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The effect of the descent technique and truck cabin layout on the landing impact forces

Stéphane Patenaude[a,b], Denis Marchand[a], Sabina Samperi[b], Marc Bélanger[a,c,*]

[a] *Département de Kinanthropologie, Université du Québec à Montréal, C.P. 8888, Succursale Centre-Ville, Montréal, Qué., Canada H3C 3P8*
[b] *Association Sectorielle Transport Entreposage 6555, boul. Métropolitain Est, Bureau 401, St-Léonard, Qué., Canada H1P 3H3*
[c] *Centre de recherche interdisciplinaire en réadaptation du Montréal métropolitain (CRIR), 2275 rue Laurier est, Montréal, Qué., Canada H2N 2N8*

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Abstract

The majority of injuries to truckers are caused by falls during the descent from the cab of the truck. Several studies have shown that the techniques used to descend from the truck and the layout of the truck's cabin are the principal cause of injury. The goal of the present study was to measure the effects of the descent techniques used by the trucker and the layout of the truck's cabin on the impact forces absorbed by the lower limbs and the back. Kinematic data, obtained with the aid of a video camera, were combined with the force platform data to allow for calculation of the lower limb and L_5-S_1 torques as well as L_5-S_1 compressive forces. The trucker descended from two different conventional tractor cabin layouts. Each trucker descended from cabin using either "facing the truck" (FT) or "back to the truck" (BT) techniques. The results demonstrate that the BT technique produces greater ground impact forces than the FT technique, particularly when the truck does not have a handrail. The BT technique also causes an increase in the compressive forces exerted on the back. In conclusion, the use of the FT technique along with the aids (i.e., handrails and all the steps) help lower the landing impact forces as well as the lumbosacral compressive forces. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Truck descent; Impact force; L_5-S_1 torque and compressive force

1. Introduction

The dangers facing truckers are not limited to those encountered during driving of the vehicle. In fact, a large number of accidents occur while the truck is immobilized. A total of 5509 reported injuries (e.g., back, knee and ankle) in the trucking industry between 1994 and 1997 in the province of Quebec were the results of either falls or jumping off an immobilized vehicle (CSST, 1997). Nearly 40% (2063) of those cases involved truckers who were in the long distance transport sector. The most prevalent lesions involved the vertebral column (1212 cases), the ankle (898 cases) and the foot (366 cases) (Bruneau, 1994). Thus, because so many injuries originate from falls, it is important to try to establish what factors may be involved.

Several studies (Bélanger, 1987; Cohen, 1985; Meunier, 1978) have concluded that the technique used by workers to descend from the truck's cabin is an important factor in the injury etiology. In an observational study, Cohen (1985) reported that in 72% of the cases, truckers descended from the cabin using a technique whereby their back was toward the truck (BT). The main motivating factor for truckers' usage of this descent technique was speed. In fact, the truckers using the BT technique, often jumped from the highest step while using the handles and handrails mainly to guide themselves. Based on a simple physics principle (velocity $=(2 \times$ acceleration due to gravity $\times$ height$)^{0.5}$), one can easily appreciate that the free fall associated with this technique will increase the speed of descent and will create a greater ground impact force. The other descent technique that can be used is one whereby the worker faces the truck (FT) while using the handrails and the steps as supports. With this technique, the

*Corresponding author. Département de Kinanthropologie, Université du Québec à Montréal, C.P. 8888, Succursale Centre-Ville, Montréal, Que., Canada H3C 3P8. Tel.: +1-514-987-3000 ext 6862; fax: +1-514-987-6616.

E-mail address: belanger.m@uqam.ca (M. Bélanger).

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trucker always maintains three contact points, thereby limiting loss of balance and the possibility of falling. In addition, the FT technique decreases the free fall height as the trucker tends to use most or all of the steps during the descent. Moreover, this technique allows for a greater utilization of the extensors of the last weight-bearing limb and therefore permits a more gentle lowering of the body.

The layout of the cabin can also be an important factor that influences the risks of injuries. The arrangement of the steps and handles can, in some cases, render the descent more difficult and hazardous (Laurent, 1985; Bélanger, 1987). Combining a poor cabin layout with a descent technique that does not easily allow for decreasing the free fall height (e.g., BT) is likely to increase the speed at ground contact, which in turn will lead to a greater impulse ($I = Ft = mv$) to be dissipated on landing. The larger impulses mean that the muscles will have to play a greater role in reducing the body speed and dampening the amplitude of the forces transferred to the bones and joints (Nigg and Herzog, 1994). The risks of injury are likely to increase if the truckers are exposed over the long term to numerous situations with high impact forces. Few studies have examined the impact forces during descent from the truck's cabin. The majority of studies have focused on the impact forces during walking, running and other sports (Lafortune et al., 1995; Chu et al., 1986; Dufek and Bates, 1991; Ferreti et al., 1992). The results obtained from these studies are not easily applicable to the descent from the cabin of a truck.

