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Maximum forces sustained during various methods of exiting commercial tractors, trailers and trucks

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Abstract

Many commercial vehicles have steps and grab-rails to assist the driver in safely entering/exiting the vehicle. However, many drivers do not use these aids. The purpose of this study was to compare impact forces experienced during various exit methods from commercial equipment. The study investigated impact forces of ten male subjects while exiting two tractors, a step-van, a box-trailer, and a cube-van. The results showed that exiting from cab-level or trailer-level resulted in impact forces as high as 12 times the subject's body weight; whereas, fully utilizing the steps and grab-rails resulted in impact forces less than two times body weight. An approach that emphasizes optimal design of entry/exit aids coupled with driver training and education is expected to minimize exit-related injuries. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Truck exit; Impact force; Vehicle safety

1. Introduction

The cabs of most commercial vehicles are equipped with steps and rails to facilitate exiting the vehicle safely; unfortunately, many drivers choose to circumvent these aids and simply jump out. In a survey of delivery drivers at two companies in the UK, Nicholson and David (1985) reported that over half of the respondents admitted to jumping from the cab when exiting. Additionally, based on observations made at a truck stop, Heglund (1987) reported that 29.8% of drivers climbing out of high-profile cab-over-engine tractors (cab level 1.45 m high) at least partially jumped out.

There are no data that specifically address the prevalence of jumping from the *back* of commercial equipment. Nevertheless, it is anticipated that this number is even higher than the number of jumps out of cabs. This is due mainly to the common lack of proper exit aids in the backs of trucks and trailers (as compared to tractors). The backs of many trucks/trailers have no handrails at all (e.g. some flatbed trucks) and no "well designed" steps; hence, the person has no alternative but to either jump or awkwardly climb down.

It is anticipated that improper exiting from commercial vehicles could lead to several potential driver injuries. There are two major potential injury risks to the driver when jumping from a commercial vehicle. First, it is expected that whenever a driver jumps/partially jumps out of a vehicle cab or trailer (due to lack of use, poor design, or absence of exit aids), the forces on the body joints would be substantially higher than the forces experienced during situations where exit aids are fully utilized. Although there is no specific data on the risks of jumping from commercial vehicles, the literature indicates that many sports that involve jumping, such as the vertical jump, volleyball, and basketball have a high number of injuries that occur during landing. The most affected areas include the ankles, knees, and the lower back (Dufek and Bates, 1991; Ferretti et al., 1992; Kannus and Natri, 1997; Maehlum and Daljord, 1984; Roberts and Roberts, 1996). Parachuting injuries are also dominated by ankle and spinal injuries caused during landing impact (Hallel and Naggan, 1975). Furthermore, jumps from the back of military transport trucks have been anecdotally associated with ankle and knee injuries (Rice, 1998). The exact injury mechanisms of landing from a jump are not fully understood and depend on many factors such as landing technique, landing height, foot wear, and surface type. Nonetheless, it is clear that jumping from an elevation could subject various body joints

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to excessive levels of force during the landing phase. This may in turn lead to various acute and/or chronic musculoskeletal injuries.

The second risk of injury involves the potential for the driver to slip and fall immediately after landing. This risk depends on many factors such as the material of the landing surface, the presence of surface contaminant(s) (e.g. oil), the type of shoes worn by the driver, and other factors. However, it is expected that the potential for slipping and falling after jumping from commercial vehicles exposes the driver to the risk of severe injury to various body parts and could potentially lead to a fatal injury. Although there is no specific evidence on slips and falls at exit/entry from the back of trucks, Miller (1976) indicated that about one-fourth of all driver injuries in the US are associated with slips and falls in and around the tractor. It is believed that these injuries account for the majority of long-term disabilities, especially back injury disabilities. The study suggested that many truck-related injuries occur during tractor cab entry and exit (Miller, 1976).

There is a lack of quantitative data to demonstrate the two major potential risks discussed above which are associated with improper exiting techniques. This manuscript will focus on the first injury potential and addresses the landing forces and their potential effects on the body. The slip-potential issue that follows the landing phase needs a detailed treatment and different analysis, which will be addressed in a follow-up manuscript. Hence, the purpose of this study was to quantify impact forces experienced during the landing phase of various exit methods from a variety of commercial equipment commonly used in the trucking industry.

