CoMV when taking into account the entire egress trial, peak CoMA during entire egress trial, and when taking into account each of the transitions, right foot FRA, and top step FCL.

Within the FC egress tactic, cab configuration showed a significant effect on RCoF, LR, CoMV, CoMA, and BoS area over step. This finding was consistent when investigating these metrics over the entire egress transition as well as taking into account each transition separately, except for the peak RCoF during the first transition and peak CoMA during the first and third transitions. Moreover, cab configuration, in the FC group, had also a significant effect on right foot angle relative to bottom step, but no effect on left foot angle relative to top step. Finally, there was no effect of cab configuration on top step foot clearance, but the difference was statistically significant on the bottom step foot clearance among the FC group.

BMI also had a statistically significant effect only on peak RCoF during E3 negotiation, among the FO group. RCoF metrics were significantly affected when considering the entire egress trial, as well as during each of the transitions. Similarly, for both egress tactics, BMI had an effect on the loading rate during interaction with all steps.

For both egress tactics, there was a significant effect of BMI on CoMV when capturing the peak CoMV during the entire egress trial. This effect was consistent for both egress tactics when evaluating the peak CoMV during each of the transitions. Generally, as BMI increased from normal weight to obese there was a decreasing trend in CoMV, except for the morbidly obese group having a CoMV for the morbidly obese group that was significantly higher than all other BMI groups, except that this effect was not the same for some cab configurations, where the COMV was lower, following the trend of other BMI groups. In other words, cab configuration differences affected the morbidly obese differently than normal.

An inverse effect of BMI on peak CoMA acceleration was observed among drivers regardless of the egress tactic used. Higher BMI individuals performed the egress trials with a lower peak CoMA acceleration except for the morbidly obese group where an increase in CoMA acceleration was observed. This effect was statistically significant when considering the total duration of the egress trial for both tactics. Similarly, the effect of BMI was also statistically significant for both egress tactics when considering each of the transitions.

Within the FO egress tactic, BMI effect was statistically significant on left foot angle during stair negotiation with the top step, but not significant for the right foot. In comparison, drivers using the FC egress tactic showed an effect of BMI on right foot angle relative to bottom step, but no significant effect on left foot angle during interaction with top step.

Within the FO egress tactic, BMI had an effect on foot clearance for both top and bottom steps. In contrast, BMI did not have an effect on foot clearances for both steps within the FC egress tactic during step negotiations. Finally, within the FC egress tactic, BMI had an effect on the BoS area over both steps but only over the left foot (top step) within the FO egress tactic.

Conclusion

While FO egress tactic seems to provide evidence of better "footing" on a given step, total BoS area takes into account the hand supports as well. Therefore, since overall results from Chapter 4 indicated that, when compared to FC egress tactic, FO egress tactic revealed lower percentages where drivers are able to maintain 3PoC, FC egress tactic may still be a safer tactic during cab egress, especially during E2 and E3 where handholds are not in an ideal functional location.

This study provides an opportunity to develop a meaningful understanding of the interaction between the foot and the step that will aid in quantifying the risk factors associated with slipping and/or falling while exiting a truck cab. This understanding is developed by evaluating anthropometric, spatiotemporal, biomechanical, force, foot orientation, and foot placement parameters. The results of this research may be utilized to improve truck design and reduce slip potential and in turn help mitigate fatal and nonfatal injuries from falls among truck drivers.

References

Alshawabka, A. Z., Liu, A., Tyson, S. F., & Jones, R. K. (2014). The use of a lateral wedge insole to reduce knee loading when ascending and descending stairs in medial knee osteoarthritis patients. *Clinical Biomechanics*, *29*(6), 650-656. doi: 10.1016/j.clinbiomech.2014.04.011.

Bureau of Labor Statistics. (2014). Transportation and material moving: Heavy and tractor-trailer truck drivers injuries, illnesses, and fatalities. Retrieved from: http://www.bls.gov/ooh/transportation-and-material-moving/heavy-and-tractor-trailer-truck-drivers.htm. doi: http://www.bls.gov/iif/oshcdnew.htm, News Release (2014).

Burnfield, J. M., & Powers, C. M. (2006). Prediction of slips: An evaluation of utilized coefficient of friction and available slip resistance. *Ergonomics*, *49*(10), 982-995. doi: 10.1080/00140130600665687.

Chang, W.R., Chang, C.-C., & Matz, S. (2011). The effect of transverse shear force on the required coefficient of friction for level walking. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *53*(5), 461-473. doi: 10.1177/0018720811414885.

Chang, W. R., Chang, C. C., & Matz, S. (2012). Comparison of different methods to extract the required coefficient of friction for level walking. *Ergonomics*, *55*(3), 308-315. doi: 10.1080/00140139.2011.642008.