One recent study by Fathallah and Cotnam (2000) examined the impact force sustained while exiting different types of commercial vehicles (e.g., conventional tractors, trailers, truck and step van). Their results indicate that when a trucker use the FT technique, the impact forces are about 2 times lower than when using the BT descent (1.8 and 5.1 body weight (BW) for the FT and BT techniques, respectively). These results may have underestimated the real impact forces since the force plate and the surrounding wooden platform were 100 mm above the ground, thereby lowering the height of the steps and cabin with respect to the ground. Moreover, there was no indication on how the lower limbs and back were used to absorb these impact forces.

In the present study, the goal was to determine if the descent technique and the layout of the truck's cabin of two types of conventional tractors influenced the impact forces and affect the forces in the lower limbs (i.e., ankle, knee and hip) and back (i.e., the lumbar region of the vertebral column). By using a biomechanical approach, it is possible to estimate the amplitude and the distribution of the forces related to the technique used and/or the layout of the cabin.

2. Methodology

2.1. Subjects

Ten professional truckers (see Table 1) participated in this study and all signed a consent form prior to the onset of testing. The mean age of the group was 41.2 ($\pm$15.4) years with an average of 22.3 ($\pm$14.6) years of work experience. The average height of the truckers was 1.78 ($\pm$0.03) m while the mean weight was 877.5 ($\pm$255.3) N.

2.2. Experimental conditions and procedures

Two conventional tractors (either a recently fabricated cabin—Western Star (WS), 1998 or an older model—Ford 9000 (F9K), 1986) with different cabin layout (characteristics detailed in Table 2; see also

Table 1
Characteristics of the subjects

	Subjects	Age	Height (m)	Weight (N)	Experience (years)	Lower limbs force (N)
Group 1	1	53.00	1.85	1270.40	33.00	1373.40
	2	66.00	1.80	891.73	40.00	1569.60
	3	44.00	1.77	713.19	25.00	1765.80
	4	37.00	1.77	749.48	15.00	1962.00
	5	63.00	1.77	802.46	48.00	1128.15
	mean $\pm$ SD	52.60 $\pm$ 12.30	1.79 $\pm$ 0.03	885.45 $\pm$ 225.43	32.20 $\pm$ 12.83	1559.79 $\pm$ 326.10
Group 2	1	26.00	1.77	869.17	1.00	1765.80
	2	28.00	1.72	713.19	8.00	1275.30
	3	27.00	1.77	691.60	15.00	1373.40
	4	43.00	1.77	1404.79	23.00	n.a.
	5	25.00	1.80	669.04	15.00	1373.40
	mean $\pm$ SD	29.80 $\pm$ 7.46	1.77 $\pm$ 0.003	869.56 $\pm$ 309.35	12.40 $\pm$ 8.29	1446.98 $\pm$ 217.52
Total	mean $\pm$ SD	41.20 $\pm$ 15.38	1.78 $\pm$ 0.03	877.50 $\pm$ 255.32	22.30 $\pm$ 14.58	1509.65 $\pm$ 272.85

Table 2
Truck cabins characteristics[a]

Truck	Cabin	1st step		2nd step		Handrail				
	Height	Height	Depth	Height	Depth	Shape	Dimensions	Distance from cab	Length	Height of lowest point above ground
Western Star 98	1385	960	na[b]	535	125	Round	25	85	1060	1436
Ford 9000	1185	855	na	415	115	Rectangular	25 × 12	45	400	1821

[a] All values are in mm.
[b] Not applicable.

Fig. 1. Illustrations of the cabins used in this study: **(A)** Western Star 98 (WS) and **(B)** Ford 9000 (F9K).

Fig. 1) were used. The main differences between the cabin layouts were the dimensions of the handrails and the design of the steps (e.g., height, depth). All testing was done at the end of the work shift. Before the test session, the truckers were asked to step on the force plate in order to measure their body weight. Each trucker had to climb down from the same cabin four times, two for each descent technique (either facing the truck (FT) or back to the truck (BT)). The techniques were first described and then demonstrated by one of the experimenters. For the FT technique, the subject had to use both steps and the handrail during the descend. It is worth noting that with this technique the trucker maintains three contact points with the vehicle. For the BT technique, the trucker descended from the first step (i.e., upper one) and was restricted from jumping from the cabin level. The truckers were asked to do several practice trials of the two techniques. The subjects were assigned to begin with the different techniques based on the availability of the trucks. The first five truckers started their descent trials with the WS design while the other five began with the F9K model. The groups were determined to be homogeneous in terms of their anthropometric characteristics (see Table 1).

