# THE KINEMATICS OF HEAD IMPACTS IN CONTACT SPORT: AN INITIAL ASSESSMENT OF THE POTENTIAL OF MODEL BASED IMAGE MATCHING

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Model Based Image Matching (MBIM) has potential to assess three-dimensional linear and rotational motion patterns from multiple camera views of head impact events in contact sports. The goal of this study is to assess the accuracy of the MBIM method for estimating 6DOF head kinematics in a vehicle-cadaver impact scenario for which Vicon motion analysis data are available as an independent measure. A three camera view MBIM reconstruction yielded RMS errors between 0.14-0.26 m/s for change in head linear velocities ranging from 0.56-5.70 m/s, and 0.27-1.38 rad/s for change in head angular velocities ranging from 6.10-41.90 rad/s. The results from this study indicate that the MBIM method is a useful approach for measuring the kinematics of head impacts in sport.

**KEY WORDS:** head motion, concussion, video analysis

**INTRODUCTION:** Impacts are integral to many sports including American Football and Rugby Union and can sometimes result in concussions. Concussion is defined as "a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces" (McCrory et al., 2013) and was found to be one of the more commonly occurring brain injuries throughout the world (McCrory, 2001). This is particularly true in sport, considering it has been estimated that over half of all concussions are sports related (Gordon, Dooley & Wood, 2006). Model-Based Image-Matching (MBIM) can be used to measure three-dimensional motion from un-calibrated video data (Krosshaug & Bahr, 2005). It is proposed here that the MBIM method has high potential for reconstructing head kinematics in sport impacts. Accordingly, the goal of this study is to assess the accuracy of the MBIM method for estimating head kinematics in a vehicle-cadaver impact case, for which Vicon motion analysis data on head linear and angular position time-histories are available as an independent measure. If the MBIM approach is successful for this case, it has the potential to aid in our understanding of the motion patterns of the head in sporting collisions.

**METHODS:** The vehicle-cadaver test methodology used in this study has been previously described in detail (Forman et al., 2015) and was chosen based on having similar head kinematic data to concussive sporting head impacts (Table 1). Briefly, the test was conducted with a deceleration-type sled at the University of Virginia. The striking vehicle buck was mounted on the sled and propelled into a stationary adult male cadaver in mid-gat stance at 40km/h as shown schematically in Figure 1. In this test, 25 Vicon cameras were used to record the cadaver motion at 1000 fps. In order to capture head kinematics, an array of 7 Vicon markers were attached around the periphery of the head (Figure 2). These were transformed to calculate the motion of the nominal head centre of gravity.

**Table 1**
**A comparison of head kinematics in a 40km/h vehicle-cadaver impact prior to windscreen contact with average American Football and Rugby Union concussive head impacts.**

| Head Impact | Change in Linear Velocity (m/s) | Change in Angular Velocity (rad/s) |
|---|---|---|
| 40 km/h side struck cadaver | 6 | 32 |
| American Football | 7<br>(Pellman et al., 2003) | 22<br>(Rowson et al., 2012) |
| Rugby Union | 4<br>(McIntosh et al., 2000) | 33<br>(Patton et al., 2012) |