Chateauroux, E., Wang, X., & Roybin, C. (2012). Analysis of truck cabin egress motion. *International Journal of Human Factors Modelling and Simulation*, *3*(2), 169-186. doi:10.1504/IJHFMS.2012.051095.

Chen, C. L., Teng, Y. L., Lou, S. Z., Chang, H. Y., Chen, F. F., & Yeung, K. T. (2014). Effects of an anterior ankle-foot orthosis on walking mobility in stroke patients: Get up and go and stair walking. *Archives of Physical Medicine and Rehabilitation*, *95*(11), 2167-2171. doi: 10.1016/j.apmr.2014.07.408.

Cooper, R., Hardy, R., Sayer, A. A., Ben-Shlomo, Y., Birnie, K., Cooper, C., ... & McNeill, G. (2011). Age and gender differences in physical capability levels from mid-life onwards: The harmonisation and meta-analysis of data from eight UK cohort studies. *PLoS One*, *6*(11), e27899. doi: 10.1371/journal.pone.0027899.

Day, L., & Rechnitzer, G. (2004). Safe tractor access platforms: From guidance material to implementation. *Journal of Agricultural Safety and Health*, *10*(3), 197-209.

Fathallah, F. A., & Cotnam, J. P. (2000). Maximum forces sustained during various methods of exiting commercial tractors, trailers and trucks. *Applied Ergonomics, 31*(1), 25-33.

Fino, P., & Lockhart, T. E. (2014). Required coefficient of friction during turning at self-selected slow, normal, and fast walking speeds. *Journal of Biomechanics*, *47*(6), 1395-1400. doi: 10.1016/j.jbiomech.2014.01.032.

Federal Motor Carrier Safety Administration. (2007). Step, Handhold, and Deck Requirements for Commercial Vehicles. 49 CFR 399 Subpart L.

Fong, D. T., Hong, Y., & Li, J. X. (2005). Lower-extremity gait kinematics on slippery surfaces in construction worksites. *Medicine and Science in Sports and Exercise*, *37*(3), 447-454.

Foster, R. J., De Asha, A. R., Reeves, N. D., Maganaris, C. N., & Buckley, J. G. (2014). Stair-specific algorithms for identification of touch-down and foot-off when descending or ascending a non-instrumented staircase. *Gait & Posture*, *39*(2), 816-821. doi: 10.1016/j.gaitpost.2013.11.005.

Gates, D. H., Lelas, J., Della Croce, U., Herr, H., & Bonato, P. (2004). Characterization of ankle function during stair ambulation. In *Engineering in Medicine and Biology Society, 2004 (IEMBS'04). 26th Annual International Conference of the IEEE* (Vol. 2, pp. 4248-4251). IEEE. doi: 10.1109/IEMBS.2004.1404184.

Giguère, D., & Marchand, D. (2005). Perceived safety and biomechanical stress to the lower limbs when stepping down from fire fighting vehicles. *Applied Ergonomics*, *36*(1), 107-119.

Gronqvist, R., Hirvonen, M., Rajamaki, E., & Matz, S. (2003). The validity and reliability of a portable slip meter for determining floor slipperiness during simulated heel strike. *Accident Analysis & Prevention*, *35*(2), 211-225.

Guan, J., Hsiao, H., Bradtmiller, B., Kau, T.-Y., Reed, M. R., Jahns, S. K., . . . Piamonte, D. P. T. (2012). US truck driver anthropometric study and multivariate anthropometric models for cab designs. *Human Factors: The Journal of the Human Factors and Ergonomics Society*. doi:10.1177/0018720812442685.

Hall, M., Stevermer, C. A., & Gillette, J. C. (2015). Muscle activity amplitudes and co-contraction during stair ambulation following anterior cruciate ligament reconstruction. *Journal of Electromyography and Kinesiology*, *25*(2), 298-304. doi: 10.1016/j.jelekin.2015.01.007.

Handsaker, J. C., Brown, S. J., Bowling, F. L., Cooper, G., Maganaris, C. N., Boulton, A. J., & Reeves, N. D. (2014). Contributory factors to unsteadiness during walking up and down stairs in patients with diabetic peripheral neuropathy. *Diabetes Care*, *37*(11), 3047-3053. doi: 10.2337/dc14-0955.

Hanson, J. P., Redfern, M. S., & Mazumdar, M. (1999). Predicting slips and falls considering required and available friction. *Ergonomics*, *42*(12), 1619-1633.

Hardy, R., Cooper, R., Sayer, A. A., Ben-Shlomo, Y., Cooper, C., Deary, I. J., ... Starr, J. M. (2013). Body mass index, muscle strength and physical performance in older adults from eight cohort studies: The HALCyon programme. *PLoS One*, *8*(2), e56483. doi: 10.1371/journal.pone.0056483.