2.3. Data collection and analysis

2.3.1. Impact force measurement

Vertical (F_V), antero-posterior (F_{AP}) and medio-lateral (F_{ML}) components of the ground impact forces for the last step were measured with the aid of a force plate (AMTI model S6A6-4, Watertown, MA, USA) that was placed near the truck's cabin in such a way that it allowed the trucker's foot (i.e., the first foot) to contact the platform near its centre. If a trucker missed the force plate during the practice trials, the force plate was repositioned with its centre located at the centre of the area where the foot made contact with the surface. The force plate was fixed to a large steel plate in order to stabilize it and to avoid vibration artifacts in the recorded signal. A level wooden surface (1500×1500 mm) surrounded the force plate to increase the contact area and to limit the possibility of a trucker falling to the side of the platform.

Because of the height of the force plate, it was impossible to place its surface level with the ground. Thus the trucks were jacked up with a hydraulic lift and placed on blocks in order to preserve the normal height of the steps above ground level. The force plate was calibrated with a 500 N weight prior to each experimental session. The force plate signals were sampled at 1 kHz (Data Shuttle Express, Strawberry Tree Inc., Sunnyvale, CA, USA) and converted into Newtons (N) via equations preprogrammed in the acquisition system (Workbench, Strawberry Tree Inc., Sunnyvale, CA, USA) and filtered at 20 Hz (Butterworths, second order, 0 lag).

Five variables were calculated from the force plate data: (1) The impulse (Force $\times$ Time, expressed in BW $\cdot$ s), which gives the total amount of force dissipated by the ground. This was determined by calculating the area under the F_{AP} and F_V from the time when the subject first contacted the floor to the end of impact absorption (i.e., when the force level returned to BW, but prior to active push-off). By taking into account the subject's weight, it was possible to calculate the impulse resulting from the descent from the cabin. (2) The F_V, which was expressed in relation to the trucker's body weight (BW), was calculated. (3) The AP angle ($\theta_{AP} = \arctan[F_V/F_{AP}]$) and (4) ML angle ($\theta_{ML} = \arctan[F_V/F_{ML}]$) were used to indicate the trajectory of the body during free fall and the direction of the force exerted on the lower limbs at contact. (5) The time required to reach maximal vertical ground impact force (t_p) was used as a damping index for the force transmitted to the body. This damping is achieved mainly by the eccentric work of the extensors of the trunk, hip, knee and ankle (Zhang et al., 2000; McNitt-Gray, 1993; Devita and Skelly, 1992).

2.3.2. *Kinematic analysis and torque calculations*

A two-dimensional kinematic analysis of the descent from the cabin was done using a video based system. Passive reflective markers were placed over the shoulder (acromion), hip (greater trochanter), the knee, ankle (lateral malleolus) and the fifth metatarsal. The markers were placed on the trucker's boots and clothes with the aid of velcro elastic bands. The markers were placed on both sides of the body because of the possible visual obstruction caused by the opening of the truck's door. The camera (Panasonic Wv-BL 600, Matsushita Electric Industrial Co., Ltd., Japan) was oriented perpendicular to the axis of movement to avoid parallax error. The camera, which sampled at 60 Hz, was connected to a video cassette recorder and viewing monitor. A light source was placed along the camera axis and the opening of the diaphragm was adjusted to increase the contrast and optimize the visibility of the markers. The coordinates of the markers, which were obtained with the aid of Peak Performance software (version 3.0) (Peak Performance Inc., Englewood, CO, USA), were used to derive the linear and angular displacements and accelerations.

The kinematic data were synchronized with the normalized ground reaction forces in order to calculate the joint torques. The ankle, knee and hip torques were calculated using a 4 link-segment model and the equations described by Winter (1990). Then the compressive force at the L_5-S_1 level was calculated from the L_5-S_1 torque which was estimated from the hip torque based on the work of Chaffin and Anderson (1991) who reported that the L_5-S_1 torque was linearly related to the hip torque and that it represented 86.5% of its value.

In the present study, the kinematics of the upper limbs were not measured, hence the contribution of the lower limbs was calculated with the assumption that the upper limbs had been placed along the side of the body. Then the L_5-S_1 reaction forces were estimated from those obtained at the hip. Starting with the principle that masses over the hip and L_5-S_1 are accelerated vertically and horizontally in the same way, it was possible to calculate the vertical and horizontal L_5-S_1 reaction forces. For example, if we take the vertical joint reaction force at the hip and then divide it by the sum of the masses at the hip (i.e., pelvis, trunk, neck, head and upper limbs) we obtained the vertical acceleration. And since hip vertical acceleration is the same as that of the L_5-S_1 segment, we multiplied the acceleration by the sum of the L_5-S_1 masses (see Eqs. (1) and (2)). This logic was applied in order to determine the vertical (F_{Vh}) and horizontal (F_{Hh}) joint reaction forces:

$$F_{Vh} = a_V m_h, \tag{1}$$

where F_{Vh} is the vertical joint reaction force at the hip, a_V represents the vertical acceleration and m_h indicates the sum of the masses at the hip and

$$F_{VL_5-S_1} = (m_h - m_p)a_V, \tag{2}$$

where $F_{VL_5-S_1}$ represents the vertical joint reaction force at L_5-S_1 and m_p indicates the sum of the masses at the pelvis.