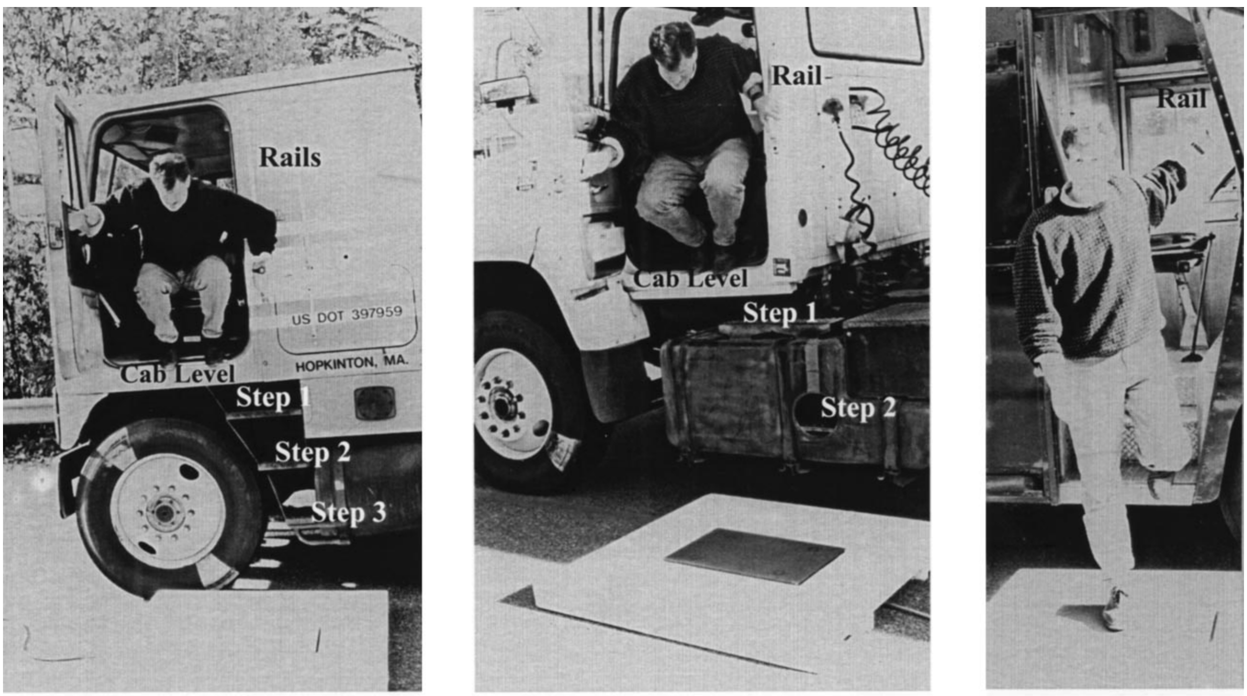
2. Methods

2.1. Subjects

Ten healthy male subjects participated in this study. The mean age was 32.7 years (10.9 S.D.), mean stature was 1.776 m (0.107 S.D.), and mean weight was 84.9 kg (22.8 S.D.). All subjects were screened to ensure the absence of any current or previous musculoskeletal disorders, especially at the ankle, knee, hip, back, and neck joints. Subjects were compensated for their participation ($50 and a pair of work-boots). The internal review committee overseeing experiments involving human subjects approved the study.

2.2. Apparatus

For the "cab exit" part of the experiment, three types of vehicles were used: (1) A cab-over-engine (COE) tractor, (2) a conventional tractor, and (3) a delivery step-van. Fig. 1 depicts the three truck cabs. The COE has two



(a) COE tractor (b) Conventional tractor (c) Step-van

Fig. 1. The three types of vehicles used in the "Cab Exit" portion of the experiment: (a) Cab-over-engine tractor (COE), (b) conventional tractor, and (c) delivery step-van. Location of various exit levels and grab-rails are also indicated.