Harrison, A. P., Danneskiold-Samsoe, B., & Bartels, E. M. (2013). Portable acoustic myography - a realistic noninvasive method for assessment of muscle activity and coordination in human subjects in most home and sports settings. *Physiological Reports*, *1*(2), e00029. doi: 10.1002/phy2.29.

Hanavan Jr, E. P. (1964). A mathematical model of the human body. *Aerospace Medical Research Laboratories Technical Reports*, *64*(102), 1-149.

Helmkamp, J. C., Lincoln, J. E., Sestito, J., Wood, E., Birdsey, J., & Kiefer, M. (2013). Risk factors, health behaviors, and injury among adults employed in the transportation, warehousing, and utilities super sector. *American Journal of Industrial Medicine*, *56*(5), 556-568. doi: 10.1002/ajim.22148.

Hobara, H., Kobayashi, Y., Tominaga, S., Nakamura, T., Yamasaki, N., & Ogata, T. (2013). Factors affecting stair-ascent patterns in unilateral transfemoral amputees. *Prosthetics and Orthotics International*, *37*(3), 222-226. doi: 10.1177/0309364612461166.

International Organization for Standardization. (2006). ISO 2867:2006: Earth-moving machinery -- access systems.

Jones, D., & Switzer-McIntyre, S. (2003). Falls from trucks: A descriptive study based on a workers compensation database. *Work*, *20*(3), 179-184.

Kennedy, R. A., Boreham, C. A., Murphy, M. H., Young, I. S., & Mutrie, N. (2007). Evaluating the effects of a low volume stair climbing programme on measures of health-related fitness in sedentary office workers. *Journal of Sports Science and Medicine*, *6*(4), 448-454.

Laudanski, A., Brouwer, B., & Li, Q. (2015). Activity classification in persons with stroke based on frequency features. *Medical Engineering & Physics*, *37*(2), 180-186. doi: 10.1016/j.medengphy.2014.11.008.

Lee, T. Y., Gerberich, S. G., Gibson, R. W., Carr, W. P., Shutske, J., & Renier, C. M. (1996). A population-based study of tractor-related injuries: Regional Rural Injury Study-I (RRIS-I). *Journal of Occupational and Environmental Medicine*, *38*(8), 782-793.

Lin, L. J., & Cohen, H. H. (1997). Accidents in the trucking industry. *International Journal of Industrial Ergonomics*, *20*(4), 287-300. doi: http://dx.doi.org/10.1016/S0169-8141(96)00060-1.

Lin, Y. C., Fok, L. A., Schache, A. G., & Pandy, M. G. (2015). Muscle coordination of support, progression and balance during stair ambulation. *Journal of Biomechanics*, *48*(2), 340-347. doi: 10.1016/j.jbiomech.2014.11.019.

Livingston, L. A., Stevenson, J. M., & Olney, S. J. (1991). Stairclimbing kinematics on stairs of differing dimensions. *Archives of Physical Medicine and Rehabilitation*, *72*(6), 398-402. doi: 10.5555/uri:pii:000399939190174H.

Logerstedt, D. S., Zeni, J., Jr., & Snyder-Mackler, L. (2014). Sex differences in patients with different stages of knee osteoarthritis. *Archives of Physical Medicine and Rehabilitation*, *95*(12), 2376-2381. doi: 10.1016/j.apmr.2014.07.414.

Loy, S. F., Conley, L. M., Sacco, E. R., Vincent, W. J., Holland, G. J., Sletten, E. G., & Trueblood, P. R. (1994). Effects of stairclimbing on VO2max and quadriceps strength in middle-aged females. *Medicine and Science in Sports and Exercise*, *26*(2), 241-247.

Luder, G., Schmid, S., Stettler, M., Mueller Mebes, C., Stutz, U., Ziswiler, H. R., & Radlinger, L. (2015). Stair climbing–An insight and comparison between women with and without joint hypermobility: A descriptive study. *Journal of Electromyography and Kinesiology*, *25*(1), 161-167. doi: 10.1016/j.jelekin.2014.07.005.

Matsufuji, S., Shoji, T., Yano, Y., Tsujimoto, Y., Kishimoto, H., Tabata, T., ... Inaba, M. (2015). Effect of chair stand exercise on activity of daily living: A randomized controlled trial in hemodialysis patients. *Journal of Renal Nutrition*, *25*(1), 17-24. doi: 10.1053/j.jrn.2014.06.010.

Merryweather, A. S., Shorti, R., Thiese, M. S., Caughey, W., & Hegmann, K. T. (2010). Commercial Truck Driver Mounting/Dismounting Behavior Related to Falls. Paper presented at the International Conference on Commercial Driver Health and Wellness, Baltimore, Maryland.

Modai, G., Sharon, B., Bar-Haim, S., & Hutzler, Y. (2015). Stair climbing test post-stroke: feasibility, convergent validity and metabolic, cardiac, and respiratory responses. *Topics in Stroke Rehabilitation*, *22*(4), 281-288. doi: 10.1179/1074935714Z.0000000021.