After the calculation of the vertical and horizontal joint reaction forces at L_5-S_1, the masses of the pelvis and the lower limbs were subtracted since they do affect the mass at L_5-S_1 as they are located below the first sacral vertebrae (S_1). Finally, the dynamic compressive force at L_5-S_1 was estimated based on information obtained from the work of Chaffin (1975). In order to calculate the compressive component of the joint reaction forces, the angle of the sacral plateau α (i.e., line joining the anterior superior iliac spine to the posterior superior iliac spine) with respect to the horizontal was obtained (Chaffin and Andersson, 1991). From there, the compressive force (F_C) acting on the sacrum could be estimated using

$$F_C = T_{L_5-S_1}/L_{ES} + F_{HL_5-S_1} \sin\alpha + F_{VL_5-S_1} \cos\alpha, \quad (3)$$

where $T_{L_5-S_1}$ represents the estimated L_5-S_1 torque, L_{ES} indicates lever arm of the Erector spinae (0.06 m; Chaffin and Andersson, 1991), $F_{HL_5-S_1}$ is the horizontal component of the joint reaction force at L_5-S_1, $F_{VL_5-S_1}$ is the vertical component of the joint reaction force at L_5-S_1 and α represents the angle of the sacral plateau.

2.3.3. Force measurement in the lower limbs

The test used to measure the force of the lower limbs was based on the work of Chaffin et al. (1978), and was somewhat similar to a "deadlift". The subject stood over a surface equipped with a handle attached to a force dynamometer (Shimpo, model FVG-500H, Nidec-Shimpo America Corporation, IL, USA). With the joints in a semi-flexed position, the subject tried to extend the lower limbs while pulling on the handle of the dynamometer which was fixed at 38 cm above the surface (i.e., an isometric contraction of the extensors).

2.3.4. Interview

A guided interview was conducted with each trucker in order to gain some insights into their work habits. The questions were based on a synthesis of the works of Laurent (1985) and Nicholson and David (1985) and the trucker had to simply answer by "yes" or "no". For certain questions, they had to elaborate to clarify the situation. Information, such as work experience and sensitivity to the problems related to the descent from the cabin, could be garnered from this interview.

2.3.5. Statistical analysis

An analysis of variance (ANOVA) was used to test differences within two independent variables (2 types of cabins × 2 descent techniques). A linear regression analysis was used to determine the relationship between maximal lower limb strength and the other measured variables. All statistics were done using the software Statsgraphics for Windows (Manugistics Inc. Rockville, MD, USA) and the significance level was set at 5% ($\alpha = 0.05$).

3. Results

3.1. Impulse and impact forces

The way in which the trucker descended from the cabin greatly influenced the impulse ($F_{1,18} = 10.21$, $p<0.05$). Fig. 2A shows that the impulse was greater when the trucker used the BT technique compared with the FT descent. Furthermore, the cabin layout affected the impulse with the F9K cabin resulting in greater impulses irrespective of which descent technique was used.

The impact forces were also affected by the descent technique and cabin layout. The vertical impact force was greater either when the trucker descended while using the BT technique or while he came down from the F9K cabin ($F_{1,19} = 6.81$, $p<0.05$) (Fig. 2B). Forces in the AP and ML directions were quite small and they were not influenced by either the descent technique and cabin layout (not shown in the figure).

The θ_{AP} was altered by the descent technique ($F_{1,14} = 8.32$, $p<0.05$) (Fig. 2C). The trucker landed with a more vertical θ_{AP} when using the FT technique ($79.8^\circ \pm 2.3^\circ$) compared with the BT descent ($71.7^\circ \pm 2.0^\circ$). In contrast, the descent technique had the opposite effects on the θ_{ML} (Fig. 2D), with the BT descent resulting in a more upright landing angle ($82.3^\circ \pm 1.1^\circ$) compared with that produced by using the FT technique ($78.2^\circ \pm 1.2^\circ$). The cabin layout had no significant effect on either the resulting θ_{AP} or θ_{ML}; however there was a tendency for the F9K to produce a slightly more vertical F_{ML}.

Fig. 3 shows that the FT technique resulted in a greater t_p compared with the BT descent (226.31 ± 69.89 vs. 103.57 ± 62.16 ms, respectively) ($F_{1,19} = 7.51$, $p<0.05$). The cabin layout also affected the t_p with WS (218.96 ± 69.89 ms) being higher than the F9K (110.92 ± 62.16) ($F_{1,19} = 5.82$, $p<0.05$). Upon closer examination of the data, one can see that the differences were mainly due to high t_p for the FT descent from the WS, with all other t_p being relatively similar.

