Neuroimaging and Finite Element Modelling – an Investigation of American Football Head Impact Biomechanics and Relationship with CTE Pathology

Karl Zimmerman, Joo Kyung Kim, Clara Karton, Thomas Hoshizaki, David Sharp, Mazdak Ghajari

I. INTRODUCTION

American football players are frequently exposed to head impacts. This is proposed to increase the risk of developing Chronic Traumatic Encephalopathy (CTE), a neurodegenerative disease characterised by the accumulation of abnormal tau pathology along small blood vessels and in the depths of the sulci [1]. A recent study has used finite element modelling to demonstrate that higher levels of tissue deformation can be found in the sulci, the location of CTE pathology [2]. Three cases, including one American football impact were used in this preliminary report. These results will be confirmed in a larger cohort of 148 American Football head impacts, incorporating kinematics data from physical reconstructions to predict the location and magnitude of strain and strain rate in different brain regions. Well established neuroimaging methods were used as a novel approach to compare the biomechanics of head impacts in players of different positions.
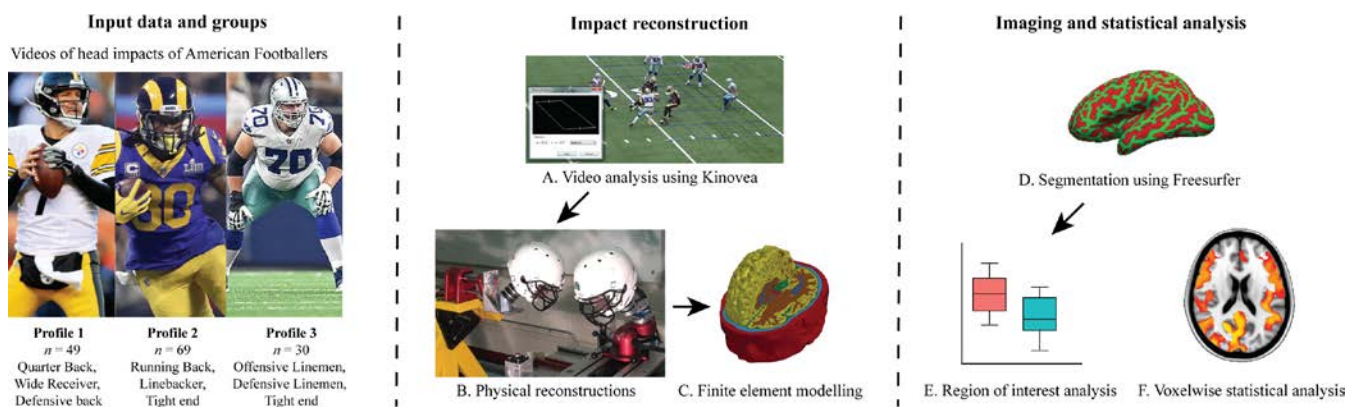
II. METHODS

Fig. 1. *Subjects and impact reconstruction (A-B):* Videos of 148 American football players sustaining a head impact were analysed using previously described methodology [3]. Recorded footage was used to establish player velocity, location and orientation using Kinovea. These parameters were used to guide physical reconstructions of the head impact events using a Hybrid III 50th percentile adult male head form and neutral unbiased neck form. Players were grouped according to players' positions and separated into three different profiles based on impact frequency, strain magnitude and time interval [3]. *Computational Modelling (C):* A high-fidelity 3D finite element model (FEM) of the human head was used to calculate brain deformations from each head impact. The FEM material characteristics and development details are described in previous work [2]. The model was loaded by linear and rotational accelerations obtained from the physical reconstructions of the impacts. We used the FEM to calculate in each element the maximum principal value of the Green-Lagrange strain tensor (called strain here) and its rate (strain rate). *Neuroimaging analysis (D-F):* Strain and strain-rate data for each impact were analysed using fMRIB Software Library (FSL) v6.0.2. Images were merged and means calculated at each element across all impacts and split between player position profiles. The T1-weighted image used to generate the model was segmented using Freesurfer and anatomically labelled resulting in regions of interest for 30 gyri and 33 sulci in each hemisphere. Mean strain and strain rates were calculated for each region of interest using Freesurfer and further averaged to calculate a mean strain and strain rate for gyral and sulcal regions. Voxelwise analysis of strain and strain rate was conducted using the general linear model with non-parametric permutation testing (5,000) in FSL Randomise.

III. INITIAL FINDINGS

Pairwise t-tests of mean strain and strain rate across all American Football impacts revealed significantly higher strain in the sulci than gyri regions (V=3, p<0.001) with no significant differences in mean strain rate (Fig 2A, B). This effect was consistent when splitting the impacts into the three player position profiles (Fig2D). Further analysis showed that there was a significantly positive relationship between both linear and rotational acceleration and 90th percentile strain, with a higher correlation coefficient for rotational components.