Monnier, G., Chateauroux, E., Wang, X., & Roybin, C. (2009). Inverse dynamic reconstruction of truck cabin ingress/egress motions. *SAE International Journal of Passenger Cars-Mechanical Systems, 2*(1), 1593-1599.

Novak, A. C., & Brouwer, B. (2013). Kinematic and kinetic evaluation of the stance phase of stair ambulation in persons with stroke and healthy adults: A pilot study. *Journal of Applied Biomechanics*, *29*(4), 443-452.

Oesch, P., Meyer, K., Jansen, B., & Kool, J. (2015). Functional capacity evaluation: Performance of patients with chronic non-specific low back pain without waddell signs. *Journal of Occupational Rehabilitation*, *25*(2), 257-266. doi: 10.1007/s10926-014-9533-6.

Ojha, H. A., Kern, R. W., Lin, C. H., & Winstein, C. J. (2009). Age affects the attentional demands of stair ambulation: Evidence from a dual-task approach. *Physical Therapy*, 89(10), 1080-1088. doi: 10.2522/ptj.20080187.

Oshkour, A. A., Talebi, H., Shirazi, S. F., Bayat, M., Yau, Y. H., Tarlochan, F., & Abu Osman, N. A. (2014). Comparison of various functionally graded femoral prostheses by finite element analysis. *The Scientific World Journal*, 2014, 807621. doi: 10.1155/2014/807621.

Patenaude, S., Marchand, D., Samperi, S., & Belanger, M. (2001). The effect of the descent technique and truck cabin layout on the landing impact forces. *Applied Ergonomics*, *32*(6), 573-582.

Pickle, N. T., Wilken, J. M., Aldridge, J. M., Neptune, R. R., & Silverman, A. K. (2014). Whole-body angular momentum during stair walking using passive and powered lower-limb prostheses. *Journal of Biomechanics*, *47*(13), 3380-3389. doi: 10.1016/j.jbiomech.2014.08.001.

Powers, C. M., Shellock, F. G., Beering, T. V., Garrido, D. E., Goldbach, R. M., & Molnar, T. (1999). Effect of bracing on patellar kinematics in patients with patellofemoral joint pain. *Medicine and Science in Sports and Exercise*, *31*(12), 1714-1720.

Ramstrand, N., & Nilsson, K. A. (2009). A comparison of foot placement strategies of transtibial amputees and able-bodied subjects during stair ambulation. *Prosthetics and Orthotics International*, *33*(4), 348-355. doi: 10.3109/03093640903074891.

Reed, M. P. (2010a). Ingress/Egress Safety for Truck Drivers. Retrieved March, 02, 2016, from http://trucksteps.org/index.html.

Reed, M. P. (2010b). Ingress/Egress System Dimensions. Retrieved March, 02, 2016, from http://trucksteps.org/dimensions.html.

Reed, M. P. (2010). Truck Ergonomics: Field and Laboratory Research. University of Michigan Transportation Research Institute (UMTRI) Truck Ergo Overview. Retrieved from: http://umtri.umich.edu/content/UMTRI_Truck_Ergo_Overview_2010_03.pdf

Reed, M. P., Ebert-Hamilton, S. M., & Hoffman, S. G. (2010a). Hand positions and forces during truck ingress. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 54, No. 15, pp. 1097-1100). SAGE Publications.

Reed, M. P., Hoffman, S. G., & Ebert-Hamilton, S. M. (2010b). The influence of heavy truck egress tactics on ground reaction force. *Research and Practice for Fall Injury Control in the Workplace*, pp. 192-195.

Reed, M. P., Ebert, S. M., & Hoffman, S. G. (2010c). Modeling foot trajectories for heavy truck ingress simulation. In *Proceedings of the Applied Human Factors and Ergonomics Conference,* Miami, FL.

Reid, S. M., Lynn, S. K., Musselman, R. P., & Costigan, P. A. (2007). Knee biomechanics of alternate stair ambulation patterns. *Medicine and Science in Sports and Exercise*, *39*(11), 2005-2011. doi: 10.1249/mss.0b013e31814538c8.

Roche, N., Zory, R., Sauthier, A., Bonnyaud, C., Pradon, D., & Bensmail, D. (2015). Effect of rehabilitation and botulinum toxin injection on gait in chronic stroke patients: A randomized controlled study. *Journal of Rehabilitation Medicine*, *47*(1), 31-37. doi: 10.2340/16501977-1887.

Society of Automotive Engineers. (2003). SAE J185:200305: Access systems for off-road machines.

Schmalz, T., Blumentritt, S., & Marx, B. (2007). Biomechanical analysis of stair ambulation in lower limb amputees. *Gait & Posture*, *25*(2), 267-278. doi: 10.1016/j.gaitpost.2006.04.008

Shiomi, T. (1994). Effects of different patterns of stairclimbing on physiological cost and motor efficiency. *Journal of Human Ergology (Tokyo)*, *23*(2), 111-120.

