Investigating Head Impact Dynamics and Cervical Spine Injuries in Karting Rollovers: An Initial Assessment of Neck Brace Efficacy

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I. INTRODUCTION

Karting is both a recreational and professional sport, practiced by millions of people worldwide [1]. Karting accidents can result in severe injuries, as karts are fast and their design offers minimal protection for drivers (no seatbelt, no roll-up structure): Between 1985 and 1996, there were 231 fatal go-kart accidents in the US, primarily caused by head injuries and neck fractures [1]. One of the primary mechanisms causing fatalities in karting accidents is rollover [1]. The neck is particularly vulnerable in rollovers due to direct impact forces from the head and inertial forces from the lower body [2]. Neck braces are commonly worn by drivers to mitigate or prevent neck injuries during kart racing. However, there are no peer-reviewed epidemiological studies and very little biomechanical research on the effectiveness of neck braces in reducing neck injuries, especially in karting rollovers [3]. Additionally, there is no standardized test to evaluate neck braces. One of the key challenges in assessing neck brace effectiveness is the lack of data on head impact conditions and neck loading during a kart rollover. The objective of this study is to evaluate head impact conditions (impact location and velocity), head kinematics during impact, and cervical spine injuries resulting from a karting rollover crash, as well as to provide an initial assessment of neck brace efficacy.

II. METHODS

The full-crash tests with a kart were performed at the Laboratoire de Biomécanique Appliquée de Marseille on two PMHS without a neck brace and one PMHS with a neck brace (Leat Kart) wearing a motorcycle helmet (Aero, Model FF311, size M). The 3 PMHS subjects were males (172±8 cm, 70±8 kg) and were embalmed with Zinc Chloride. The kart was propulsed onto a ramp at 45 to 50 km/h to force the roll-over of the kart. These crash conditions were selected based on video analysis of two real crashes that resulted in severe head and neck injuries, as well as on multibody simulations of kart rollovers (study not yet published). The PMHS were put in a driving position with the hands on the wheel. The PMHS were imaged by tomodensitometry before and after the impact and their cervical spine were dissected by a neurosurgeon after the impact to assess potential injuries.

The surrogates were equipped with sets of three tri-axial linear accelerometers (capacity of ±250 g, EGAS S403A-250- /L1.5M, TE Connectivity, Schaffhouse, Switzerland), in the mouth and on the helmet. The accelerometers recorded at 10 000 Hz. The impacts were filmed by four high speed cameras at 1000 Hz, two high speed cameras at 500 Hz and one video camera at 30 Hz. The accelerometers data were filtered with a low-pass second-order Butterworth filter (cut-off frequency of 1000 Hz) as recommended by the SAE J211 specifications. The images of the crash were analysed using the software Kinovea. The velocity of the helmet was measured by following a distinct point on the helmet. A perspective grid was added to the images to account for the non-planarity of the event in regards to the camera [4]. Three different grids were placed (closer or farther form the camera) and the average of the three measurements was reported.

Table 1 : Metrics of the head impact and resulting injuries observed in the PMHS

PMHS n°	*Height/ Weight/age*	*Normal velocity(m/s)*	*Tangential to ground velocity (m/s)*	*Peak Head accel. (g)*	*HIC*	*Injuries*
1	172 cm/ 66 kg / 77yo	4.1 (± 0.5)	10.4 (± 1.7)	103	183.5	C5-C6 anterior disc rupture C4-C5 intervertebral laxity C5 right spinous process fracture
2	180 cm/ 80 kg/ 86yo	4.5 (± 0.4)	11.5 (± 1.3)	118	162.7	No sign of injury
3	164 cm/ 65 kg/ 86yo	4.9 ± 0.2	11.1 (± 0.3)	54	64	C6-C7 interspinous ligament rupture C7 Fracture of right articular facet C7-T1 intervertebral laxity

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III. INITIAL FINDINGS

The three subjects fell on their head first (Figure 1). The normal and tangential velocities relative to the floor were measured as done previously with the Kinovea software at the contact with the floor. The mean normal velocity was 4.5 m/s ± 0.4 and the tangential velocity was 11.0 m/s ± 0.5. These results are very close between the three-test showing a good repeatability of the experimental protocol (Table 1). The post-impact status of the helmets can be seen in Figure 1. We can see that the first impact was in the superior lateral part of the helmet for the three tests. Also, important abrasive marks were seen on the chin and on the left part of the helmet due to the axial rotation of the head after the impact as seen in the video. Some abrasions were also observed at the anterior part of the neck brace, but without important deformation. Peak head acceleration measured in the mouth (mean : 92g ± 33) was approx. 3 time smaller than that measured in the helmet (mean : 315g ± 120) and was well bellow injury threshold for severe brain injury (HIC << 1000) suggesting that the helmet was effective at protective the head for this type of impact. Looking at the maximum mouth resultant accelerations for the three karting roll-over tests (Figure 1), we see that the resultant acceleration was two times lower for test 3, which might be due to the neck brace contacting with the helmet at the beginning of the impact (Figure 1) and limiting the acceleration of the head. The injuries are detailed in Table 1. Only the subject 1 and 3 (despite wearing a neckbrace) sustained injuries at the cervical spine.

Figure 1: Head impact during rollover: (a and b) position of the PMHS and kart at the head impact, (c) first impact zone on the helmet for subject 1 to 3, (d) resultant head linear acceleration curves at impact

IV. DISCUSSION

This study presents the first karting rollover performed with PMHS and the first neck brace efficacy evaluation using PMHS. It provides valuable data on head impact conditions, neck loading, and cervical spine injuries. All three rollovers resulted in lateral head impacts with similar normal and tangential head velocities, but only two led to neck injuries.Two hypotheses may explain why PMHS 2 did not sustain a neck injury: first, his greater stature (above the 75th percentile, compared to below the 30th percentile for Subjects 1 and 3) may have provided some protection; second, video analysis shows that the helmet impact was more posterior than in the other two crashes. This likely caused PMHS 2 to roll onto his shoulder, which may have helped protect the cervical spine. In contrast, PMHS 1 and 3 experienced impacts to the top lateral part of the helmet and were subjected to neck hyperextension.Regarding the effectiveness of the neck brace, the videos show contact between the helmet and the brace early during the head impact, potentially dissipating some impact energy and reducing head acceleration. However, axial rotation of the head was still observed upon ground contact, which is consistent with recent studies showing that axial rotation is the least restricted movement by the neck brace [5]. As a result, the neck brace did not fully protect the PMHS from cervical spine injuries in this test configuration, and the injuries sustained were severe. This study presents several limitations, including the lack of head rotational kinematic measurements—an important metric for both head and neck injuries—as well as the absence of reflexes and active musculature in the PMHS, which might have altered impact posture and limited the risk of neck injury. While these findings are based on only three experiments, they offer valuable insights into kart rollover kinematics, support the development of numerical models, and contribute to the understanding of neck injury mechanisms. Further research is needed to fully assess the influence of neck braces on neck kinematics and injury risk [6].

V. REFERENCES

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