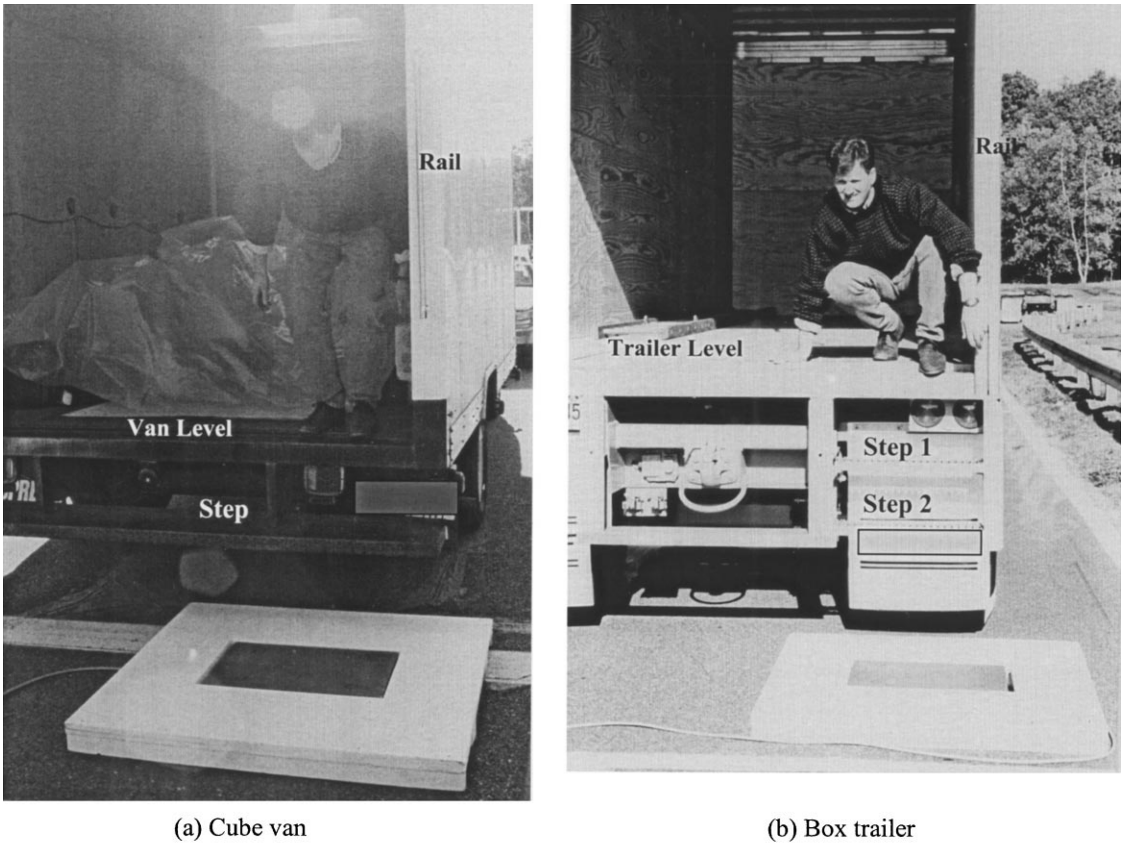


Fig. 2. The "box trailer" and the "cube-van" used in the "back exit" portion of the experiment. Location of various exit levels and grab-rails are also indicated.

grab rails along the side of the cab and three steps. The conventional tractor has one grab rail and two steps, whereas the step-van had three exit steps and a grab rail along the exit door. The subjects were instructed to use all three steps while exiting the van (last step at 0.43 m). In certain conditions for the delivery step-van, the subjects carried a $0.23 \times 0.28 \times 0.30$ m 9.5-kg box.

For the "back exit" portion of the experiment, two conditions (back of vehicles) were investigated: (1) the back of an 8 m "box" trailer, and (2) the back of a 4.3-m "cube" van. Fig. 2 shows these two conditions. The trailer had two custom-installed steps, and the cube-van had a step that ran along the whole back of the van. The trailer had an edge that ran along its sides, which was used as a grab rail, whereas the cube-van had a 0.89-m grab rail custom-installed on its right side (see Fig. 2).

A three-dimensional forceplate (Bertec 4060A; Bertec, Worthington, OH) was used to capture the impact forces in each of the experimental conditions. The forceplate was placed inside a 1.22×1.22 m wooden platform that was flush with the forceplate surface (i.e. the forceplate and platform were at identical heights from the ground). This was necessary in order to increase the landing surface in case the subject missed landing his feet/foot within the forceplate surface area. The six analog signals from the forceplate (three forces and three moments) were captured via an analog-to-digital (A/D) converter using a pentium-based laptop microcomputer. Customized software was developed to capture the data and convert the forceplate signals to forces (N) and moments (N m), using vendor-supplied calibration matrices. The data were collected at a 200 Hz sampling rate.

2.3. Experimental design

Table 1 lists the conditions for each piece of equipment (two tractors, one trailer, and two trucks/vans). Note that all the heights reported above are with respect to the forceplate level (0.1 m high). Each piece of equipment was treated as a separate one-way within-subject design. This was necessary since the treatments were not identical across trucks. The presentation of equipment was random; also, within a given piece of equipment, the conditions were randomly presented. The dependent variables were maximum impact force in Newtons, and in multiples of body weight.

2.4. Experimental procedure

Prior to the experiment, all subjects watched a videotape that demonstrated each of the experimental

Table 1
Description of the conditions for each piece of equipment. Note that each condition is assigned a unique condition code/number

Condition	Condition code/number	Exit height (m)
Cab exit — COE tractor		
Squat jump forward from cab level	COE1	1.25
Exit using rail and first step	COE2	0.97
Exit using rail, first and second steps	COE3	0.69
Exit using rail, first, second and third steps	COE4	0.38
Cab exit — conventional tractor		
Squat jump forward from cab level	CNV1	1.07
Exit using rail and first step	CNV2	0.86
Exit using rail, first and second steps	CNV3	0.43
Cab exit — step van		
Normal exit with no rail	STV1	0.43
Normal exit with rail	STV2	0.43
Fast exit with no rail	STV3	0.43
Normal exit with no rail and carrying a package	STV4	0.43
Normal exit with rail and carrying a package	STV5	0.43
Fast exit with no rail and carrying a package	STV6	0.43
Back exit — trailer		
Squat jump-forward	TRL1	1.14
Squat jump-backward	TRL2	1.14
Exit using rail and first step	TRL3	0.76
Exit using rail and first and second step	TRL4	0.51
Back exit — cube van		
Squat jump-forward	CBV1	0.71
Exit using rail from van level	CBV2	0.71
Exit using rail and step	CBV3	0.36

conditions. All subjects consented to participate in the experiment and were provided with identical work-boots in order to control for potential shoe-differences. At the beginning of the experiment, each subject was asked to stand on the forceplate in order to measure body weight. The experimenters demonstrated the expected manner in which to perform the upcoming condition, and the subject was encouraged to ask any pertinent questions. The subject performed two "acceptable" trials in each condition. A trial was repeated in cases where the subject's feet did not completely land within the forceplate boundaries. However, for all subjects, the majority of the trials were "acceptable" (there was a maximum of four repeated trials for one subject). For both tractors, the cab-level conditions required the subject to "squat" jump from the cab level facing forward (away from the tractor); while all other conditions (using steps and rails) required the subjects to face the tractor. For the step-van conditions, the subjects were asked to exit facing away from the vehicle (see Fig. 1).