Shorti, R., Merryweather, A., Thiese, M., Kapellusch, J., Garg, A., & Hegmann, K. (2014). Fall risk factors for commercial truck drivers. *Journal of Ergonomics*, *9*(3), 1-9. doi: 10.4172/2165-7556.S3-009.

Sinitski, E. H., Hansen, A. H., & Wilken, J. M. (2012). Biomechanics of the ankle-foot system during stair ambulation: Implications for design of advanced ankle-foot prostheses. *Journal of Biomechanics*, *45*(3), 588-594. doi: 10.1016/j.jbiomech.2011.11.007.

Song, Q., Yu, B., Zhang, C., Sun, W., & Mao, D. (2014). Effects of backpack weight on posture, gait patterns and ground reaction forces of male children with obesity during stair descent. *Research in Sports Medicine*, *22*(2), 172-184. doi: 10.1080/15438627.2014.881823.

Spielholz, P., Cullen, J., Smith, C., Howard, N., Silverstein, B., & Bonauto, D. (2008). Assessment of perceived injury risks and priorities among truck drivers and trucking companies in Washington State. *Journal of Safety Research*, *39*(6), 569-576. doi: 10.1016/j.jsr.2008.09.005.

Standifird, T. W., Cates, H. E., & Zhang, S. (2014). Stair ambulation biomechanics following total knee arthroplasty: A systematic review. *The Journal of Arthroplasty*, *29*(9), 1857-1862. doi: 10.1016/j.arth.2014.03.040.

Startzell, J. K., Owens, D. A., Mulfinger, L. M., & Cavanagh, P. R. (2000). Stair negotiation in older people: A review. *Journal of the American Geriatrics Society*, *48*(5), 567-580.

Studenski, S., Duncan, P. W., Chandler, J., Samsa, G., Prescott, B., Hogue, C., & Bearon, L. B. (1994). Predicting falls: The role of mobility and nonphysical factors. *Journal* *of the American Geriatrics Society*, *42*(3), 297-302.

Taddei, F., Palmadori, I., Taylor, W. R., Heller, M. O., Bordini, B., Toni, A., & Schileo, E. (2014). European Society of Biomechanics S.M. Perren Award 2014: Safety factor of the proximal femur during gait: A population-based finite element study. *Journal of Biomechanics*, *47*(14), 3433-3440. doi: 10.1016/j.jbiomech.2014.08.030.

Telonio, A., Blanchet, S., Maganaris, C. N., Baltzopoulos, V., Villeneuve, S., & McFadyen, B. J. (2014). The division of visual attention affects the transition point from level walking to stair descent in healthy, active older adults. *Experimental Gerontology*, *50*, 26-33. doi: 10.1016/j.exger.2013.11.007.

Tiedemann, A. C., Sherrington, C., & Lord, S. R. (2007). Physical and psychological factors associated with stair negotiation performance in older people. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *62*(11), 1259-1265.

The Maintenance Council. (1989). RP-404B: The maintenance council (TMC) recommended practice 404B – Truck and Truck Tractor Access Systems.

Tuncer, M., Hansen, U. N., & Amis, A. A. (2014). Prediction of structural failure of tibial bone models under physiological loads: Effect of CT density-modulus relationships. *Medical Engineering & Physics*, *36*(8), 991-997; discussion 991. doi: 10.1016/j.medengphy.2014.04.006.

Turner, L. M., & Reed, D. B. (2011). Exercise among commercial truck drivers. *American Board for Occupational Health Nurses (ABOHN) Journal*, *59*(10), 429-436. doi: 10.3928/08910162-20110916-01.

Valtonen, A. M., Poyhonen, T., Manninen, M., Heinonen, A., & Sipila, S. (2015). Knee extensor and flexor muscle power explains stair ascension time in patients with unilateral late-stage knee osteoarthritis: A cross-sectional study. *Archives of Physical Medicine and Rehabilitation*, *96*(2), 253-259. doi: 10.1016/j.apmr.2014.09.011.

Van Bergen, C. J. A., Van Eekeren, I. C. M., Reilingh, M. L., Sierevelt, I. N., & Van Dijk, C. N. (2013). Treatment of osteochondral defects of the talus with a metal resurfacing inlay implant after failed previous surgery: A prospective study. *Bone Joint Journal*, *95*(12), 1650-1655. doi: 10.1302/0301-620X.95B12.32455.

Varnell, M. S., Bhowmik-Stoker, M., McCamley, J., Jacofsky, M. C., Campbell, M., & Jacofsky, D. (2011). Difference in stair negotiation ability based on TKA surgical approach. *The Journal of Knee Surgery*, *24*(2), 117-123.

