Method to determine motion in anatomical regions of the brain

Post A[1,3], Dutrisac S[2], Xu S[2], Rovt J[2], Brien S[4], Poon K[5], Frei H[2], Goodwin S[1], Jalali A[1], Petel OE[2], Hoshizaki TB[1]
[1]University of Ottawa, Ottawa, ON, Canada, [2]Carelton University, Ottawa, ON, Canada
[3]University College Dublin, Dublin, Ireland, [4]Hull Hospital, [5]Clinique Neurooutaouais

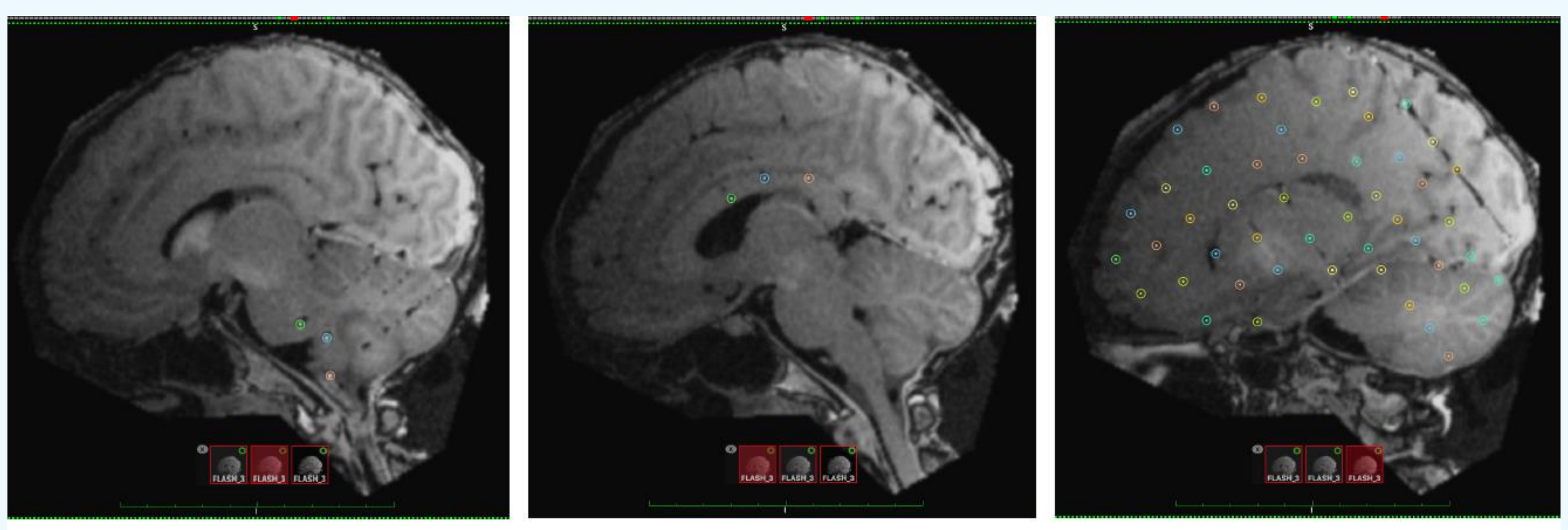
Introduction

Brain injury occurs as a result of head motion producing damaging strains to the brain tissues[1]. In sport, these strains occur through the interaction of the kinematics of the head as a result of impact and the motion of the brain[2], which is affected by the material characteristics of the tissues [3]. However this relationship between impact and the resulting motion of the brain is not well understood. Past research examining human brain responses has used a variety of direct impact and impulsive loading methods in an attempt to understand the relationship between impact characteristics and the resulting brain motion[4,5]. This research did not examine how an impact would affect different anatomical regions of the brain and its implications for injury and finite element modelling. In contrast, the purpose of this research was to develop a method to investigate the mechanics of brain motion in different anatomical regions.

Methods

A post-Mortem Human Subject (PMHS) head was impacted for this research. Once the inclusion criteria were met, the head was harvested and MRI performed to confirm the suitability of the brain and rule out any previous tissue damage. Following inclusion, radiopaque markers were inserted into the brain using the pre-impact MRI as a guide to target the specific anatomical regions (Figure 1). An unbiased neck was then attached to the base of the skull so that the specimen could be installed onto a linear impactor table. The vasculature was then perfused, and the head and ventricles were perfused with aCSF.

For this preliminary dataset, one PMHS specimen was impacted using a linear impactor. An aluminum rod (13 kg) with a hard MEP 60 Shore A striker tip was propelled into the frontal region of the head at velocities from 1 m/s to 4.5 m/s. The marker motions were tracked throughout with a high-speed x-ray system (7500 fps, with a resolution of 1280 x 960 px, with a pre-roll of 20 ms and a total recording time of 500 ms). Dynamic response of the head from impact was measured using a DTS 6DX SLICE (sampling at 20 kHz, CFC 180 filter) that was affixed to the superior aspect of the neck at the base of the skull using a steel frame. Although a total of 54 markers were inserted into the brain, this research focused on the motion of the thalamus, corpus callosum, cerebellum, and brainstem as well as more general brain responses in the frontal, temporal, parietal, and occipital regions.



a b c

Figure 1. MRI of the marker placements: (A) brainstem; (B) corpus callosum; and (C) throughout the cerebral cortex

Results

Across all impact velocities, the thalamus and cerebellum had the highest horizontal (y – axis) displacement, with the corpus callosum and brainstem having lower displacements (Figure 2; Table 1). Interestingly, the thalamus also had very low vertical (x – axis) displacement. The displacement profiles of the specific anatomical regions and the general brain responses were unique which suggests that the motion in these regions are affected by the mechanical characteristics of the brain tissues (Table 1).

