Real car versus driving simulator comparison of head dynamics in emergency braking events

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***Abstract** – This paper presents a pilot study which aims at comparing the results of dynamic ranges of motion made in real conditions versus virtual conditions. Whiplash remains a big socio-economic issue and the need to implement virtual reality to better understand the head stabilization strategies is here spelled out. To do so, we proposed two experiments in which subjects are seated on the front passenger seat and are subject to a given deceleration. The vehicle accelerates to a given speed, maintain its speed for a short time then proceed to the braking event which is either a custom one or the natively equipped emergency automated braking system. Range of motion and acceleration of the head are recorded. The final goal of the study is to replicate the experiment on a hexapod driving simulator. We expect the results of this replication to legitimate the comparison between results from real tests and results obtained using driving simulators. Doing such tests should reduce their human and technical costs and give a better knowledge of the participant cognition by the perfect control of the visual environment.*

***Keywords:** Whiplash, braking, virtual reality.*

Introduction

Whiplash

Whiplash is usually defined as a combination of hyperextension and hyperflexion of the neck resulting in a wide range of injuries with various gravity degrees: neck pain [Bon00], headaches [Dro03], neck stiffness [Dal01], reduced neck range of motion [Arm05] and proprioception disorders [Heik98].

Whiplash remains a huge health and socio-economic issue. It costs 10 billion euros a year in Europe [Cas97]. More than half of the total car accidents are rear-end car crashes [Rev04]. These types of accident are known to be favourable to result into whiplash injuries and 85% of the reported whiplash injuries indeed result from rear-end accidents [Yog02].

Many studies have been investigating the mechanism of whiplash. Considering the epidemiology evoked above, whiplash and more generally head stabilization have been traditionally studied with *in-vivo* volunteers subject to linear accelerations on sleds on which they are seated. Their dynamic response is then recorded using inertial measurement sensors. However, the whiplash mechanism is still not completely understood [Lap16] [Che09]. Many factors must be considered. These factors can be divided into passive factors and active factors.

Influencing factors

Women are twice more exposed to whiplash injuries [Ono06], [Min00]. This is usually explained by geometrical arguments. A few of them are: a different alignment of the cervical spine between women and men [Ono06], the dimensions of the head are higher relatively to the neck for women resulting in higher solicitations of the neck during accelerations [Vas08], additionally neck muscles of women are usually less strong than men ones [Hil08]. These explanations highlight the high interindividual variability which exists also between individuals of the same gender. More generally, anthropologic studies have shown the variability in terms of weight, size, gravity center location and inertia moment of the human body segments [Mcc81].

Cognitive factors explain also a lot of the dynamic response of a human subject exposed to a sudden acceleration. Sandoz *et al.* have shown that the neck movement of subjects is reduced with a precontraction of the neck muscle or closed eyes during the event [San16]. Thus, muscle activity is also a key factor during the deceleration event for the neck response. Cognitive factors influence the neck muscles response's, Hazlett *et al.* revealed that the muscular tonus is higher among participants that have been exposed to a stressful stimulus. Blouin *et al.* have shown that men and women have a significatively different muscular activation temporality. The team also demonstrated the effect of a loud sudden sound prior to the acceleration event on the muscle activation and the effect of the startle reaction which happen during the very first exposition to the event [Blo06]. According to Blouin *et al.,* the startle has a higher effect on the dynamic response than the unknowledge of the event [Blo06].

In light of the above, one can imagine the importance of the cognition of a vehicle occupant's during a crash on their head/neck response. Additionally, with the increasing automation of our vehicles, a new categorization of car-crashes injuries may arise, as reported in [Sub17].

In particular, one can assume that the energy implied in crashes is likely to be reduced as one can expect the autonomous car to be more reactive than the human-being. As reported by Segui-Gomez *et al.* and Castro *et al.*, whiplash injuries are most common in medium-severity car crash (mostly because at higher speeds, more serious injuries happen) [Seg00] [Cas97]. Thus, the number of whiplash in car crashes will possibly get bigger in the future.

Moreover, the attention of the occupants will be less focused on the road as they will be given the possibility to do other activities during travels. This will most likely result in the occupants less aware of their external environment and in their head/neck dynamic response to differs.

Considering the above, we can assume the need to better understand the head stabilization strategies of the human-being. To this end, Virtual Reality (VR) appears a great tool: it enables to modify the visual environment and thus the cognition of subjects. As far as we know, no research team has previously studied the head dynamic response using VR.

Virtual reality

VR and more particularly driving simulators allow to set the visual environment of volunteers while simulating a car travel. However, VR has its own inherent problematics such as simulator sickness or presence. Simulator sickness refers to a range of symptoms that may appear among subjects after a certain duration of exposition to a virtual simulator. The Simulator Sickness Questionnaire (SSQ) allows quantifying the level of sickness of subjects during an experiment [Ken93]. Simulator sickness is known to change postural stability [Häk02]. We can assume that simulator sickness may have an impact on the head stabilization strategies.