For the trailer-level exits of the back of the trailer conditions, the subject was asked to squat jump either forward or backwards while supporting his body by placing one hand on the trailer's surface. For exits that called for using the steps, the subjects faced the back of the trailer while using part of the edge of the trailer as a grab handle and the appropriate step(s) (step 1 or steps 1 and 2). The minimum rest periods allotted to the subjects were 1-min between two trials, 2-min between levels (e.g. steps), and 5-min between conditions (e.g. trucks). The study was performed in one experimental session that ranged between 1.2 and 1.5 h.

2.5. Data analysis

For each trial, the peak force, in Newtons, were determined in the lateral (X), anterior-posterior (Y), and vertical (Z) directions with respect to the center of the forceplate. The vector (geometric) sum of all three forces was also calculated (square-root$[X^2 + Y^2 + Z^2]$). This figure was then divided by the subject's body weight (geometric sum of all three forces), as determined from the reading taken from the forceplate at the beginning of the experiment. This unitless variable represents the total impact force magnitude in multiples of body weight observed in a given trial. For each condition, the average of the two trials represented the impact force of that condition.

Descriptive statistics (means and standard deviations) were computed for the maximum force (in Newtons) observed in each of the three axes and the vector sum of the three axes, as well as for the "multiples of body weight" variable. Separate analyses of variance (ANOVAs) were performed on "multiples of body weight" for each cab exit and back exit condition. All statistical and graphical analyses were performed using STATISTICA for Windows (StatSoft, 1995).

3. Results

Table 2 shows the maximum impact forces for the three forceplate axes and for their vector sum under each of the "cab exit" and "back exit" conditions. Note that, as expected, the dominant force was in the vertical (*Z*) direction; hence, the magnitude of the vector sum was fairly close to the magnitude of the maximum force in the *Z* direction.

The ANOVA results revealed a significant difference among the four levels of the COE tractor ($p < 0.01$). Fig. 3 shows the average impact force, in multiples of body weight. Post-hoc results (Newman-Keuls) are also indicated in Fig. 3. The "cab-level" condition exhibited the highest force (7.1 times body weight) followed by "step 1" (6.5 times body weight), "steps 1 and 2" (2.1 times body weight), and "steps 1, 2, and 3" (1.4 times body weight), respectively. Note that the "cab-level" and "step 1" conditions did not significantly differ from each other; however, both of these conditions were significantly higher than the "steps 1 and 2" and "steps 1, 2, and 3" conditions (which were not statistically different from each other).

The one-way ANOVA results for the conventional tractor also revealed a significant difference among the three conditions ($p < 0.01$; see Fig. 4). Again, the "cab-level" condition revealed the highest average maximum force (7.2 times body weight) and was significantly higher than both the "step 1" (5.1 times body weight), and "steps 1 and 2" (1.8 times body weight) conditions. Note that the "step 1" condition was significantly higher than the "steps 1 and 2" condition ($p < 0.05$, Fig. 4).

There was a significant difference among the various step-van conditions ($p < 0.01$; see Fig. 5). The "fast exit while carrying a package" condition revealed the highest average maximum force (3.5 times body weight), whereas the lowest impact force was observed under the "using rail and carrying package" condition (1.9 times body weight). Detailed post-hoc analyses (Newman-Keuls) are also presented in Fig. 5.

Table 2
Impact (maximum) forces, along each of the three-dimensional axes and for the vector sum of the three axes under each of the "cab exit" and "back exit" conditions. Units are in Newtons

Condition	*X* (lateral)		*Y* (Ant/Posterior)		*Z* (Vertical)		*XYZ* Vector	
	Max	S.D.	Max	S.D.	Max	S.D.	Max	S.D.
Cab exit-COE tractor								
Jump-cab level	648.2	489.3	882.6	391.3	5720.4	2214.8	5792.4	2273.6
Step 1	325.3	344.5	1136.1	540.4	5127.6	1540.3	5250.0	1620.3
Step 2	66.3	79.7	175.1	161.1	1719.8	872.1	1731.1	886.6
Step 3	75.6	57.1	105.8	75.7	1147.4	401.5	1151.8	404.4
Cab exit-conven. tractor								
Jump-cab level	825.1	590.1	975.2	421.0	5716.2	1921.6	5832.2	1920.6
Step 1	288.2	244.2	905.7	500.5	4076.1	1482.4	4162.4	1514.3
Step 2	166.7	84.0	206.6	106.4	1398.9	417.9	1407.4	421.7
Cab exit-step van								
No rail	144.8	81.8	296.0	134.7	2135.7	689.1	2143.0	688.2
Rail	111.0	46.6	225.6	82.7	1622.0	498.1	1630.0	497.5
Fast exit	210.3	111.8	260.2	101.2	2420.6	649.2	2450.2	656.0
No rail-package	169.6	73.4	347.0	184.0	2291.6	664.7	2303.3	669.2
Rail-package	109.1	62.3	244.0	114.2	1522.2	517.6	1534.7	526.8
Fast exit-package	194.1	83.9	251.9	107.5	2756.4	663.3	2784.9	664.5
Back exit-trailer								
Jump-forward	454.5	359.3	752.9	322.6	4930.6	1396.8	4986.9	1440.0
Jump-backward	132.7	149.9	1290.3	609.9	4645.5	1660.7	4813.2	1727.5
Step 1	74.5	59.9	298.7	183.2	1944.0	600.0	1975.7	610.1
Step 2	57.3	49.1	175.8	92.7	1651.8	496.1	1661.5	498.5
Back exit-cube van								
Jump-forward	324.3	361.8	620.3	389.0	4373.1	1606.0	4410.9	1638.1
Rail-van level	73.7	55.7	280.5	252.1	1614.2	855.2	1637.1	874.0
Rail-step level	49.3	35.8	94.0	86.8	1164.7	464.3	1171.4	471.2

