POSSIBLE HEAD IMPACTS FOR STANDING PASSENGERS IN PUBLIC TRANSPORTATION
- INFLUENCE OF AN OBSTACLE ON THE PASSENGER KINEMATICS -

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THE SAFETY OF STANDING PASSENGERS IS A MAJOR CHALLENGE for the development of public transportation (Pereira et al., 2001). One of the key issues is related to minor but frequent incidents. De Graaf and Van Weperen (1997) reported that in the Netherlands, out of 2300 persons arriving in one year to an Emergency Department after an incident in public transportation, 1200 of them were injured in an incident without collision. Recent surveys on transport safety (Pereira et al., 2001; Björnstig et al., 2005; Halpern et al., 2005) confirmed that the most exposed passengers are the standing passengers: they suggest that even slight incidents such as emergency breaking or light collisions can cause injuries because they can induce important losses of balance and large motion, which may lead to secondary impacts with other occupants or interior equipments.

Factors such as the increasing number of vulnerable passengers due to the overall ageing of the population, the increasing proportion of standing passengers, and the apparition of new, complex, traffic situation (e.g. hybrid train-trams) are likely to make this issue even more critical.

While this problem would be difficult to solve in general, the development of countermeasures is currently limited by the relative lack of knowledge of the motion of standing passengers associated with minor incidents. A first priority would be to study the risks of impact to the head since this segment is the most frequently injured (Pereira, 2001 et al.; Björnstig et al., 2005; Halpern et al., 2005).

In a previous study (Robert et al., 2007), 10 volunteer subjects were placed in situations representative of public transportation incidents. Their balance recovery was measured and analyzed in terms of 3D head trajectory; maximal head excursion; corridors of the head tangential velocity versus the head position. As a first approximation, these data could be used to predict the risks of impact between the head of passengers and their surrounding environment, and thus could help designers to improve future interior layouts with regard to the standing passenger safety. However, one of the limitations of this study was that there was no obstacle in the trajectory of the passengers. The presence of such an obstacle – which is expected in a real injurious incident – could influence the reaction from the subjects and thus the head kinematics.

For the current study, complementary experiments performed with 4 free standing subjects were analyzed in order to highlight the possible effects of an obstacle on head kinematics. The obstacle was simulated by elastic ropes that were positioned in front of the subjects at a distance corresponding to their maximal balance recovery performance. Each subject was submitted to two different levels of perturbations.

MATERIAL AND METHODS

TEST SET-UP: The experimental setup was the same as the one previously described in (Robert et al., 2007). Only key elements will be repeated here. At first, subjects were standing quietly on a platform. They were isolated from the sounds of the laboratory by headphones and an operator was asking them a succession of short questions in order to distract them from the balance recovery. Then, without any warning, the platform was suddenly translated toward the back of the subject (cf. Fig 1). A harness was used in order to prevent the risk of fall onto the ground or out of the platform. In order to ensure the surprise effect, the order of the trials was also randomized.

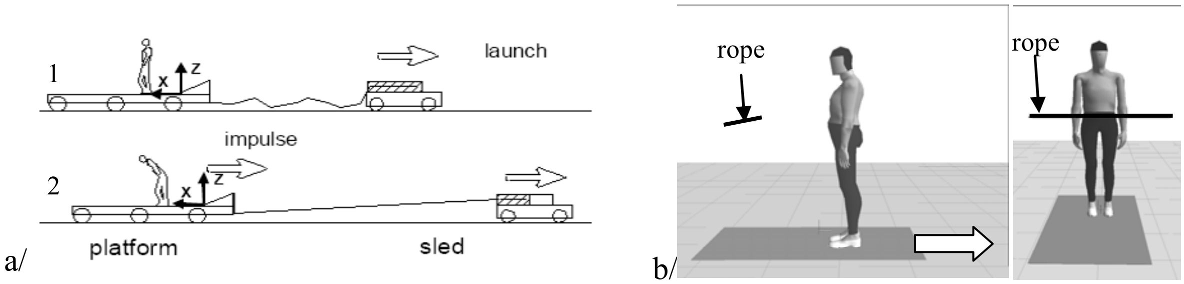


Fig 1: Experimental set-up. The subject is standing on a still platform which is suddenly pulled backwards (left). He is instructed to avoid touching the rope located 80 cm in front of him (right).

The four subjects participating to this experiment were selected in the pool of subjects from a previous study (Robert et al. 2007): they were young males (26.2 ± 3.3 years hold), with an average stature (177 ± 3 cm) and weight (73 ± 3 kg), and they never had equilibrium troubles or any medical interventions on the lower limbs. It was verified that the response of these subjects during the previous experiment was not atypical.

