A Wearable Mild Traumatic Injury Warning Device of Daily Activities

I. Background

Mild Traumatic Brain Injury (mTBI) [1] isn't easily noticed because it shows no symptoms. In addition to mTBI, which is caused by a direct hit to the head, whiplash injury [2] may also cause the head injury. The current HIC (Head Injury Criterion) [3] is not enough to conduct researches focused on more than a single impact.

II. Purpose

We developed a wearable mTBI warning device which can detect any movement that potentially causes damage to our brains. While most researches were focused on mTBI caused by a single impact, we designed a device that can produce multiple impacts to simulate continuous hits and evaluated the potential damage of mTBI.

III. Hypothesis

A. Based on reference [4], the HIC threshold of mTBI was defined as 51.

B. An acceleration sensor was used to collect data, which then were converted into HIC values. Formula 1 is the equation of HIC (a : acceleration / $t_2 - t_1$: a certain time interval).

$$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a \cdot \mathrm{d}t \right]^{2.5} (t_2 - t_1) \right\} \cdots (1)$$

IV. Procedure

A. Development of a wearable mTBI warning device

In this study, this device contains acceleration sensors that were in turn put on the volunteer's head to collect data, and it also included a microcontroller unit (MCU) with three analog-to-digital-converters (ADC) (Fig. 1). The warning device reads the data and then converts them into HIC numbers (Fig. 2).

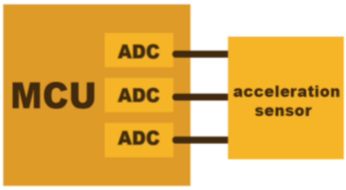


Fig. 1. Block diagram of the warning device

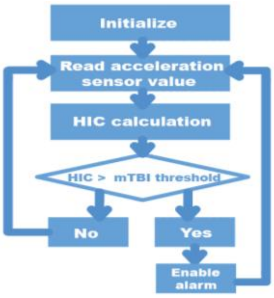


Fig. 2. System software flowchart

Fig. 3. Prototype of the wearable mTBI warning device

B. Measurement of acceleration

To avoid inaccuracy of the collected data, the sampling rate were defined based on the Nyquist theorem [5].

To verify whether the sampling rates are high enough, the Fast Fourier transform (FFT) was used to transform the signal from time domain to frequency domain.

The chosen acceleration sensor collects three axial data. Formula 2 helps us combines the three axial data sets into a single data set (a_x : collected data of x axis / a_y : collected data of y axis / a_z : collected data of z axis).

$$|\vec{a}| = \sqrt{{a_x}^2 + {a_y}^2 + {a_z}^2} \cdots (2)$$

C. Implementation of a continuous head-impact simulator

The current Closed-Head Impact Model of Engineered Rotational Acceleration (CHIMERA) relies on discrete pulsed-air-pressured impacts and cannot generate continuous patterns of collisions. However, this new model produces continuous impacts using an electromagnetic module. Fig. 4 is the configuration of the proposed continuous head-impact simulator, which contains an electromagnetic impact module (a), a controlled box (b), and an impact platform (c).

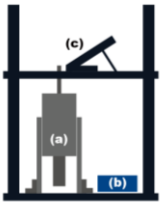


Fig. 4. Continuous head-impact simulator

Based on the Formula 3, the impacts our simulator produces can be precisely controlled. The longer time period is, the stronger impact the simulator generates (F : force / S : displacement / P : power / t : time).

$$F \times S = P \times t \cdots (3)$$

Formula 4 is the correlation formula [6], which implies the relevance between the known data and the newly generated input data. Based on this relationship, the critical value of brain injuries can be defined (j : sampling point / n : the number of sampling rates of x data / M : the number of sampling rates of y data).

$$R_{xy}(j) = \sum_{i=0}^{n-1} x_i \cdot y_{i+j}, \qquad -(n-1) \leq j \leq M \cdots (4)$$

V. Results/Observations

A. Selection of sampling rates

Fig. 5 is a signal captured during the head-impact experiment. The signal was transformed into frequency domain, which is shown on Fig. 6.

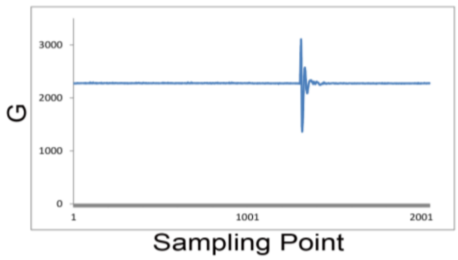


Fig. 5. Signal represented in time domain

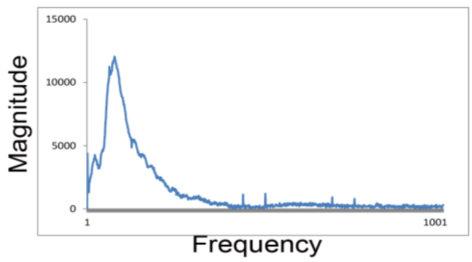


Fig. 6. Signal represented in the frequency domain

After the experiment, the sampling rate should be set higher than 300 Hz. The time interval of HIC in the formula has been limited to 15 microseconds. For to this reason, the sampling rate was defined as 3000 Hz.

