The Influence of Heavy Truck Egress Tactics on Ground Reaction Force

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Slips and falls during cab egress are an important cause of injuries to truck drivers. Previous work has shown that the egress tactics may influence risk. Inward-facing tactics (driver faces the truck) are universally recommended, but biomechanical evidence supporting this recommendation is sparse. As part of a laboratory study of truck driver ingress and egress behavior, the ground reaction forces during first contact with the ground on egress were recorded for both inward and outward facing egress tactics using either interior or exterior handholds and four step configurations. Twenty-five male and five female truck drivers with a wide range of body size participated. Peak vertical ground reaction force (PVGRF) averaged 1.44 times body weight for the inward-facing tactic and 1.85 times body weight for the outward-facing tactic. Handle position (interior vs. exterior) and step configuration did not affect PVGRF. Drivers with high body mass index choose inward-facing tactics more frequently than other drivers. The average 28-percent increase in peak ground reaction force with the outward-facing tactic may indicate an increased risk of both cumulative and acute injury.

Introduction

Truck drivers are frequently injured entering and exiting tractor-trailer cabs. Lin and Cohen (1997) studied data from injury reports obtained from US trucking companies. Of the slip-and-fall injuries reported, approximately 25% occurred while workers were mounting, dismounting, entering, or exiting vehicles. Egress injuries were three times more common than ingress injuries. Jones and Switzer-McIntyre (2003) identified 352 cases of falls from non-moving vehicles as part of a workplace safety study in Ontario. In 24% of these cases the driver slipped or fell from a step on the truck.

Drivers are routinely trained to enter and exit the truck facing inward, toward the cab, but drivers often exit facing away. In a study of firefighters exiting a truck, ground reaction forces were significantly higher when facing away from the vehicle than

when facing the vehicle (Giguere and Marchand 2005). Using a sample of 10 men, researchers at Liberty Mutual Research Center demonstrated that truck egress tactics affected ground reaction forces, with vertical forces up to 12 times body weight observed for men jumping down from a high cab-over-engine truck (Cotnam and Fatallah, 1998; Fathallah and Cotnam, 2000).

As part of a broader effort to develop improved design guidelines and assessment tools for truck ingress and egress, a laboratory study was conducted with experienced drivers. This paper presents an analysis of the influence of step configuration, handhold position, tactic, and driver characteristics on ground reaction force.

Methods

Mockup

A reconfigurable laboratory mockup was constructed to represent the critical features of the ingress/egress system of a conventional tractor cab (Figure 1). A force platform was located in the floor adjacent to the mockup as well as on the adjustable steps and handholds. The force platform on the ground and the surrounding platform area were covered with a concrete tile material (Hardiboard) with a coefficient of friction similar to concrete pavement. The handhold at the rear of the door opening was either within the door opening (internal) or outside and rearward of the door opening (external). The internal rear handle was presented with an internal front handle at approximately the same height.

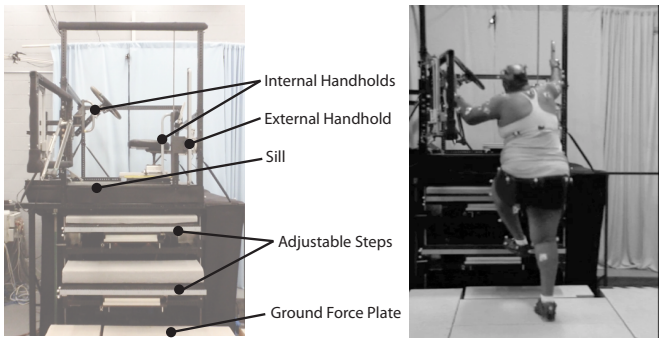

Figure 1. Laboratory mockup, showing handles, adjustable steps, and ground force plate

Subjects

Testing was conducted with 25 male and 5 female truck drivers, all licensed to drive tractor-trailers in Michigan. The drivers' statures ranged from 1554 to 1902 mm (median 1763 mm) and body weight from 69 to 179 kg (median 90 kg). Body mass index (BMI), calculated as body weight in kg divided by stature in meters squared, ranged from 22 to 50, with a median of 30 kg/m^2. Drivers ranged in age from 22 to 65 years (median 50 years), and had between one and fifty years of driving experience (median 12 years).

Test Conditions and Procedures
Participants were tested with four step configurations selected to span a substantial percentage of the U.S. truck fleet with respect to the lateral step placement. Each step configuration was tested with internal handholds and with external handholds (see Figure 1). The handholds on the door were always available.

In the first trial in each condition, no instructions as to tactic were given, and the tactics chosen by the drivers (inward or outward facing) were recorded for each egress event. Following undirected trials in all conditions, each test condition was repeated, except that on egress the driver was directed to use the alternative tactic. For example, a driver who chose to exit facing outward in a particular condition was instructed to face inward for the corresponding directed trials.

Data and Analysis
Ground reaction forces were recorded at 3 kHz and low-pass hardware-filtered at 100 Hz, then downsampled to 100 Hz for analysis. The highest peak vertical force was generally observed immediately following the initial foot contact with the force plate. The forces at the maximum vertical peak were extracted for analysis. Data from 28 trials were excluded because the participant's foot partially missed the force platform. The vertical reaction force was normalized by dividing by body weight. The required coefficient of friction was calculated by dividing the resultant horizontal force by the vertical force.

Analysis of variance (ANOVA) was conducted to assess the effects of step configuration, handhold placement, tactic, and tactic instruction (directed vs. undirected). The effects of stature and BMI were also investigated. Statistical analyses were conducted in the software package R (www.r-project.org).