Two platform acceleration pulses were tested. Both were half sinusoidal, with durations of approximately 400 ms and maximum accelerations of 2 m/s² and 10 m/s² respectively (Robert et al. 2007). Those were defined in the EC funded SAFETRAM project (SAFETRAM, 2004) to be equivalent to an emergency braking situation and a low severity collision respectively.

Two elastic ropes going across the platform were positioned at 15 cm or 80 cm in front of the subject for the lowest and highest perturbation respectively. These distances were selected to match the maximum performance level (stopping distance) estimated during preliminary experiments. The heights of the two ropes were approximately 30 cm and 110 cm. The subjects were instructed to restore their balance before reaching the ropes.

The protocol was approved by the regional ethical committee (CCPRB, 2004).

MEASUREMENTS AND DATA PROCESSING: The kinematics of the balance recovery was recorded using a Motion Analysis® opto-electronic system. Fifty reflective markers (25mm spheres) were placed on specific external points of the volunteers. A 3D inverse kinematics methods and a numerical dummy, both adapted to these motions (Verriest, 1998; Robert, 2006), were used to compute and represent the whole body kinematics. Joint angles were low-pass filtered using a Butterworth 2nd order zero lag filter. Cut-off frequencies between 7 Hz and 20 Hz were automatically determined by a residual analysis method (Winter, 1990).

The head kinematics was reduced to the motion of its Centre of Mass (CoM). The tangential velocity was obtained by differentiation of the CoM coordinates. As in the previous study, the head kinematics was only analyzed along the longitudinal axis (X-axis). The maximal excursion of the head was then computed as the maximal X-coordinate of the head CoM during the movement.

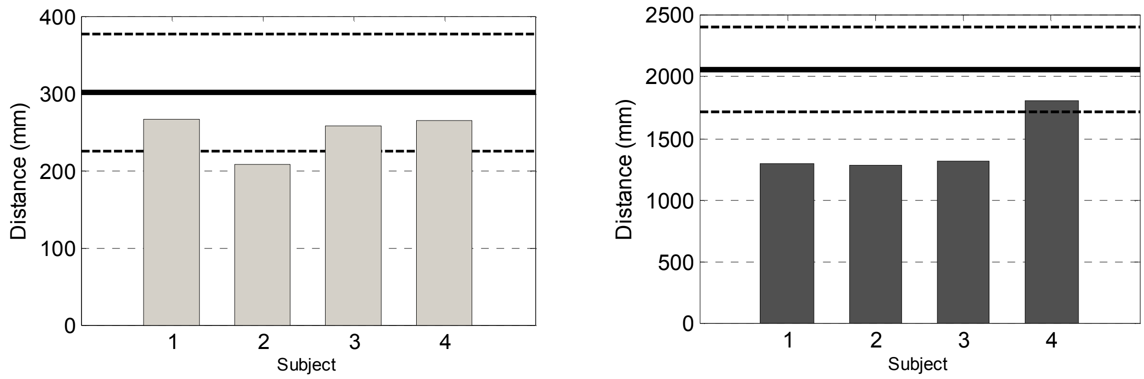
The experiments were analyzed in terms of head maximal excursion and head tangential velocity versus X displacement curves. In order to highlight the influence of the obstacles, the results were compared with the results obtained in the previous study (without obstacle).

RESULTS

One subject managed to stop just before contacting the rope in every case. Two subjects (#2 and #3) slightly touched the rope in the low acceleration case, and one subject (#4) could not respect the instructions and walked through the ropes for the high acceleration situation. Except for this last case, the overall subject to subject variations were relatively limited.

MAXIMAL HEAD EXCURSION: The histograms on Fig. 2 compare the head maximal excursion observed in the current study with the previous results from Robert et al (2007). The presence of an obstacle (the rope) limited the head excursion of the subjects for both levels of perturbation: in the case with rope, the mean excursions were 249 mm and 1425 mm for the low and high perturbation respectively, while the corresponding values without rope were 301 mm and 2060 mm. The subject (#4), who could not restore his balance before touching the rope in the high acceleration case, had in consequence a higher head excursion than the other subjects. However, it remained lower than the average from the previous study (without rope).