Presence can be defined as the sense of being here [Sla94]. Presence conditions how subjects will act in a simulation. The higher the presence, the more naturally they will act. Presence is thus a subjective feeling, but presence questionnaires provide a way to quantify the feeling of presence of the participants [Wit98]. As presence influences the way subjects respond in an experiment, we can assume that presence may also influence the head/neck dynamic response in whiplash studies.

Considering the potential impact of simulator sickness and presence on the head stabilization strategies of subjects during experiments, one can wonder if we can legitimately compare results from real tests with results from a virtual simulator. Using VR in whiplash studies should simplify the design of the study by reducing the human cost and the technical means of such tests. Thus, the goal of this study is to permit a comparison between data from real tests with data from tests which use virtual environments. Here, only the methodology of the second part of the experiment will be presented as the results are not yet available.

Methods

The study is divided in two different parts. The first one used a real car for the braking event. The results presented here will be compared with those from a second experiment, which will use a 6-axis driving simulator.

Angle and acceleration measures

To quantify the dynamic response of our subjects, we equipped them with Inertial Measurement Units (IMU) which are composed by three accelerometers and three gyroscopes. This allow us to record the acceleration and the orientation of the IMU in a global

Figure 1. SAAM: hexapod driving simulator

frame. Three IMU are set on the subject. The first one is set on the top of his head with a headset. The two others are set on the T1 and S1 vertebras. Head acceleration and relative angles are processed.

Relative angles (Head/T1 and T1/S1) are defined as Euler angles.

Trials on the vehicle

Ten healthy male volunteers took part in the present study (Mean±SD: 35±13 y.o., 179±4 cm, 77±3 kg). Three inertial measurement units (IMU, Xsens) were placed on the subjects as previously reported. A fourth IMU was attached into a rigid part of the car to record its kinematics. The head acceleration and the relative angles were processed and synchronized with the vehicle braking.

Subjects were seatbelted with a 3 points seatbelt at the front passenger seat and asked to look forward in a car natively equipped with an automatic emergency braking (AEB) system triggered when the car approach a dummy which is detected by the stereovision detection system. Two different speeds (8 and 15 $km.h^{-1}$) combined with two braking deceleration conditions were tested and randomized. Each of the 2x2 conditions was performed three times for a total of 12 trials.

Braking was achieved either using the native AEB of the car triggered the stereovision system or by a “pedal robot” unexpectedly triggered by a back-seat passenger operator. The pedal robot was developed and used to precisely reproduce a human-like braking behavior, from deceleration curves registered in a previous work [San18]. The maximum AEB deceleration reached 1 to 1.3g while the human-like braking reached 0.5g. The human-like braking is triggered by an external operator while the AEB is trigger when the vehicle is close enough from a car crash dummy. An audible signal is generated one second before the AEB is triggered.

The level of linear deceleration was chosen to be reproducible on a hexapod driving simulator.

Trials on the simulator

The second part of the study will include 15 similar volunteers in a car simulator. The test carried out into the real car will be reproduced in VR thanks to the data recorded by the fourth IMU during the experiments. The driving simulator (SAAM) is composed by a real car cockpit set on a hexapod and by a cylindrical screen surrounding 150° of the passenger’s field of view (Figure 1). Using this kind of simulator is important for us as they involve a higher presence on subjects which we believe is an important parameter for our future experiments.

A large variety of movements is made possible by the hexapod. Table 1 summarize the amplitude, velocity and acceleration allowed according to the degree of freedom.

Table 1. Characteristics of the SAAM

DOF	Displacement	Velocity	Acc.
Heave	±0.178 m	±0.3 m/s	±0.5 g
Surge	±0.259 m	±0.5 m/s	±0.6 g
Sway	±0.259 m	±0.5 m/s	±0.6 g
Pitch	±22 deg	±30 deg/s	±500 deg/s^2
Roll	±21 deg	±30 deg/s	±500 deg/s^2
Yaw	±22 deg	±40 deg/s	±400 deg/s^2

Subjects will be proposed an SSQ and a presence questionnaire after the experiment.

The recorded kinematics of the vehicle will be used to pilot a dynamic platform using a tilt coordination algorithm. The goal will be here that the acceleration felt by the occupants is the same than it would have been in reality with the same kinematic conditions. An IMU will be attached to a rigid part of the cockpit of the SAAM to ensure that the acceleration is the same than the acceleration recorded in the vehicle. Results from the second part of the study will be the acceleration recorded on this IMU to validate that we were able to reproduce the same kinematics conditions and a comparison with the results from the first study in terms of head/neck dynamics.

The virtual environment will be reproduced. The trials conditions (auditory signal, visual cues) will also be reproduced.

Results

The results from the first part of the study have been processed. Figure 2 shows the acceleration of the different IMUs during a trial (8km/h and pedal robot braking): car, S1, T1 and the head. The IMUs allow us to access the temporality and the different levels of acceleration. S1 then T1 and then the head reach its peak according to the graph, this correspond to the wave propagation starting from the seat of the passenger to his head.