3.2. Torques and compressive forces

The descent technique affected the L_5-S_1 torques, but not the ones at the hip, knee and ankle (Fig. 4). The L_5-S_1 torques were greater when using the BT descent (96.63 ± 7.83 N m) compared with the FT technique (68.27 ± 8.76 N m) ($F_{1,14} = 156.08$, $p<0.05$). Similarly, the cabin layout affected the hip torques with the F9K (111.19 ± 11.43 N m) cabin resulting in greater values compared to the WS truck (76.56 ± 13.6 N m) ($F_{1,14} = 7.17$, $p<0.05$). Also, although not significant at the 0.05 level, there was a tendency for the knee torque to be greater when descending from the F9K cabin. In contrast, the cabin layout had no influence on the torques of the ankle, and L_5-S_1.

As with the torques, the descent technique influenced the compressive forces at the L_5-S_1 level ($F_{1,14} = 84.00$, $p<0.05$), while the cabin layout had no effects (Fig. 4E). The compressive forces at the L_5-S_1 level were greater when descending while using the BT technique (2297.02 ± 129.69 N) compared with utilizing the FT descent (1543.75 ± 145.06 N).

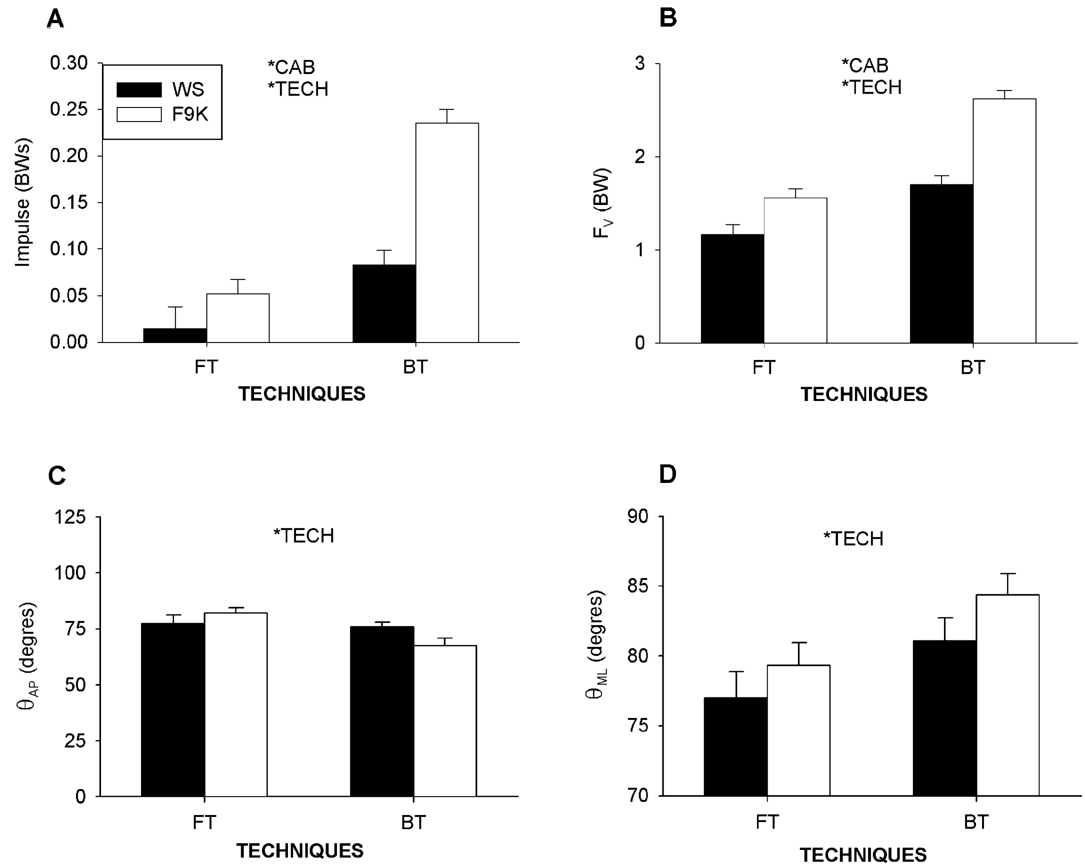

Fig. 2. Mean and standard error for the impulse (A), the vertical impact force (F_V) (B), the angle of the force in the antero-posterior plane (θ_{AP}) (C), the angle of the force in the medio-lateral plane (θ_{ML}) (D). FT represents the descent technique whereby the trucker faces the truck's cabin while BT stands for the technique whereby the trucker's back is towards the cabin. The solid and empty bars represent the WS and F9K cabins, respectively. Significant differences ($p<0.05$) for the cabin layout and descent technique are indicated by *CAB and *TECH, respectively.