Vincent, H. K., George, S. Z., Seay, A. N., Vincent, K. R., & Hurley, R. W. (2014). Resistance exercise, disability, and pain catastrophizing in obese adults with back pain. *Medicine and Science in Sports and Exercise*, *46*(9), 1693-1701. doi: 10.1249/MSS.0000000000000294.

Williams, A. F., & Goins, S. E. (1981). Fatal falls and jumps from motor vehicles. *American Journal of Public Health*, *71*(3), 275-279.

Wong, T., Wang, C. J., Wang, J. W., & Ko, J. Y. (2014). Functional outcomes of uni-knee arthroplasty for medial compartment knee arthropathy in asian patients. *Biomedical Journal*, *37*(6), 406-410. doi: 10.4103/2319-4170.132877.

Yamaguchi, T., Yano, M., Onodera, H., & Hokkirigawa, K. (2013). Kinematics of center of mass and center of pressure predict friction requirement at shoe-floor interface during walking. *Gait & Posture*, *38*(2), 209-214. doi: 10.1016/j.gaitpost.2012.11.007.

CHAPTER 6

CONCLUSION

This study examines the effects of truck cab IE elements (handholds and steps, truck driver personal factors, egress tactics, and anthropometry) on temporal, kinetic, kinematic, and biomechanical parameters during truck driver egress. This effort included a systematic evaluation of truck driver egress motions and behaviors to develop a more accurate definition and interpretation of risk factors for slipping and loss of contact, which may lead to falls.

Chapter 1 discussed a review of the literature regarding slips and falls, the previous research landscape of falls among truck drivers, and the objectives of the present research. The data analyzed in this dissertation include data from two studies. The first study, included as Chapter 2, was data from a large cross-sectional study of 794 commercial truck drivers that were used to identify risk factors associated with falls and near falls among commercial truck drivers. Chapters 3-5 presented results from analysis of data from a large-scale laboratory study of ingress and egress motions conducted at the University of Michigan Transportation Research Institute (UMTRI). This research study included eight step configurations and two handhold configurations that were tested using a simulated truck cab. Chapter 3 provided a detailed description of truck driver behaviors during egress, including results of driver tactics, behavior patterns, contact with cab elements, and temporal parameters, as well as a definition of the cab egress phases used for analysis. Chapter 4 examined the most common driver stepping pattern observed, step-over-step (SoS). In this chapter, the variability in truck cab layout and how it effects drivers' points of contact (PoC) during egress was investigated. In Chapter 5, further analyses were performed to better understand the effect of driver tactics and cab configuration on driver-cab biomechanical parameters, which, in turn, may influence the probability of injury or slip or fall. In addition, an investigation into how those behaviors are associated with personal or vehicle characteristics was undertaken.

In this chapter, Chapter 6, the study's relevant and significant findings are discussed chapter-by-chapter, as are research-to-practice relevance, study limitations, and recommended future work.

Synopsis of Chapter 2

Following is a brief synopsis of material that was covered in Chapter 2.

1) Frequency of falls was associated with the location of falls, with the majority of falls occurring around the cab (80.6%) and 19.4% on the trailer. This implies that future studies should assess cab and trailer features that may be increasing the chance of falls in these two areas.
2) Proportionally, more falls occurred during dismounting the cab than mounting the cab. Results from this study are consistent with previous research suggesting that falls during dismounting are more likely than falls during mounting.
3) A total of 68.8% of drivers indicated that environmental contaminants were factors that influenced their fall. These results suggest that when combined with

the layout of the cab, environmental factors may not be suitable to support dismounting the truck cab safely.

4) Reports of feeling physically exhausted or mentally exhausted were associated with reports of falls.

5) Being overweight, obese, or morbidly obese gave drivers higher odds of lifetime falls when compared to normal weight truck drivers.

Synopsis of Chapter 3

What follows is a brief synopsis of material covered in Chapter 3.

1) The most common foot behavior among all trials performed was the SoS foot behavior, 58.5%, followed by the SoSbS foot behavior, 22.86%.

2) Driver foot behaviors differed significantly across overall egress tactic (FC vs. FO). However, hand behavior was not associated with foot behavior or overall tactic.

3) Driver BMI was associated with driver foot behavior mainly among drivers using the facing outward egress tactic. As BMI category increased, there was a shift from a more demanding stair stepping technique, step-over-step (SoS), to a less demanding technique, SbSoS, indicating some compensation as a result of BMI.

4) It was hypothesized that the step configuration changes would affect driver behavior patterns during cab egress. Surprisingly, step configuration was not significantly associated with foot behaviors.

5) Step configuration influenced driver ratings of difficulty and acceptability. Cab

configurations 2 and 4 were rated as being more difficult and unacceptable.

Synopsis of Chapter 4

Below is a synopsis of material covered in Chapter 4.