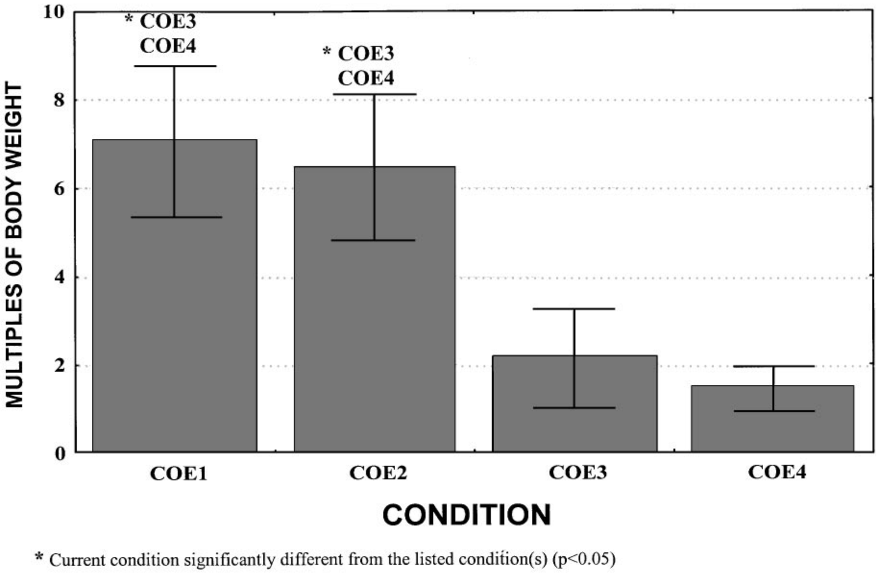


Fig. 3. Average impact force (± S.D.), in multiples of body weight, for the COE tractor. Significant paired post-hoc comparisons are also indicated. Refer to Table 1 for description of the conditions.

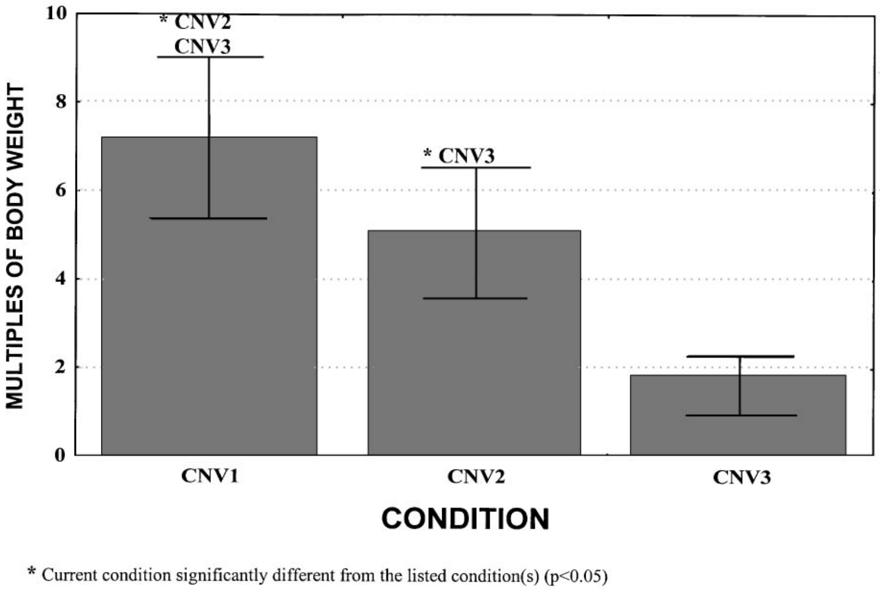


Fig. 4. Average impact force (± S.D.), in multiples of body weight, for the conventional tractor. Significant paired post-hoc comparisons are also indicated. Refer to Table 1 for description of the conditions.