Results

Table 1 shows the selection of inward/outward tactic for undirected trials by BMI category. Drivers with high BMI were significantly more likely to choose inward-facing egress tactics ($\chi^2(1) = 13.6$, $p < 0.001$). Tactic selection was not significantly affected by step or handhold configurations.

Table 1. Egress tactic selection in undirected trials

Number of Trials	Body Mass Index (kg/m^2)	
	< 30	≥ 30
Inward Facing	56	92
Outward Facing	57	33

Figure 2 shows peak vertical ground reaction force (PVGRF) across conditions. PVGRF was significantly affected ($p<0.001$) by egress tactic, investigator direction, and BMI. ANOVA showed a significant three-way interaction ($p<0.001$) among these

variables, which is made apparent by the box plots in Figure 3. The overall mean PVGRF was 1.64 times body weight (BW) with a large scatter across trials. The mean was higher for directed than for undirected trials, 1.76 BW vs. 1.53 BW. PVGRF was higher for outward-facing than for inward-facing egress, but the magnitude of the increase differed across BMI groups and whether the trial tactic was directed or undirected.

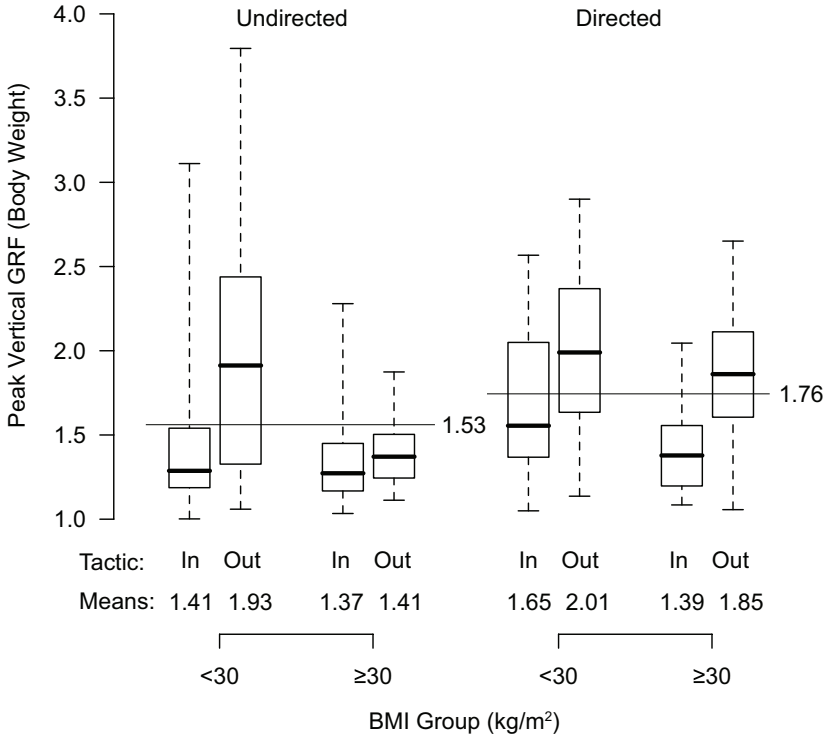

Figure 2. Effects of BMI, inward/outward-facing egress tactic, and investigator direction on peak vertical ground reaction force normalized by body weight. Boxes show median and interquartile range, whiskers span the range of the data. Numeric values on the plot are group means.

In the undirected trials, with drivers choosing their egress tactic, non-obese drivers (BMI < 30 kg/m^2) showed much larger average increases in PVGRF than obese drivers. In the directed trials, which forced the heavier drivers who had chosen inward-facing egress to switch to outward-facing, both high and low BMI groups showed similar increases in mean PVGRF between inward- and outward-facing tactics. Overall, in undirected trials, drivers who exited facing away from the steps experienced average peak ground reaction forces of 1.75 times body weight, compared with 1.25 times for those who exited facing the steps. Averaging across all trials captures the same number of inward- and outward-facing egress events for each driver, and hence gives the best estimate of the within-subject increase in force

resulting from a change in tactics (excepting missing data). Using these values, PVGRF in outward-facing egress was 28% higher (1.85 vs. 1.44 times body weight).

RCOF was significantly affected only by tactic ($p<0.001$) and the effect was small. The mean RCOF was 0.085 for inward-facing and 0.07 for outward-facing egress.

Discussion

The lower ground reaction forces observed with inward-facing egress provide a biomechanical justification for recommending that tactic, since lower ground reaction forces are associated with reduced tissue stresses. In undirected trials, drivers with higher BMI were more likely to choose the lower-stress tactic, providing some evidence of risk compensation. Surprisingly, step and handhold configuration did not affect either tactic selection or ground reaction force. A more detailed analysis is needed, but one possibility is that driver tactic preference based on years of experience tends to override any effects of short-duration exposure to a new step and handhold configuration. The data show large inter-subject variability, however, and tactic changes may have occurred within the broad categories used here.

These data are limited by the laboratory setting and test equipment. Some drivers moved more slowly than is typical for drivers in their own trucks, which likely makes the current conclusions conservative – higher-speed egress would lead to higher PVGRF and an increased risk for outward-facing egress. The postures at the time of ground contact also differ substantially between tactics and may lead to different stress even with the same ground reaction force.

Acknowledgements

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References

Cotnam, J.P. and Fathallah, F.A.,1998, Landing forces resulting from existing tractors and trailers. SAE Technical Paper 982754. SAE International, Warrendale, PA.

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

Lin, L-J, and Cohen, H.H., 1997, Accidents in the trucking industry. *International Journal of Industrial Ergonomics*, 20:287-300.

Jones, D. and Switzer-McIntyre, 2003, Falls from trucks: a descriptive study based on a workers compensation database. *Work*, 20:179-184.