1) In general, during egress, study participants used the right handhold most frequently, followed by the door handle and then the steering wheel. The steering wheel use indicates compensation for the lack of appropriately positioned handholds. Furthermore, the participants did not utilize any handle for most of the duration of first (30.5%) or third transitions (36.7%). This indicates either a mismatch between the needed and available handholds or their location around the cab. The use of steering wheel during cab egress among drivers descending with the FC tactic also implies similar conclusions.
2) In general, egress tactic influenced driver technique, i.e., interaction with the cab (PoCs) and egress timeline. Those who exited with the FO tactic did so in a faster time compared to those who exited the cab using the FC tactic.
3) Egress tactics influenced the percentages at which participants are able to maintain points of contact. For instance, those exiting the cab with the facing the cab (FC) tactic were observed to have higher mean values of percent in 3PoCs and 4PoCs than those who exited the cab facing outward (FO). Consistently, FO tactic showed an overall higher percentage of 1PoC and 2PoC compared to those who exited the cab using the FC tactic.
4) Study participants maintained single limb support (1PoCF) roughly 70% of the duration when using the facing the cab egress tactic and 65% of the duration

when using the facing outward egress tactic. This is an important finding since this study also showed that double hand support percentages are roughly 55% and 35% for the FC and FO groups, respectively. These percentages would need to be 70% and 65%, to match 1PoCF, to allow for maintaining 3PoC during cab egress.

Synopsis of Chapter 5

Finally, the synopsis of material covered in Chapter 5 is listed.

1) In general, peak RCoFs during cab egress were relatively high with a range of 0.41-0.48 between step configurations. Cab configurations with shallow depths (D1) of 50 or 80 mm between the sill and edge of top step—step configurations 2, 4, and 5—were shown to have high required coefficient of friction (RCoF) values. These findings are important to consider when choosing proper footwear that can provide maximum grip during step negotiation, or best step design to allow for proper available coefficient of friction (ACoF).
2) When considering the egress transitions, interaction with the second step shows the highest overall peak RCoF—which is during the second transition (top step to bottom step motion). This is also associated with a trailing foot on a step having shallow depths of 50-85mm, resulting in less ideal foot placement, as shown through BoSAS and FCL.
3) Exiting the cab with the facing the cab egress tactic reveals lower overall peak RCoF during the first and second transitions, but has higher floor transitions.
4) Overall, CoM velocities and accelerations showed similar findings when comparing egress tactics, with the FO egress tactic exhibiting higher values.

5) Interestingly, in examining the normal, overweight, and obese groups, there was a decreasing trend among these groups in CoMA and CoMV. This indicates a measure of risk compensation during every egress transition when taking into account the entire egress tactic.
6) Driver limbs using the FO technique were exposed to higher overall loading rates during interaction with top, bottom, and floor steps and this exposure was most pronounced during interaction with the floor.
7) Cab configuration differences had an effect mainly during the second transition, between the top and bottom step, and were associated with step configurations having shallow step depth, top step to bottom step clearance (D2) being 150mm. Consistently, a lower loading rate was associated with deeper step configuration (step depth of 350mm). These results support the hypothesis that cab step dimensions affect driver exposure to factors that may lead to a fall. An increase in step depth, for a larger available stepping area, is shown to decrease loading rates during the bottom step negotiation.
8) While FO egress tactic seems to provide evidence of better "footing" on a given step, total BoS area takes into account the hand supports as well. However, overall results from Chapter 4 indicated that when compared to the FC egress tactic, FO egress tactic had lower percentages of drivers being able to maintain 3PoC; therefore, the FC egress tactic may still be a safer tactic during cab egress, especially during E2 and E3 where handholds are not in an ideal useable location.

In summary, drivers' resulting biomechanics is largely dependent on their interaction with the cab, tactics, foot behaviors, and the quality of contact with the steps. Since the majority of drivers used the SoS stair negotiation pattern, the ability to maintain three points of contact would be increased if during driver training, maintaining both hands contact during single foot contact is emphasized. Furthermore, it should be made clear that a SbS foot behavior, along with facing the cab, should be adopted when one of the hands is occupied, such as when holding a clipboard, cellphone, drink, etc.

Since findings from this research indicated that drivers are likely to perform egress facing away from the cab, and given the prevalence of high BMI among this population, handhold and step location and design should incorporate the BoS and stability metric calculations. Doing so would provide this population with proper "footing" and allow for their CoM to be as close to the truck as possible in the event the drivers utilized the FO egress tactic.

Finally, BMI is a factor that has been associated with an increased level of risk. Therefore, driver training should include opportunities for educating the drivers' about lowering their weight and increasing their fitness level. Additionally, drivers may also benefit from stability and strength training as stair stepping is physically more demanding and requires more stability than walking.