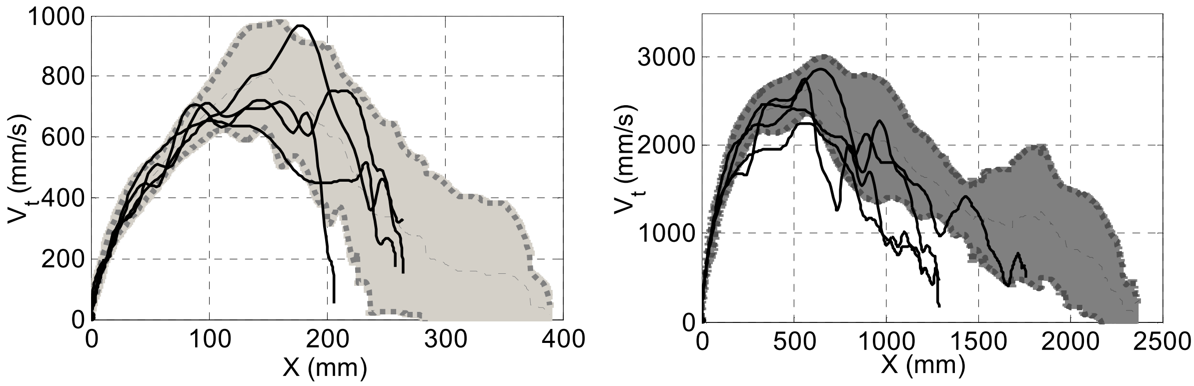
In general, the obstacle limited the subject to subject variations of the head excursion. This is especially noticeable on the responses of the subjects 1, 2 and 3 to the high acceleration pulse. We can also notice that the head excursions (e.g. 1425 mm in average for high acceleration cases) are larger than the initial distance to the rope (800 mm for high acceleration cases). One explanation for this is that the higher rope being at 110 cm above the ground, the trunk can flex over the rope without touching it. The subjects can therefore respect the instructions (not touching the rope), while their head excursion is larger than the distance to the rope.



low perturbation high perturbation

Fig 2 - Maximal head excursion of the four subjects in case of low perturbation (left) and high perturbation (right). Note the difference of amplitude between the two graphs. The thick solid and dashed lines represent the average and standard deviation of the head excursion observed in previous study (Robert et al., 2007) using the same experimental situations but without the obstacle. Subjects of this experiment were taken from the pool of subjects participating to previous study.

TANGENTIAL HEAD VELOCITY AGAINST ITS X DISPLACEMENT: The fig 3 represents the tangential head velocity versus the X displacement for the four subjects, superimposed with the corridors obtained in the same experimental situation without the obstacle.



low perturbation high perturbation

Fig 3 - Tangential head velocity against head X displacement for the 4 subjects (black solid lines) in case of a low level of perturbation (left) and a high level of perturbation (right). Note the difference of amplitude between the two graphs for both X and Vt axis. The grey corridors plotted in the background were obtained in the previous study (Robert et al., 2007) using the same experimental situations but without the obstacle. Subjects of this experiment were taken from the pool of subjects participating to previous study.

For the four subjects, the peak velocity and the X location of the peak velocity were nearly unaffected by the obstacle: for the high acceleration case with obstacle, the mean peak velocity and X location of the peak were 776 mm/s and 143 mm respectively, while they were 799 mm/s and 143 mm without rope. The velocity vs. displacement curves mostly remained within the corridors obtained without obstacles before the peak, but more differences were visible toward the end of the motion in relation with their lower maximal head excursion. However, these differences remained limited, especially for the low amplitude perturbation.

DISCUSSION AND CONCLUSIONS

In this study, the effect of an obstacle on the kinematics of standing volunteers subjected to sudden accelerations could be observed and quantified. Caution should be used when interpreting the results as the number of volunteers was very limited (four). However the fact that similar effects were observed on all four volunteers is encouraging and the addition of more volunteers in future studies is expected to confirm the current results. Another limitation of the current study was the extreme simplification of the obstacle (two elastic ropes). Future study should evaluate the influence of different obstacles that are more representative of an actual interior, including the presence of obstacles in front of the head of the subjects.

Despite all those limitations, the first results obtained in this study indicate that: 1/ the distance to stop decreases in presence of an obstacle; 2/ but that the main part of the head kinematics is only slightly affected. More specifically, the influence of the obstacle on the peak head velocity is almost non-existent, both in terms of amplitude and location.

Even if more experimental data are needed, the results of this study tend to confirm the hypothesis made in the previous study, which was that the balance recovery observed without obstacle were close to represent the maximal performance of the subjects. Therefore, this study tends to suggest that the results without obstacle (Robert et al., 2007) can reasonably be used even if an obstacle is located in front of the subjects.

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