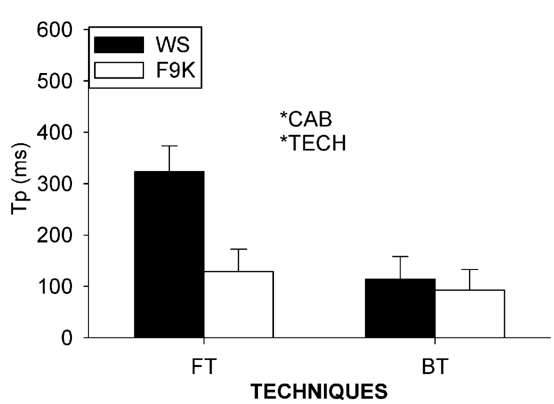

Fig. 3. Mean (±standard error) vertical impact force times to peak (t_p) (see legend in Fig. 3).

3.3. Lower limb strength

The mean maximal strength of the lower limbs was 1476.5 (±277.6) N (see Table 1). It is worth noting that there was no correlation between the trucker's weight and the lower limbs strength ($R = 0.32$, see also data in Table 1). Correlations were done in order to see if there was a relationship between lower limb strength and vertical impact force (F_V) and time of application of the vertical force (t_p). The correlation between the subjects' maximal lower limbs strength and vertical impact was very weak for both the FT ($R = 0.49$) and BT ($R = 0.46$) techniques. On the other hand, the correlation between the maximal force of the lower limbs and the time of application of the vertical force was significant for both the FT ($R = 0.79$, $p<0.05$) and BT ($R = 0.63$, $p<0.05$) techniques.

3.4. Information from the interview

The truckers worked, on average, 10.5 (±1.41) h per day, during which time they did 25.38 (±15.44) descents from their cabin. In 75% of the cases, the truckers declared that the truck cabin layout was all right and did not need any major modification. One out of 2 truckers maintained that he could not see where to place his feet during the descent. The steering wheel was used by 75% of the truckers during the descent. Only one trucker