The evolution of the accelerations of each IMU has also been investigated, particularly the IMU set on the head's subject as it can be an injury criterion [Hil08]. We introduce the Range Of Motion (ROM), which stands for the difference between the maximal and minimal relative angle between the IMU on the head and the IMU on T1. Figure 3 shows the evolution of this relative angle during a trial. Only the car acceleration is signed to show the braking event. This quantity is widely used in the literature [San16] [San18] [Blo06]. The head goes first backward then proceeds to a hyperflexion and goes back to its initial position. Geometric unalignment during the movement of the head is compensated.

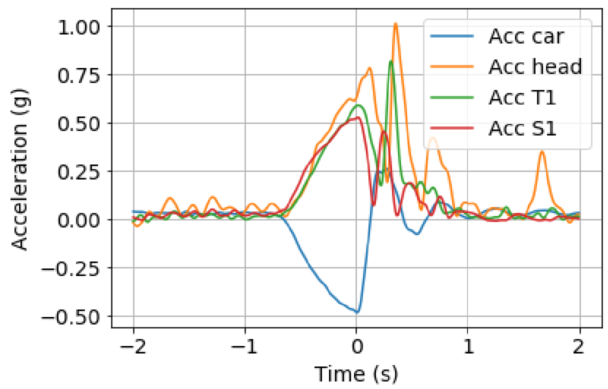

Figure 2. Accelerations of the IMUs during a trial

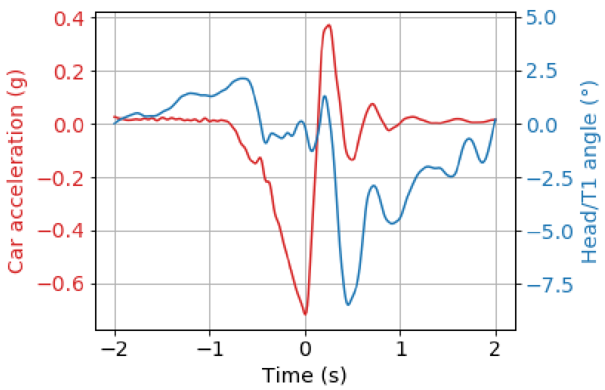

Figure 3. Relative head/T1 angle and car acceleration during a trial

Figure 4 shows the boxplots of the head acceleration according to the speed (8km/h or 15km/h) and the braking modality (either the pedal robot or the AEB system). The head accelerations were in average lower in the case of AEB case compared with the human braking case and the difference is significant ($p = 8.9 \times 10^{-4}$).

Figure 5 shows the boxplots of the ROM according to the speed and the braking modality. The ROMs were in average higher in the case of the AEB braking but the difference is not significant ($p = 0.74$).

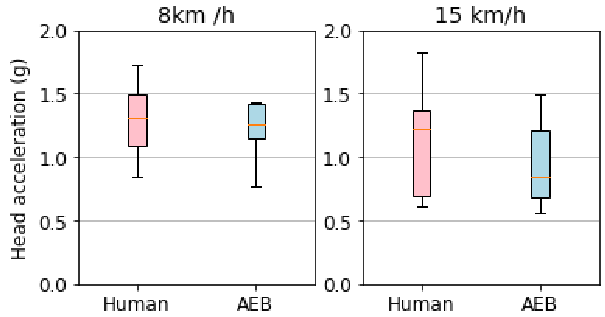

Figure 4. Head acceleration boxplots

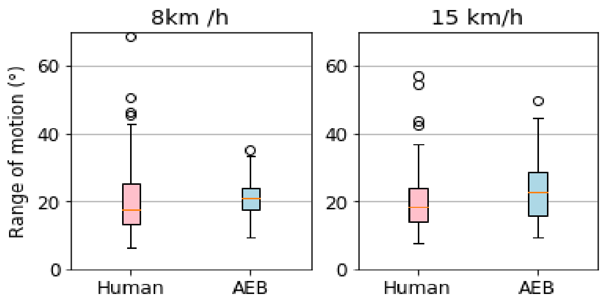

Figure 5. Range of motion boxplots

Discussion

A significant difference between levels of head acceleration has been observed between AEB and human braking whereas no significant difference has been found for the ROMs. There are two major reasons: an audible signal alerts the passenger of the incoming braking one second before the AEB is triggered and the AEB system is fired when the vehicle is getting too close from a car crash dummy. These reasons let us think that the subject may have prepared himself as reported in [Blo06].

Despite the deceleration being higher in the case of the AEB, the head acceleration is lower. This proves that the reaction of the subjects has been appropriate as they managed the braking event better.

Conclusion

We presented in this paper the issues of whiplash and the need to implement VR in the investigations. We designed a pilot study which aims at legitimating the comparison of results from virtual environments with results from real conditions. Only the results from the first part of the study were presented here. The second part of the experiment will be performed in a near future.

The final goal of this study is to explore the possibility of using a virtual environment in head stabilization strategies studies and to see if the comparison can be legitimately done in the dynamic context including a sudden braking.

This will allow us to explore cognitive parameters in a more controlled environment to get a better understanding of the head stabilization strategies in dynamic environments.

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