B. Results of daily activity experiment

On Table 1, it is shown that dancing may have a bad influence on the brain. The movement 4, which involves shaking one's head hard in the shape of 8, even led to HIC = 39. And Table 2 shows the results of taking amusement rides that involves intense movement. The highest HIC value produced by ride 1 is only 3.3, which is even lower than most of those dancing movements on Table 1. From Tables 1 and 2, the potential damage of certain dancing movements seem to be more severe than that of taking amusement ride.

Table 1. Results of dancing experiment

	Duration 1		Duration 2		Duration 3	
	G	HIC	G	HIC	G	HIC
Movement 1	14.2	3.3	11.1	2.9	5.5	0.4
Movement 2	10.1	3.1	8.7	3.2	7.8	2.3
Movement 3	8.5	2.7	5.8	1.0	7.4	2.0
Movement 4	29.8	38.6	16.6	6.4	15.0	3.0
Movement 5	11.6	3.8	9.0	1.7	6.8	3.0
Movement 6	20.6	12.0	13.0	4.1	12.8	3.7
Movement 7	11.8	6.9	11.8	7.1	10.0	4.7
Movement 8	16.5	8.4	16.4	10.2	11.0	4.3
Movement 9	5.8	1.2	5.4	1.0	4.4	0.6
Movement 10	7.4	1.8	6.5	1.4	5.8	1.1
Movement 11	7.1	1.8	4.4	0.6	3.1	0.2
Movement 12	4.0	0.5	3.8	0.3	3.9	0.4
Movement 13	5.4	0.9	4.9	0.8	3.1	0.2

Table 2. Results of amusement ride experiment

	Duration 1		Duration 2		Duration 3	
	G	HIC	G	HIC	G	HIC
Ride 1	11.2	3.3	11.0	3.2	7.8	1.6
Ride 2	11.5	2.0	11.6	1.2	11.6	2.3
Ride 3	5.0	0.6	1.7	0.1	1.7	0.1
Ride 4	3.8	0.1	3.6	0.3	4.0	0.1
Ride 5	3.2	0.2	3.4	0.1	2.6	0.1
Ride 6	4.6	0.5	3.8	0.4	3.6	0.1

Table 3. Results of dancing movement collected by three sensors

	Movement 4	
	G	HIC
Right (max)	13.7	25.2
Middle (max)	7.5	5.6
Left (max)	6.8	4.4

C. Experiments of a continuous head-impact simulator

Fig. 7 illustrates the almost linear relationship between time and force. It also shows that our simulator indeed can produce multiple hits during a short time period.

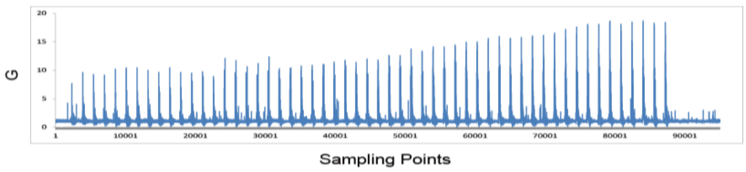
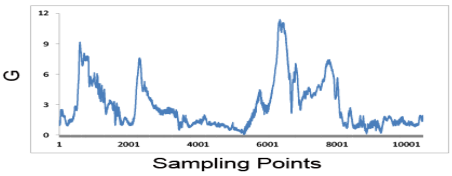
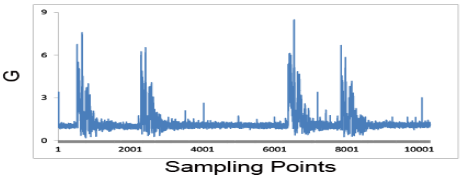


Fig. 7. Continuous head-impact simulator

The data on Fig. 8(a) was put into the simulator and Fig. 8(b) is the output result. Fig. 9 shows the correlation value of Figs. 8(a) and 8(b). The high value proved that our simulator could produce the results I want.



(a) Raw data



(b) The output data of simulator

Fig. 8. The consistency of the proposed model of CHIMERA

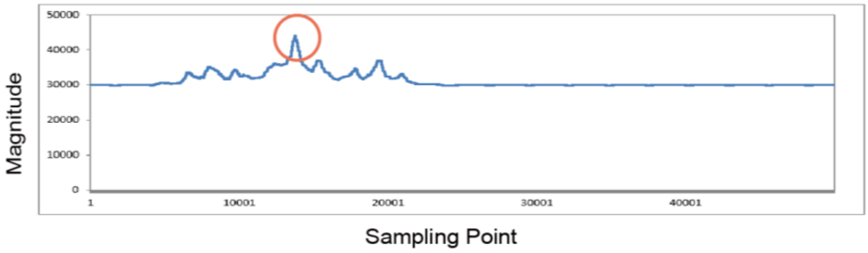


Fig. 9. Correlation value of figure 8(a) and 8(b)

VI. Conclusion

A. The wearable mTBI warning device is developed and capable to collect data in a short period of time.

B. Street dancing has a potentially high risk of leading to brain injury. Its HIC value can be shown up to is 38.6, which is close to the threshold value defined in this study.

C. Despite its intensity, the amusement rides contribute to no severe brain damage. The most significant HIC value measured is 3.3, which is far lower than the threshold value defined in this study.

D. The continuous impacts model of CHIMERA based on electromagnetism was introduced, and it eliminates the main drawback of the current pulsed-pressure-based CHIMERA and will be expected to have extended application for mTBI.

VII. Earlier Work : none

VIII. Acknowledgments

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