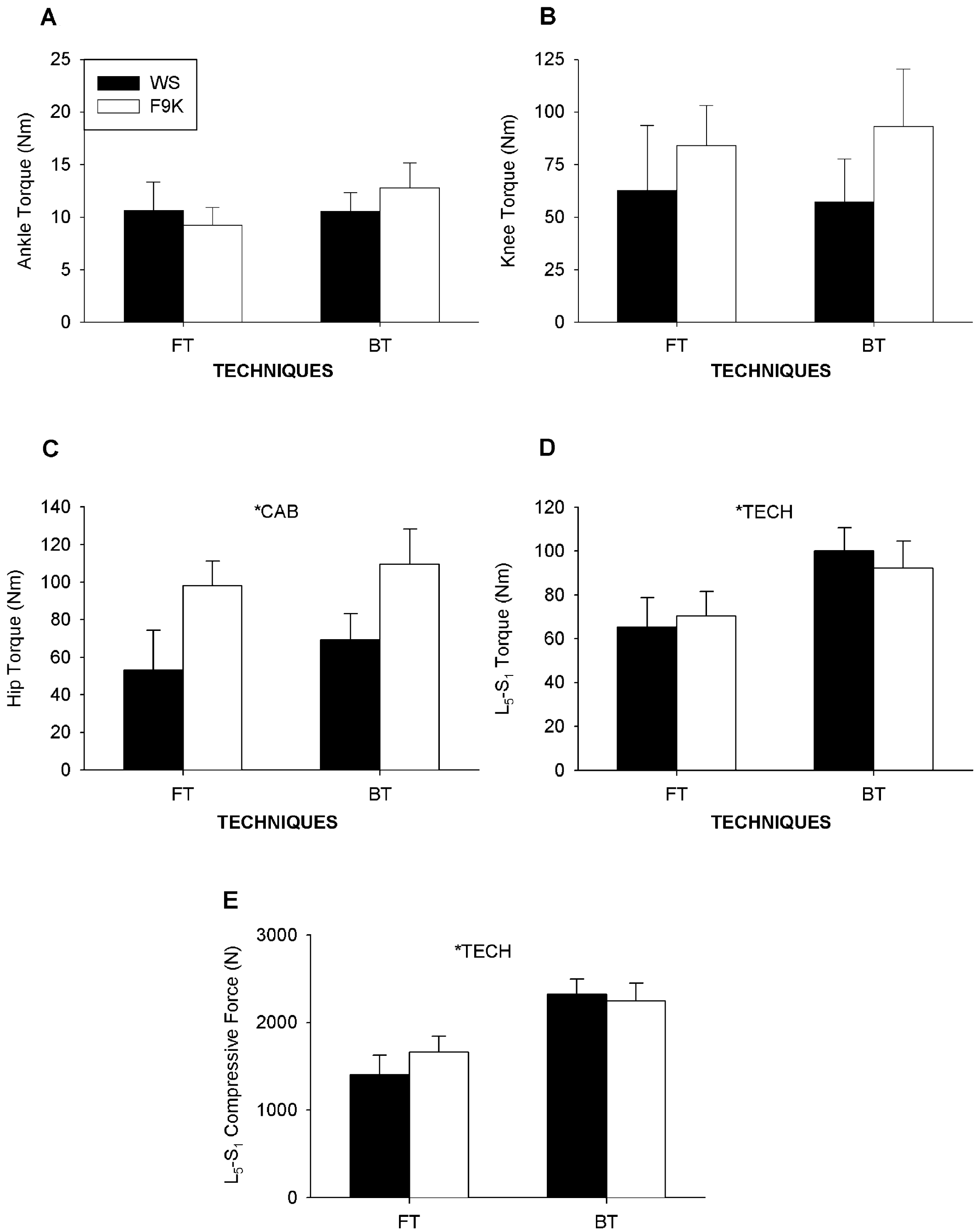

Fig. 4. Mean (±standard error) torques for the ankle (A), knee (B), hip (C) and L_5-S_1 (D). The compressive forces at L_5-S_1 are shown in (E) (see legend in Fig. 3).

confirmed that he used the BT technique while descending from his truck during his work. Nearly one-third (37.5%) of the truckers declared that they fell during a descent but none of the falls resulted in injuries. Finally, all the truckers affirmed that environmental factors (e.g., rain, snow and ground characteristics) could increase the risk of injuries during the descent.

4. Discussion

During the descent from the cabin, the ground impact force could reach mean values that were 1.36 and 2.16 times body weight for the FT and BT techniques, respectively. These differences can be explained by the fact that during the FT technique, the truckers use the necessary supports while descending. During the descent, the trucker slowed down the drop by holding the handrails and handles with the upper limbs. Moreover, the limb contralateral to the ground support side rested on the last step of the cabin. The hip and knee extensors of this limb could slow the descent by doing eccentric work, and thus, decrease the speed of the drop and proportionally reduce the ground impact force.

The impact forces while using the FT technique were quite similar to those obtained by Fathallah and Cotnam (2000). In contrast, for the BT technique, their results were about twice as high as those observed in the present study. This difference was not due to the height of the steps since they were about the same in both studies. One possible explanation may be that in the present study, the truckers all made one foot landing while this may not have been the case in their study. In a one foot landing, the contact limb must support all of the impact whereas in a two foot landing, both limbs can share the impact equally. The differences in the impact forces between the two studies may be related to the instructions given to the subjects prior to the descent. In the present study, the subjects were told not to jump during the BT technique. It was not clear if this was the case in the study by Fathallah and Cotnam (2000). Another explanation may be the boots used by the truckers. In the present study, the subjects used their work boots which were flexible and with which they felt comfortable whereas, in their study, Fathallah and Cotnam (2000) had subjects wearing new work boots which may have been slightly stiffer, thereby resulting in greater impact forces.

The results of the θ_{AP} showed that the FT technique produced a more vertical trajectory than the BT descent (79.8° and 71.7°, respectively). A θ_{AP} that approaches vertical (90°) means that the body's centre of gravity is more likely to be located over the base of support. On the other hand, as the θ_{AP} deviates from the vertical ($<90°$), the footing is compromised and the risk of fall due to slippage (either forwards or backwards) increases. This is the case for the BT technique, but more importantly, the trucker cannot use his upper limbs and the handrails to compensate for the possible imbalance. Hence, the FT technique is much safer because of the more erect landing and better use of the upper limbs. However, in order to use this technique to its fullest potential, handles should be replaced by handrails and their placement should be optimal (i.e., the trucker should be able to maintain contact with the handrail until the feet are in contact with the ground). Obviously, the use of proper handrails would not only help the descent but it would also facilitate the climb into the cabin. It is interesting to note that the minimal point of the handrail for the F9K truck was 1821 mm which was higher than the average height (1780 mm) of the truckers in the present study.

The amount of impact absorption by the extensors of the hip, knee and ankle during the descent is generally reflected by the shape of the impulse generated (Zhang et al., 2000; McNitt-Gray, 1993; Devita and Skelly, 1992). For example, if the impulse duration is short and the force is elevated, this would tend to indicate that the subjects are likely not using their lower limb muscles to absorb the ground impact. It is principally the bony structures that absorb the transmission of this ground impact force. When the transmission is very rapid, the risks of injuries are higher (Nigg and Herzog, 1994). As suggested above, during the FT technique, the trucker can slow down the descent and thus decrease the impulse by using the upper limbs. Also, this technique allows the trucker to use the contralateral limb to brake the descent since the foot of that limb is still on the last step as the ipsilateral foot strikes the ground. Obviously, by using this technique, in which the impact forces are lower, one would decrease the risks of musculoskeletal injuries (Lafortune et al., 1995; Chu et al., 1986; Yoganandan et al., 1997; Dufek and Bates, 1991; Ferreti et al., 1992).

