RECONSTRUCTION OF SABRE FENCING HEAD IMPACTS VIA SIMULATION: A PILOT STUDY

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The purpose of this study was to reconstruct sabre fencing head impacts from real video events to examine the protective capabilites of a fencing mask taking into account the velocity of the sabre blade tip and dominant wrist during head contacts. Eighteen videos selected from YouTube were analysed using Peak Motus® motion analysis software. A pneumatic linear impactor was used to simulate sabre fencing head impact events, which included impacts on the front and sides. Each event was replicated 10 times to ensure consistency. The outcome revealed moderate to high reliability across replications. The front location appeared to mitigate more linear impact acceleration than the side during combat. The results provided some information about the behaviour and protective capabilities of a fencing mask during dynamic impacts for future research studies.

KEYWORDS: fencing, sabre, sword velocity, pneumatic horizontal impactor, peak linear acceleration, head impacts, mask testing, concussion.

INTRODUCTION: Sabre fencing is an open skill combat sport where the environmental aspect in this sport is constantly changing and the reaction from the fencers has to be adaptive (Tsolakis, Kostaki, & Vagenas, 2010). Sabre is the fastest weapon in nature and it possesses the fastest tempo and the quickest burst of speed (Chen et al., 2017). Sabre fencers strategically focus more on the attacking actions, followed by defensive, counter-attacking, and finally simultaneous actions (Aquili et al., 2013). This combat technique uses multiple methods to score including the cutting or thrusting action, as the whole blade is available to hit the opponent and score points (Aquili et al., 2013; Chen et al., 2017). Sabre fencers are also allowed to score a hit by using the side or cutting edge of the blade (Chen et al., 2017). The fencing mask functions to keep the head and face of the fencers away from direct contact with the blade. There are two types of fencing masks available and used, the European Level 1 (CEN 1) fencing mask and European Level 2 (CEN 2) fencing mask (Farrell, 2012). Fencing masks are comprised of the mesh, the bib, the rib, and straps (Farrell, 2012). Similar to other sports (e.g., hockey, soccer and football), head and brain injuries are the most concerning in the sport of sabre fencing as they can cause neurological dysfunction or even death (Gawin, 2016; Jeffries, 2018). Past research has stated that the concussion threshold for the typical fencing mask ranges from 165 N to 412 N (Gawin, 2016); while this research did not measure concussion threshold acceleration values in units of gravity (*g*), relevant research with football players suggested that a football player will be in risk of sustaining a mild concussion when the linear acceleration is greater than 98.9 *g* (Greenwald et al., 2008). Sabre fencers are reported to be at the highest risk of sustaining injuries in fencing among all fencers (Harmer, 2008). Despite this concern, there is not a lot of research that has investigated the sword and wrist velocity of the sabre blade during head impacts and none that has determined the safety properties of the fencing mask and its function in concussion prevention. Based on this gap in existing literature, the purpose of this study was to reconstruct sabre fencing head impacts from real video events to examine the protective capabilites of a fencing mask by taking into account the velocity of the sabre blade tip and dominant wrist during head contacts. The following hypotheses guided the study: a) there was no significant difference between the linear velocity of the wrist and sword as both appeared to move at the same velocity when the blade or pommel guard touch the head of the opponent; and b) there were no differences on measure of linear impact acceleration between the front and side locations of the sabre fencing mask.

METHODS: Thirty videos were chosen from YouTube media application. Each video was checked for quality and co-planarity. Due to digitizing time constraints, only 18 videos were randomly selected from the pool of 30 videos for males and females respectively. The videos included the matches of nine men's sabre and nine women's sabre elite fencers. These videos involved only World Championship and World Grand Prix (2017-2018 season) matches starting from the semi-finals onwards in the competitions. The researchers only selected head impact events from these videos and used Peak Motus® motion analysis software to acquire the velocity measures of the blade and wrist. The chosen videos were digitized manually using a 2D spatial template model, which contained a three-point multi-segment body model representing the wrist, pommel guard of the blade, and the tip of the blade. The two *engarde* lines located 4 meters apart in each video were used as the fixed reference in the plane of motion to calibrate the data. For each video, the reference was digitized 10 times to obtain a more accurate pixel/meter ratio conversion. The sampling rate used in the present study was 60 Hz. The wrist and tip of the blade were digitized and analysed for all frames in the videos. A cubic spline interpolation filter was used to smooth the data and minimize digitization errors. Once the head impact velocity was determined from the video data, a pneumatic linear impactor and National Operating Committee on Standards for Athletic Equipment (NOCSAE) head assembly mounted on a mechanical neckform and sliding table were used to simulate the head impacts of sabre fencing. In this pilot study, the velocity applied to the linear impactor was 2.01 m/s representing the 5th percentile of the wrist velocity based on the research work of Jeffries (2017). The researchers followed the same guidelines of the NOCSAE standards for helmet testing. The researchers, however, only tested the front and side impact locations based on the head contact information provided from the video analysis procedure. The front location was positioned in the median plane approximately 25 mm above the anterior intersection of the median and reference plane as defined by the NOCSAE testing standard (NOCSAE, 2017). The side location was positioned at the intersection of the reference and coronal planes on either side of the headform (NOCSAE, 2017). A total of 30 impacts were completed for each location separately to ensure reliability of the measures. The researchers impacted the front location first and then the side with an impact velocity of 2.01 m/s, which equated to a pressure of 24 psi on the pneumatic impactor based on calibration data from previous research (Jeffries, 2018). The linear acceleration data in the x, y, and z directions were captured by accelerometers mounted inside the surrogate headform. The data from the sensors were fed into an analogue to digital amplifier unit, which was interfaced to the PowerLab© hardware and software system. The resultant linear acceleration was computed using the PowerLab© software arithmetic computations based on Equation 1:

$$\text{Resultant Acceleration} = \sqrt{x^2 + y^2 + z^2} \qquad (1)$$

where:

x = linear acceleration in the x-direction
y = linear acceleration in the y-direction
z = linear acceleration in the y-direction