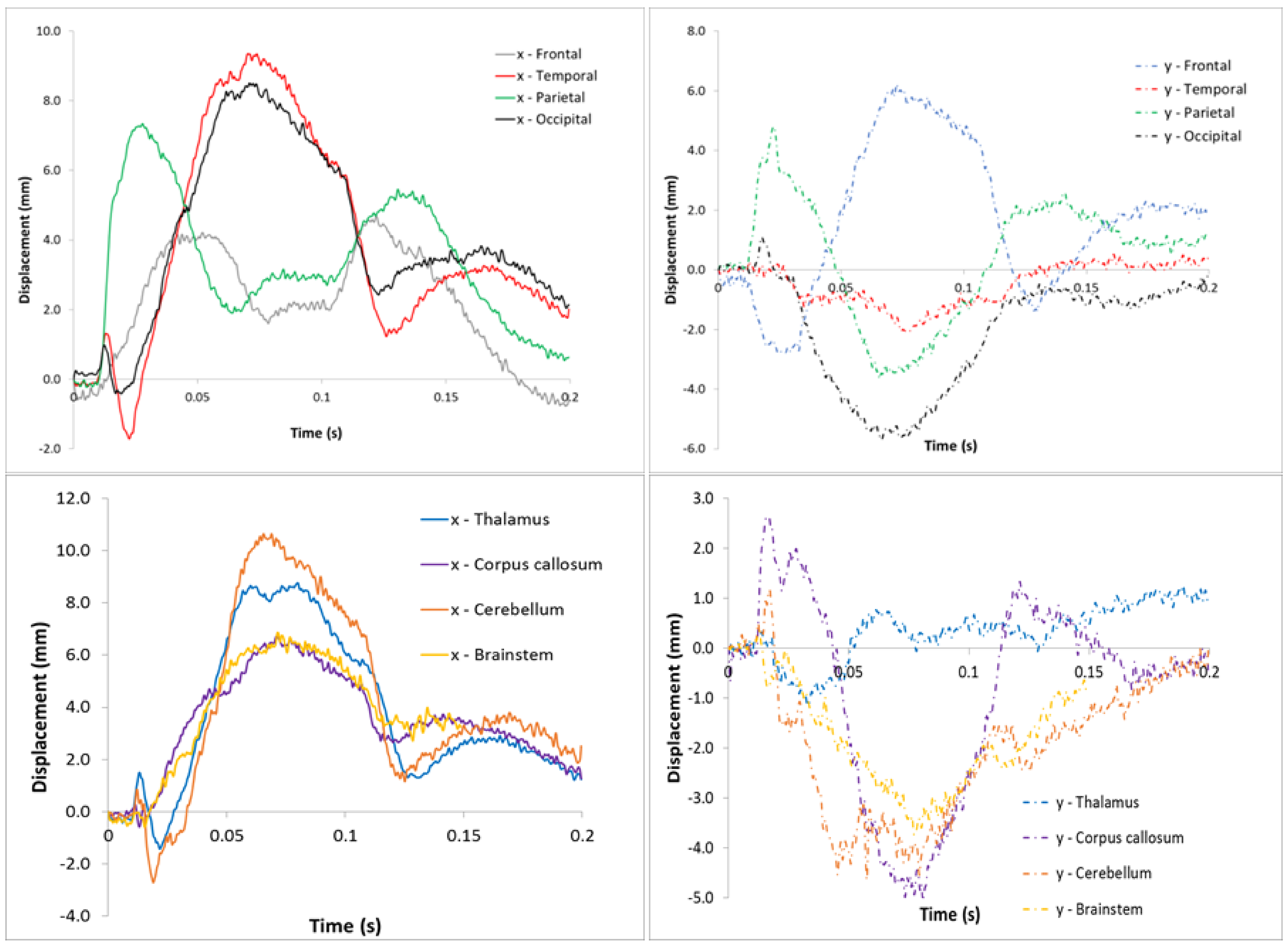


Figure 2. The x and y axis displacement traces of a MEP impact to the front location of the PMHS at 3.38 m/s

Discussion

The method was successful in creating and quantifying motion in the brain according to anatomical region. Areas such as the corpus callosum and brainstem had distinct motion profiles from the rest of the brain tissues for a frontal impact. This data demonstrates that the brain has a heterogeneous response to impact specific to anatomical location. These differences have implications for the understanding of the mechanisms of brain injury and finite element model validation and development.

References

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Table 1. The impact acceleration and peak displacements for each anatomical brain region for each impact

	Peak Resultant Acceleration at head center of gravity		Peak Marker Displacement (mm)															
			Thalamus		Corpus Callosum		Cerebellum		Brainstem		Frontal		Temporal		Parietal		Occipital	
Impact velocity (m/s)	Linear (g)	Rotational (rad/s^2)	x	y	x	y	x	y	x	y	x	y	x	y	x	y	x	y
1.22	57.5	3330	2.51	0.57	2.54	1.67	3.47	0.73	-	-	1.61	1.13	2.54	0.37	2.16	1.17	2.70	0.56
2.99	75.7	3890	7.23	0.68	5.18	1.94	8.24	0.7	5.32	0.50	3.25	3.04	7.25	0.24	5.31	1.82	6.05	1.07
3.38	98.9	5240	8.43	0.61	5.34	2.64	9.29	1.18	6.09	0.36	4.22	3.65	8.27	0.28	7.34	4.80	7.29	1.10
3.84	108.7	5670	5.36	3.04	6.67	5.93	10.49	1.64	5.35	1.61	1.38	4.23	6.23	2.04	5.58	2.96	8.9	2.91