The torque results demonstrated that whatever descent technique is used, the absorption of the ground impact force is done principally at the hip and the lumbosacral region of the vertebral column (L_5-S_1). However, the technique has some effect on the compressive force at the L_5-S_1. The compressive force at the lumbar vertebra is greater during the BT technique compared with the FT descent. This increase is likely due to the combination of high ground reaction forces with the high horizontal and vertical trunk acceleration and the orientation of the trunk at ground contact. The trunk extensor muscles must contract to stabilize the torso at ground contact. The FT (i.e., three points of support) technique considerably decreased the ground impact force as well as the horizontal and vertical trunk acceleration (not shown), which means that the compression at L_5-S_1 is going to be much less. The present results indicate that the frequent use of the BT technique can expose the trucker to greater risk of musculoskeletal injury at the lumbar level.

It should be noted that the highest average L_5-S_1 compressive force calculated for the BT technique (2297 N) in the present study is within the NIOSH limits of 3400 N (Waters et al., 1993). More importantly, these values were obtained at the end of the work shift in which the truckers perform on average 25 descents per day. The high number of descents is likely to have an influence on the capacity to continually absorb the impact force.

The subject's weight influenced the ground impact force during the descent from the cabin. Our results also showed that an increase in the subject's weight was not associated with a concomitant increase in the strength of the lower limbs. Thus, the greater the impact forces of heavier subjects can be problematic since their muscles are often not capable of absorbing that force. Consequently, heavier subjects are more vulnerable to musculoskeletal injuries since the muscles can be overloaded during the absorption of the ground impact force.

In addition, the lower limbs strength influence the dissipation of the vertical impact force component over time. In other words, the lower limbs strength has an effect on the transmission times of the forces rather than on the quantity of force transmitted to the ground. Thus, weaker subjects are more likely to have a lower capability for absorbing the impact force and hence have higher risks of musculoskeletal injuries (Nigg and Herzog, 1994; Atkinson and Haut, 1995; Lotz and Hayes, 1990). However, the results of the lower limb strength could be influenced by those of the upper limbs and the trunk. In fact, this test can be limiting for subjects who have weak upper limbs or for those who have back problems.

Based on the results of our interview, the truckers appear to be satisfied with the layout of the cabin. On the other hand, it appears that the layout is not totally adequate to facilitate a descent without risks of injuries. One half of the subjects stated that they could not see where they placed their feet during the descent from the cabin. This uncertainty can provoke some instabilities and increase the risk of falls particularly if obstacles such as a gas tank cap (see Fig. 1B), decorative running boards or icy steps are present.

Another factor which suggests that the layout of the cabin is inadequate was that 75% of the truckers stated that they use the steering wheel as support during the descent. The steering wheel is not conceived to be used as a handle. The frequent absence or the poor design of a handle inside the door on the driver's side could be one of the main factors that the truckers use the steering wheel as a support. Hence improving the handle location and orientation inside the driver's door could avoid usage of the steering wheel as support. Moreover, insuring that the door, inside which the handle is installed, is prevented from moving (i.e., fixed at a certain angle) would help to optimize handle usage as opposed to steering wheel utilization.

In this study, it was difficult to fully evaluate the biomechanical constraints encountered during the descent from the cabin in real work situations. The truckers participated voluntarily in the study and the goal had to be explained to them. By knowing the goal of the study, some subjects may have altered their behaviour when they were being evaluated.

Other methodological limitations of the present study stem mainly from the kinematic analysis. Two-dimensional analysis was used to examine the task and only movements in the sagittal plane could be observed. Also, in our two-dimensional kinematic analysis, the upper limb displacements were not measured. It was assumed that upper limbs were parallel to the body during the descent when calculating the L_5-S_1 torque. This undoubtedly neglected the contribution of the upper limbs and the forces exerted by the hand on the handrail on the L_5-S_1 forces. Another limitation is the estimation of the L_5-S_1 segment which was based on the location of the hip with respect to the shoulder.

5. Conclusions

Despite certain methodological limitations, the results of this study cannot confirm with certainty that the use of the BT descent technique for coming down from a F9K type cabin can cause more stress on the lower limbs and back. In contrast, the results of this study demonstrated that the BT technique produces greater impact forces than the FT descent, particularly if the truck does not have a handrail or that it is too short. A handrail that is long enough and properly placed would allow the trucker to reach the ground while still using the upper limbs to guide, stabilize and resist the descent. This lack of proper handrail can also increase the compressive forces in the lumbar region and hence, augment the risks of lesions to the intervertebral discs (Nigg and Herzog 1994). The use of the FT technique allows for a more upright landing, thereby reducing the risks of fall and slippage. Finally, the truckers should be instructed to use the FT technique with the aids (i.e., handrails and all the steps) whenever possible to help lower the landing impact forces.

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