Future Work

In doing this detailed research work, several limitations were identified. These shortcomings ought to serve as strengths for future studies as well as provide opportunities for expansion upon this research. The following are the shortcomings of this study and the opportunities for expansion of truck driver slips and falls research:

1) In this current research, the truck sill was not instrumented with a force transducer to measure reaction forces during driver interaction with the sill. This information is valuable when analyzing the feet biomechanics during the loading and unloading rates. It is also useful for the estimation of the level of risk as a function of RCoF, LR, and ankle moment relative to percent capable, or other metrics indicative of level of risk during truck IE. Furthermore, having the reaction force profiles allows for easier and accurate marking of the egress events during the first egress transition E1.
2) This study, in Chapter 3, revealed that the truck drivers did indeed use foot behaviors—behaviors that can be identified using events based on foot interaction with the cab elements, i.e., sill, steps, and ground. The latter Chapters, 4 and 5, only analyzed the SoS driver foot behavior. Future research should be designed such that foot behaviors are controlled for; this would allow for evaluation of differences between foot behaviors. Such a measure would permit an examination of uncommon foot behaviors, as these uncommon behaviors may be associated with increased levels of risk. This level of risk may be defined through PoC, tactic, and biomechanical factors that may indicate higher levels of risk or chances of falls, such as increased levels of RCoF.
3) In Chapter 5, a simple approximation of the base of support over step was developed. This approximation can be incorporated into the calculation of total functional base of support by including the handholds and linking the single and double stance. In addition, this metric can be more accurately and easily calculated if the study markers were chosen such that no virtual marker

calculation is needed. Finally, this method can be easily incorporated into foot insole instrumentation, that is, pressure sensor grid, to allow for estimation of percent of foot contact with step in the instances where such sensors are not available simpler methods may be employed.

4) In addition to BoS calculation, incorporation of CoP and the projection of CoM onto the BoS would be a valuable approach to investigate stability parameters during egress. Traditionally, for level gait stability parameter calculations involving the BoS, CoM projection and CoP variables utilize the ground plane. It is recommended for cab IE, stair negotiation, and sloped gait research to incorporate a modified plane during calculation. This plane should be modified from the level horizontal ground plane and used as a function of the distribution of forces on each of the limbs during each frame of the stair negotiation. For instance, the plane is rotated from 0-90 degrees as a function of the ratio of the forces at PoC at that moment. Therefore, the forces at PoC serves as the boundary condition for the definition of the plane that is used for the stability metric calculation.

5) The foot placement calculations in this study provided valuable information, but future studies should consider the incorporation of the relationship of this easily calculated metric to the ankle moment and population percent ankle moment generation capability. This will allow this metric to be used in the industry as an indicator of increased levels of ankle moments.

6) Further RCoF research is needed. In this research, a new approach was used to calculate the RCoF profile during the entire egress, and stair negotiations in

general, and could be leveraged in future studies. While this approach furthers current research on RCoF during step negotiations, the calculations still utilized the traditional horizontal ground plane. It is recommended that the plane of the foot during single stance be used. During double stance, a modified plane based on the ratio of the magnitude of force distribution on feet should be used for the RCoF calculations. Future research should also incorporate the interface of the foot with the step and control for the kind of shoe used during the analysis. Finally, the foot interaction with the step is very different when comparing egress tactics; therefore, further research into the characterization of those interactions is needed. It should be noted that foot interactions are also different during ingress, or when ascending stairs, when compared to egress, or when descending stairs. Ascending stairs involves propelling the body into a higher elevation, but the descending involves controlled lowering and different muscle engagement is utilized, isometric vs. concentric contractions, respectively. In observing truck drivers in this study during ingress and egress, it was observed that the drivers incorporated planting the foot and passive moment generation during egress and ingress.

7) The force profiles during stair negotiations are valuable to the calculations of several metrics that could be used for slip and falls risk, such as RCoF, LR, and other stability parameters. Further analyses are needed to better understand the relationship between the foot CoM trajectories and foot kinematics and their associated and resulting force profile changes. For example, such analysis will aid in understanding the effect of a range of foot flexion angles, during the

loading phase, on the resulting force profile of both feet during stair negotiations. These analyses could leverage digital human models that involve the application of recursive dynamic simulations, an approach that has been applied in different fields such as the military and the robotics field. This will allow for the foot kinematics and placement metrics to be incorporated as part of the boundary conditions (before and after) and provide more than just traditional statistical comparisons between means of metrics that are based on specific static events.

8) The current custom biomechanical model used in this study has some limitations. It was developed based on male anthropometry and is not designed to take into account differences between BMI and other gender differences. Future studies would benefit from the development of a biomechanical model that can take into account gender and BMI to allow for more accurate total CoM trajectory, position, and acceleration calculation. Our analysis showed these factors are altered as a function of BMI. Therefore, taking into account these biomechanical differences could provide very accurate inputs for the biomechanical stability parameters when calculating the projection of CoM over the BoS.