The ANOVA for the exiting from the back of the box trailer also showed a significant difference among the three conditions ($p < 0.01$; see Fig. 6). Post-hoc analyses (Newman-Keuls) are also presented in Fig. 6. The "forward squat-jump" condition had the highest average maximum force (6.44 times body weight), whereas the lowest impact force was observed under the "steps 1 and 2" condition (2.1 times body weight). The two squat-jump conditions did not significantly differ from each other, nor did the two conditions that required using the steps (step 1, and steps 1 and 2); however, the two squat-jump conditions had substantially higher maximum force than the two conditions requiring the steps ($p < 0.05$, see Fig. 5).

Under all the "cube van" conditions, the "squat jump" produced the highest impact force (5.5 times body weight) and was significantly higher than both the "rail, van-level" (1.9 times body weight) and the "rail, step level" (1.4 times body weight) conditions ($p < 0.05$, see Fig. 7). However, the "rail, van-level" and the "rail, step level" did not significantly differ from each other.

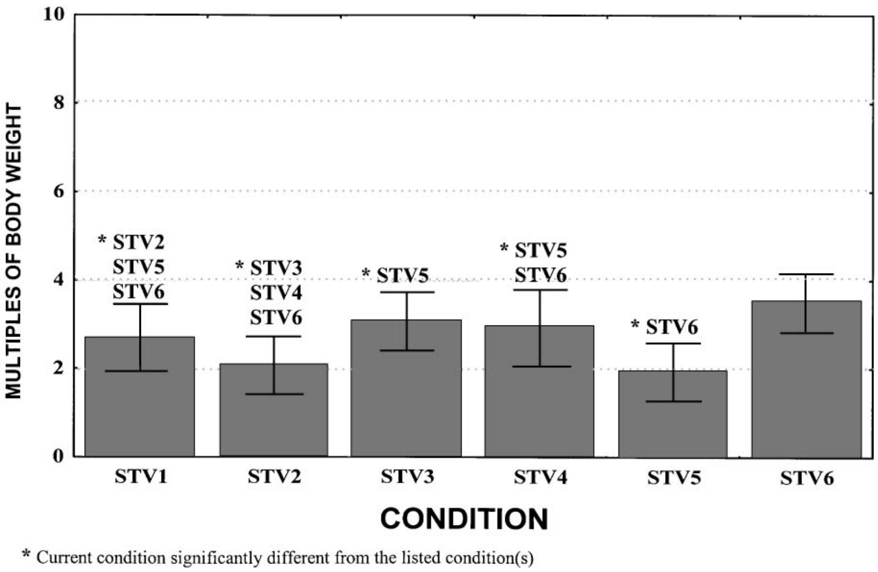


Fig. 5. Average impact force (± S.D.), in multiples of body weight, for the delivery step-van. Significant paired post-hoc comparisons are also indicated. Refer to Table 1 for description of the conditions.

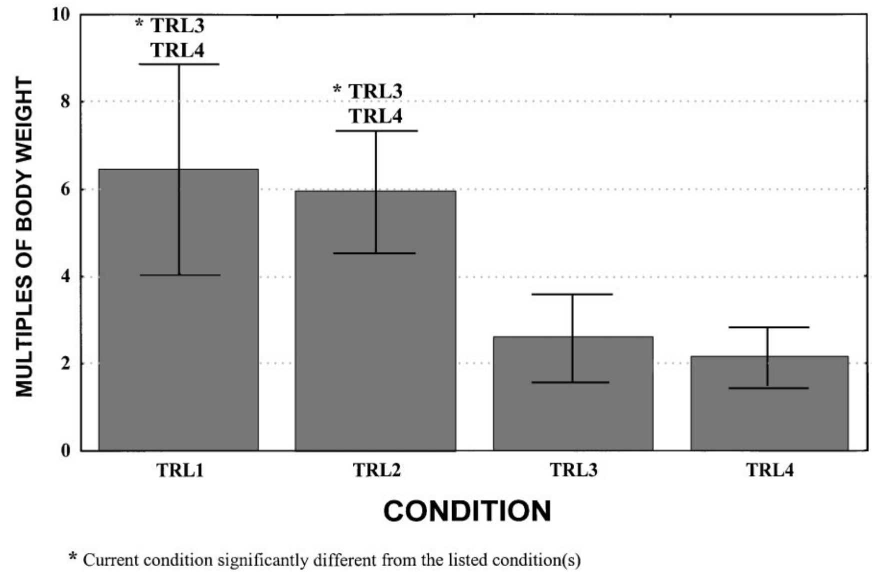


Fig. 6. Average impact force (± S.D.), in multiples of body weight, for the box trailer. Significant paired post-hoc comparisons are also indicated. Refer to Table 1 for description of the conditions.

4. Discussion

Improper exit from commercial vehicles exposes the driver to two major potential injury mechanisms. First, the musculoskeletal system is subjected to elevated and potentially injurious levels of impact force during the landing phase of the exit. Second, the driver may slip and fall immediately after landing, possibly leading to various bodily injuries (e.g. fractures), even fatality. The purpose of this study was to focus on the first injury mechanism by quantifying landing impact forces during various exit methods from three cabs and from the backs of two trailers.

