Measurement and Simulation of Head Impacts in Mixed Martial Arts

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I. INTRODUCTION

Concussion is a mild form of Traumatic Brain Injury (mTBI), the fifth International Conference on Concussion in Sport has defined it as "*a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces*" [1]. Sports and recreation activities are one of the main sources of TBI in the United States of America, with 90% of these injuries being classified as mTBI's [2]. This investigation has measured head accelerations in Mixed Martial Arts (MMA) and applied these to a finite element head model to determine strains within the brain. This is one of very few studies to measure '*in vivo'* head accelerations in an unhelmeted sport. MMA is a competitive, full-contact sport that involves an amalgamation of elements drawn from boxing, wrestling, karate, taekwondo, jujitsu, muay thai, judo, and kickboxing [3]. The fighters wear 110g to 170g gloves and do not wear head protection. A ten-year review of injuries in MMA found that head trauma was the single biggest reason for match stoppages (28.3%) [4].

II. METHODS

Twenty-two elite amateur and professional MMA athletes took part in the study. The study was approved by the Institute of Technology Tallaght Ethics Committee (REC-STF1-201819). Participants were fitted with the Stanford University instrumented mouthguard (MiG2.0) [5]. The mouthguards were manufactured from a dental impression, to ensure close coupling with the skull, it is a 6 DOF device with a tri-axial accelerometer and gyroscope. Linear data was collected at 1000Hz and rotational velocity at 8000Hz, the data was filtered using a 4th order Butterworth low-pass filter with cut-off frequency of 300Hz. Rotational acceleration was calculated using numerical differentiation. Data was also only recorded when the linear acceleration exceeds 10g. All events were video recorded and false positives and negatives identified.

The measured head accelerations were applied to a partially validated, 50th percentile male human model managed by the Global Human Body Modelling Consortium (GHBMC) [6]. This investigation utilised a neck and head model isolated from the full body in order to reduce computational time as the whole body has been shown to have little effect on short duration impacts [7].

III. INITIAL FINDINGS

To date 251 head impacts have been recorded at eight sparring sessions and 152 impacts at eight competitive events. No injuries were sustained during the sparring sessions despite the recording of three very serious impacts (>90g), and one very severe impact (241.8g and 1600rad/s^2). The competitive bouts had fewer but more acute impacts with 11 impacts recorded in excess of 100g and 10krad/s^2. Immediately following the competitive events four of the fighters were diagnosed, by a medical doctor, with a concussion. Another fighter was diagnosed with post-concussive symptoms during a 48-hour follow-up medical examination. Symptoms reported included: a very short loss of consciousness (< 1 second), persistent headaches in the days following the event, visual aura and imbalance.

The impacts with the highest rotational acceleration from each competitive event were applied to the simulation model. Details of these impacts are shown in Table I. Principal strain in the corpus callosum was examined as it has been determined to be an indicator of mTBI [5]. Also strains are compared to brain tissue injury thresholds in this region [8].

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IV. DISSCUSSION

This study has revealed some interesting results for both concussed and non-concussed athletes. Eleven very severe impacts occurred during the competitive events that exceeded 100g and 10krad/s^2, the duration of these impacts is relatively short (<31ms). Four of the fighters who sustained these impacts were concussed.

TABLE I
ACCELERATION DATA FOR THE IMPACT WITH THE HIGHEST ROTATIONAL ACCELERATION IN EACH COMPETITIVE EVENT

	Linear Acceleration (g)	Duration (ms)	Rotational Acceleration (rad/s/s)	Duration (ms)	Max Principal Strain in the Corpus Callosum	Concussion
Fighter 1	110	19	13191	17	3.70%	mTBI
Fighter 2	308	18	21881	31	50%	mTBI
Fighter 3 - Bout 1	41	22	2906	24	7%	mTBI
Fighter 3 - Bout 2	32	17	23479	15	25%	uninjured
Fighter 4 - Bout 1	141	25	13609	22	5%	mTBI
Fighter 4 - Bout 2	163	10	23757	15	25%	uninjured
Fighter 5	434	10	33315	12	8%	mTBI
Fighter 6	52	14	17457	19	1.5%	uninjured

One fighter (fighter 3 – Bout 1) suffered from a concussion despite not having sustained any large impacts. Two fighters who suffered four very severe impacts (in excess of 100g and 10krad/s^2) were not injured. These impacts are more severe than those reported by other authors which have resulted in concussion [9]. The Stanford instrumented mouthguard was used in a study to record two concussive cases in US football [5]. The impacts recorded in their study have considerable lower linear and rotational accelerations but are of a longer duration (up to 65ms), due to the helmets and padding worn by the players. A further study was conducted where a total of 27 concussive and 13 non-concussive impacts in unhelmeted sports were reconstructed, and using a simulation model the levels of strains in the brain were recorded. This study found the following tentative thresholds for a 50% probability of a concussion occurring; 13%, 15% and 26% in the thalamus, corpus callosum and white matter respectively. The study also determined mean levels of strain for the cases where a concussion had occurred of; 26%, 31% and 44% in the thalamus, corpus callosum and white matter respectively [8]. As can be seen in Table I above, three fighters exceeded the 15% (50% probability) threshold for strain in the corpus callosum, yet only one was diagnosed with an mTBI. Four other fighters did not exceed this threshold but were diagnosed with an mTBI. The human tolerance to short severe impacts in unhelmeted sports is unknown, but data in this study is important to help understand the magnitude and variation of these tolerances. The number of fighters and events in this study was limited, but the study is on-going.

V. REFERENCES

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