When comparing across different player position profiles, a voxelwise analysis showed widespread regions of significantly higher strain in Profile 1 compared to Profiles 2 and 3 (Fig2C). This corresponded to a significant effect of profile on linear (F=3.887, p=0.0227) and rotational acceleration (F=4.583, p=0.0118). A region of interest comparison looking at gyral and sulcal regions across different player profiles was consistent with these results, showing an effect of profile on strain (F=4.401, p=0.014) and strain rate (F=4.672, p=0.0108) as a result of higher strain (p=0.016) and strain rate (p=0.012) in subjects of Profile 1 compared to Profile 3 (Fig2 D).
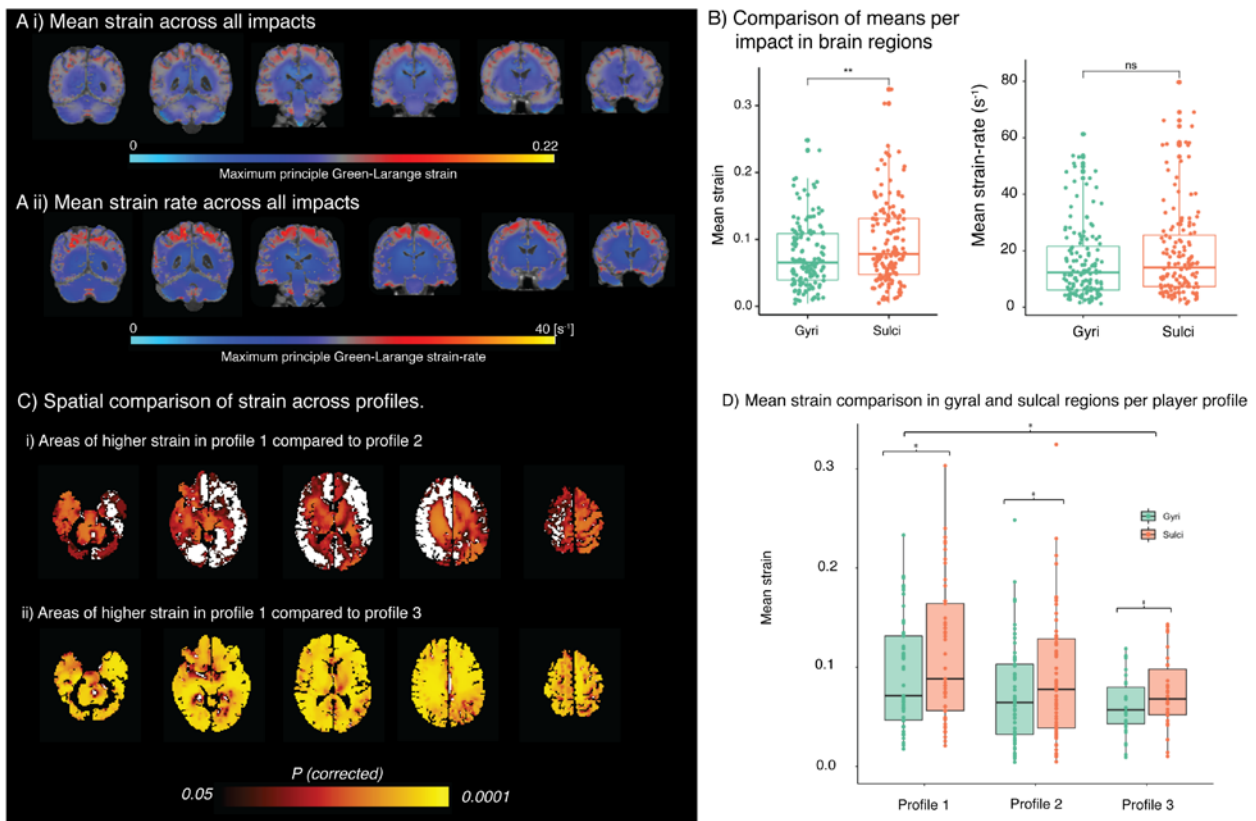

Fig. 2. *A:* Mean strain and strain rates across all simulated impacts, with regions in red/yellow showing areas of highest strain and strain rate. *B:* A pairwise comparison of mean gyral and sulcal strains showing higher strain in sulcal than gyral regions. *C:* A voxelwise comparison showing areas where there exist significantly higher strain in Profile 1 compared to Profiles 2 and 3. *D:* Mean strain comparison across the three different player profiles split by gyral and sulcal regions.

IV. DISCUSSION

Our results further support previous studies in showing higher strain in the sulci than gyri, providing a possible mechanistic link with the development of CTE pathology. Furthermore, we show significant differences in brain deformation for typical impacts for players of different positions in American Football. These results warrant further investigation as to if there are different player-position risks for developing CTE. We also demonstrate the utility of neuroimaging approaches in analysing FEM outputs, which can be easily implemented to include spatial and temporal information often discarded in other modelling analysis methods.

V. REFERENCES

[1] McKee et al. Vol. 68, Neurop Exp Neur. 2009.   [3] Karton C, et al. Sci Reports. 2020.
[2] Ghajari M, et al. Brain. 2017.