For the tractor cab exit conditions, the results demonstrated that the lowest impact forces were observed when the subjects used the grab-rail(s) in combination with the entry/exit steps. On the other hand, impact forces reached an average of over seven times body weight and as high as 12 times body weight when the subjects jumped from the COE cab-level (average of about 5800 N and

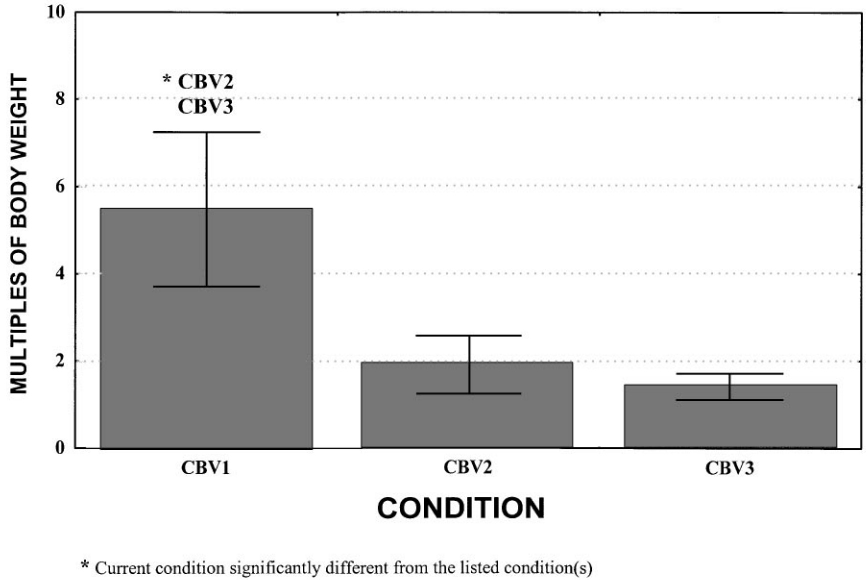


Fig. 7. Average impact force ($\pm$ S.D.), in multiples of body weight, for the cube-van. Significant paired post-hoc comparisons are also indicated. Refer to Table 1 for description of the conditions.

maximum of about 11,000 N). It is difficult to determine how much of this force is transmitted through each joint of the body; however, it is expected that the ankle joint is subjected to the majority of this force given its proximity to the contact surface (force plate). There is limited information about the fracture tolerance of the ankle joint. Yoganandan et al. (1997) demonstrated that fractures at the proximal tibial end of the ankle, and to the plantar side of the ankle occurred in cadaveric specimen when subjected to mean maximum forces of 10.2 kN (1.5 S.D.), and 15.1 (2.7 S.D.), respectively. Klopp et al. (1997) also have shown that the 50% probability of injury to the plantar side of the ankle could occur at 9.3 kN contact force. These findings indicate that forces observed during the jump conditions in this study approached the fracture tolerance of the ankle joint. In addition, these forces are near the compressive strength of the L5/S1 spinal joint (Adams and Dolan, 1995; Jäger and Luttmann, 1991). However, given that the structure of the human body cannot be considered rigid, the ground impact reaction force is expected, in most cases, to be attenuated for higher level joints such as the knees and the lower back. The level of attenuation (or in some instances magnification) depends on many factors such as the natural frequency of the joints, joint posture, and acceleration (Pope et al., 1997). Note though, that even with 30–50% attenuation of ground reaction force, the forces experienced at the spine level would still be considered substantial and may exceed some recommended exposure limits (e.g., the NIOSH limit of 3.4 kN; Waters et al., 1993).

For the COE tractor, the results unexpectedly showed that the "jump from step 1" condition was not significantly different from the "jump from cab-level" condition. However, after observing the manner in which the subjects performed these conditions, the reason for this lack of difference became clearer. When subjects jumped from the cab level, they squatted down rather extensively, lowering the body's center of gravity (COG) closer to the subjects' feet (at about cab level height). On the other hand, under the "step 1" condition, subjects were exiting in a more or less erect posture, keeping the COG at a more substantial distance from the subjects' feet (at about the step height). This may have resulted in making the COGs under these two conditions to be at similar distance from the ground and contributed to the lack of significant difference in impact force between these two conditions. In addition, unlike the "jump from cab level" condition, when jumping from step 1, the subjects were not able to substantially squat their legs during landing since they were facing the cab. This finding emphasizes the importance of *fully* utilizing the step and grab system. In this instance, partially using the exit aid system (i.e. jumping after grabbing the rail and using only the first step) resulted in substantial impact forces that were comparable to those observed while not using any exit aid (i.e. squat jump from the cab level).

For the delivery step-van, using the handrail significantly reduced the impact force for both the "with package" and "without package" conditions (a reduction of over 40%). This decrease may result in a substantial reduction in the potential "cumulative" effect of exit impact forces. This is especially important in the case of the delivery van driver who is expected to exit the vehicle many times throughout the day (as compared to a tractor-trailer truck driver). It is interesting to note that, on average, the "using the rail and carrying a package" condition was slightly lower, though not significantly different, from "using the rail without package" condition. This finding may be due to the possibility that subjects exited a little slower when they were carrying a package, and in turn this may have offset the expected effect of the package weight. In addition, the fact that the package weight was relatively small compared to the subjects' body weight may have contributed to this lack of difference.