Descriptive statistics were conducted to determine the means and standard deviations of the linear velocity of the sword and hand from the 18 videos before reconstructing the head impacts. In addition, a repeated measures t-test was conducted to investigate if there was a significant difference between the linear velocity of the wrist and sword in order to select the appropriate velocity to simulate the mechanism of injury when using the linear impactor as the opponent sometimes contacted the head with the blade or pommel guard. Similar to the research work of Zerpa et al. (2016), an intra-class correlation analysis using the split half method technique was implemented via IBM© SPSS statistics to assess the reliability of the acceleration measures across replications for each impact location separately. After providing evidence of reliability, a descriptive statistics analysis was conducted to determine the means and standard deviations of the acceleration measures across all trials for each impact location separately.

RESULTS: The descriptive statistics analysis of the 18 videos showed that the mean linear velocity of the sword (M=5.28 m/s, SD=4.22) appeared to be higher than the mean linear velocity of the wrist (M=4.61 m/s, SD=3.03). The t-test for repeated measures, however, found no significant difference between the wrist and sword linear velocities, $t(34)=-1.073$, $p=.298$. Based on this outcome, the researchers decided to reconstruct the head impacts for the wrist with a speed of 2.01 m/s representing the 5^{th} percentile of the data from the videos. The intra-class correlation analysis via the split half method technique, revealed good evidence of reliability across replications of the impacts for the front location (ICC=.707, n=30, $p<0.05$) and moderate evidence of reliability for the impacts on the side location (ICC=-.407, n=30, $p<0.05$). After providing evidence of reliability across replications of the acceleration measures, the descriptive statistics analysis revealed that the side location of the CEN Level 1 fencing mask appeared to have higher linear impact acceleration measures (M=10.68 gs, SD=1.10) than the front side location (M=6.22 gs, SD=.61) at the speed of 2.01 m/s across replications.

DISCUSSION: The purpose of this study was to reconstruct sabre fencing head impacts from real video events to examine the protective capabilites of a fencing mask by taking into account the velocity of the sabre blade tip and dominant wrist during head contacts. The first hypothesis of this study stated that there was no significant difference between the linear velocity of the wrist and sword as both appeared to move at the same velocity when impacting the head. This hypothesis was accepted as the inferential analysis reavealed no significant differences between the wrist and blade velocities during head contacts. Although Newton's law of motion states that the mass is inversely proportional to the velocity, in the current study, the smaller mass for the tip of the blade appeared to have a higher velocity than the wrist with a larger mass. Yet, the inferential analysis seemed to suggest that the difference between the mass of the blade and wrist was not large enough to cause a significant increase in the velocity of the blade. Based on this outcome, it became more appropriate to use the average velocity of the wrist at 2.01 m/s to reconstruct head impacts on the front and side of the sabre fencing helmet to simulate pommel guard-to-head impacts, which are more prominent to cause concussions in the sport of sabre fencing (Hussard, 2016). The second hypothesis of this study stated that the sabre mask would mitigate impact acceleration equally across impact locations. Although the researchers cannot reject or accept this hypothesis based on descriptive statistics analysis, the results appeared to suggest that the front location of the fencing mask mitigated more linear impact acceleration than the side location and consequently, it appeared that the front location would provide more protection against head trauma than the side location. This outcome, however, is in line with previous research, which found that the geometry of the helmet plays a critical role in mitigating impacts to the head and that helmets do not protect the head equally across impact locations (Jeffries et al., 2017). In the current study, it may be the unique design of the fencing mask, as the front location appeared to be curved which made the fencing mask an arched shaped object. This geometric shape might have played a role in mitigating impact in the front location. Despite the higher peak linear acceleration of the side location, however, the finding showed that the impacts experienced did not exceed the concussion threshold levels of peak linear acceleration of 98.9 *g*s as stated by Greenwald et al. (2008). Besides that, the intra-class correlation analysis provided some evidence of reliability across locations for the mask testing procedure. Nevertheless, the side location revealed a lower correlation coefficient across replications when compared to the front locations and this finding is similar to the result provided by Jeffries et al. (2017). As stated by Jeffries et al. (2017), this finding could be due to the discrepancies in the behaviour of the side location in minimizing impact accelerations as compared to the front location due to the geometry of the mask. Future research is needed to better understand safety properties of the fencing mask in mitigating linear impact accelerations at different speeds. This outcome can be accomplished by gradually increasing the pressure of the pneumatic impactor to produce linear impact velocities ranging from 2.01 m/s to 4.80 m/s as conducted by Jeffries et al. (2017). There are a few limitations in this study that should be noted. First of all, only one fencing mask was used in this pilot study. As mentioned above, the mask may not have had enough time to rebound to its initial state after each impact and this may have affected the consistency of the peak linear accelerations computed from the mask testing procedures. Moreover, the use of only one type of mask makes it difficult to generalize the outcome to other mask types. In the future, it will be ideal to use different types of masks and allow adequate time for the masks to rebound to its original shape after impact.

CONCLUSION: The findings of this study provide some information on the capacity of a sabre fencing mask in mitigating impacts to the head and consequently concussions. The outcomes also shed light on the need to further invetigate the material properties of sabre fencing masks using pneumatic impactors to reconstruct head collision incidents. This information can be beneficial for researchers, mask designers, coaches, and fencers to better understand the behaviour of the fencing masks in protecting the head against brain injuries.

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