The conditions resulting from exiting from trailers and the backs of trucks have demonstrated the importance of both installing and using exiting aids. For the box trailer, squat jumping (forward and backward) from the trailer level resulted in high impact forces (as high as 11 times body weight). These forces were, on the average, three times higher than the forces observed when fully utilizing the retrofitted step system (i.e. two-third reduction in impact force when using the system). Similar reduction was observed with the cube van when comparing the squat jump condition to the "exit from step-level" condition. These reductions are expected to reduce the risk of injuries (cumulative or acute) to people who often perform tasks such as loading/unloading in trailers and backs of trucks. It should be noted that many trailers and flatbed trucks do not offer adequate aids to facilitate safe entry to/exit from these units. In many instances, entry/exit aids such as ladders or rails are optional features to these units rather than standard equipment. Hence, proper operator training alone may not be sufficient to contain the risks associated with exiting commercial vehicles if these units are not equipped with adequate entry/exit aids.

It should be emphasized that the jumping conditions (e.g. squat jump from cab level) investigated in this study were collected under ideal situations in terms of speed of exit, the manner of exit, and surface quality. The subjects were given ample time to prepare for the jump conditions and were instructed to "squat" jump. Whereas, in real-world delivery situations where the driver quickly jumps out of the cab, the speed of exit and the manner in which the jump is executed (e.g. straight legs) may cause the impact forces to be even higher than those reported in this study. When combining these high impact forces during jump exits with less than ideal landing surface conditions (e.g. icy surface), the potential to slip and fall after landing, leading to an injury (or multiple injuries), is expected to be increased. As noted earlier, this topic of slip-potential after jumping from commercial vehicles will be treated in detail in a follow-up article.

In summary, this study demonstrated the potential benefits of using exit aids such as steps and grab-rails in commercial vehicles, and stressed the importance of installing these aids in units that do not have them, such as trailers. Reasons drivers do not use these aids, besides saving time, may include design issues such as anthropometric mismatch (e.g. grab-handle difficult to reach), size and location of aids, among others. Therefore, an approach that emphasizes optimal design of entry/exit aids, coupled with driver training of proper use of these aids and education on the potential risks associated with unsafe entering/exiting techniques (e.g. jumping out) is expected to minimize vehicle-related musculoskeletal injuries.

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References

Adams, M.A., Dolan, P., 1995. Recent advances in lumbar spinal mechanics and their clinical significance. Clin. Biomech. 10 (1), 3–19.

Dufek, J.S., Bates, B.T., 1991. Biomechanical factors associated with injury during landing in jump sports. Sports Med. 12 (5), 326–337.

Ferretti, A., Papandrea, P., Conteduca, F., Mariani, P.P., 1992. Knee ligament injuries in volleyball players. Am. J. Sports Med. 20 (2), 203–207.

Hallel, T., Naggan, L., 1975. Parachuting injuries: a retrospective study of 83,718 jumps. J Trauma. 15 (1), 14–19.

Heglund, R.E., 1987. SAE Technical Paper Series: falls entering and exiting heavy truck cabs. Proceedings of the Truck and Bus Meeting and Exposition. Society of Automotive Engineers, Dearborn, MI.

Jäger, M., Luttmann, A., 1991. Compression strength of lumbar spine elements related to age, gender, and other influencing factors. In: Anderson, P.A., Hobart, D.J., Danoff, J.V. (Eds.), Electromyographical Kinesiology. Elsevier, Amsterdam, pp. 291–294.

Kannus, P., Natri, A., 1997. Etiology and pathophysiology of tendon ruptures in sports. Scand. J. Med. Sci. Sports. 7 (2), 107–112.

Klopp, G. et al., 1997. Mechanisms of injury and injury criterial for the human foot and ankle in dynamic axial impacts to the foot. Proceedings of the 1997 International IRCOBI Conference on the Biomechanics of Impact. Bron, France, IRCOBI.

Maehlum, S., Daljord, O.A., 1984. Acute sports injuries in Oslo: a one-year study. Br. J. Sports Med. 18 (3), 181–185.

Miller, J.M., 1976. Efforts to reduce truck and bus operator hazards. Human Factors 18 (6), 533–550.

Nicholson, A.S., David, G.C., 1985. Slipping, tripping and falling accidents to delivery drivers. Ergonomics 28 (7), 977–991.

Pope, D.P., Croft, P.R., Pritchard, C.M., Silman, A.J., Macfarlane, G.J., 1997. Occupational factors related to shoulder pain and disability. Occup. Environ. Med. 54 (5), 316–321.

Rice, V.J., 1998. Personal communication.

Roberts, S.N., Roberts, P.M., 1996. Tournament water skiing trauma. Br. J. Sports Med. 30 (2), 90–93.

StatSoft, 1995. STATISTICA for Windows [Computer program manual]. StatSoft, Inc., Tulsa, OK.

Waters, T.R., Putz-Anderson, V., Garg, A., Fine, L.J., 1993. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics 36 (7), 749–776.

Yoganandan, N., Pintar, F.A., Kumaresan, S., Boynton, M., 1997. Axial impact biomechanics of the human foot-ankle complex. J Biomech Eng 119 (4), 433–437.