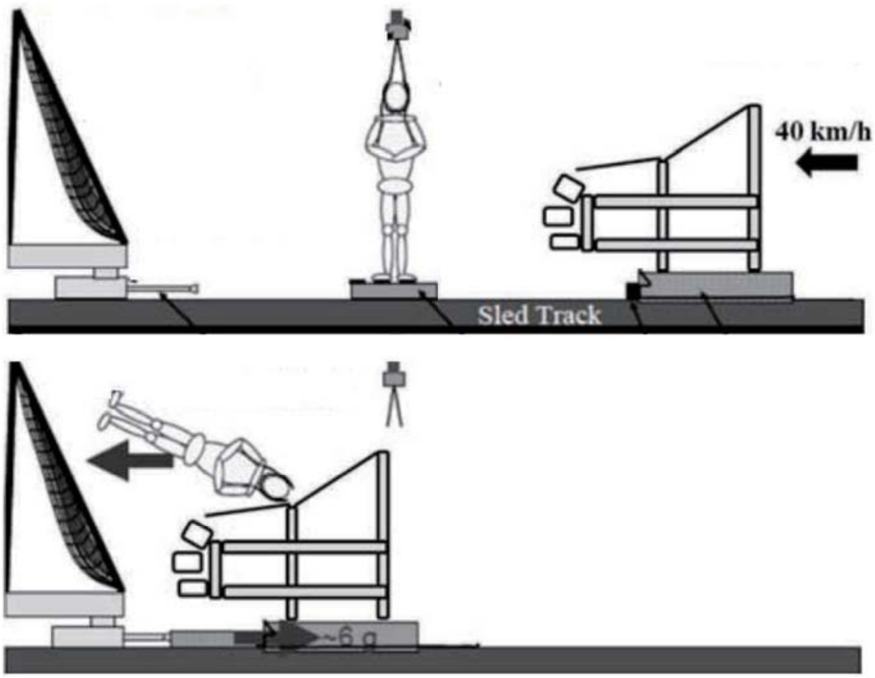


**Figure 1: Schematic of Vehicle-cadaver impact adapted from Kerrigan et al. (2005)**

The Model Based Image Matching technique has been previously described in detail (Krosshaug & Bahr, 2005). Briefly, this approach uses a multibody skeleton model to estimate human body joint angle time-histories from multiple camera views of human movement. For each frame, the skeleton model joint angles are adjusted manually to minimise the segment position and orientation difference of the model with respect to the target athlete in the multiple video views. In this case, only the skeleton's skull was manipulated to fit the cadaver's head for each video frame. The local axes of the skull can be seen in Figure 3. The matching was conducted on synchronised video of 3 camera views of the vehicle-cadaver impact, ending just prior to windscreen contact. The camera locations were unknown by the user.

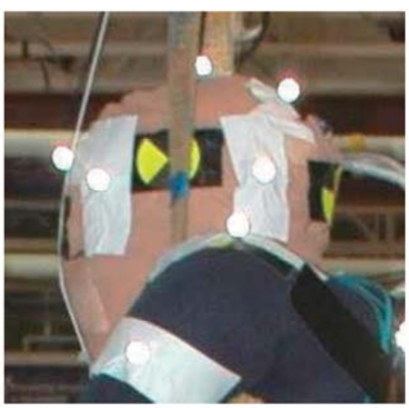

**Figure 2: The Vicon marker array affixed to the cadaver head**

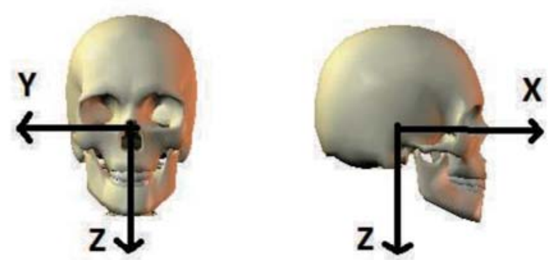


**Figure 3: The local axes of the head**

MBIM was performed using 3-D animation software Poser 4 and Poser Pro Pack (Curious Labs Inc, Santa Cruz, California). The surroundings were built in a virtual environment based on the dimensions of the impact test laboratory. The video was imported into the background of the Poser workspace. The surroundings were then matched to the background video footage for every camera view. This was achieved by manually adjusting the camera positioning tool which contains three translational and three rotational degrees of freedom, as well as variable focal length. MBIM was only conducted on 100 fps video, which is typical of slow motion replays for a normal sports broadcast (Collins & Evans, 2012). A time lapse of the skull matching can be seen in Figure 4. Both the Vicon and MBIM head CG trajectories and the successive rotation angles were derived. A customised Matlab script was then used to calculate the linear and angular velocities of the head about the local head axes (Figure 3). The differences between the Vicon motion analysis and MBIM technique were quantified using Root Mean Square (RMS) error.

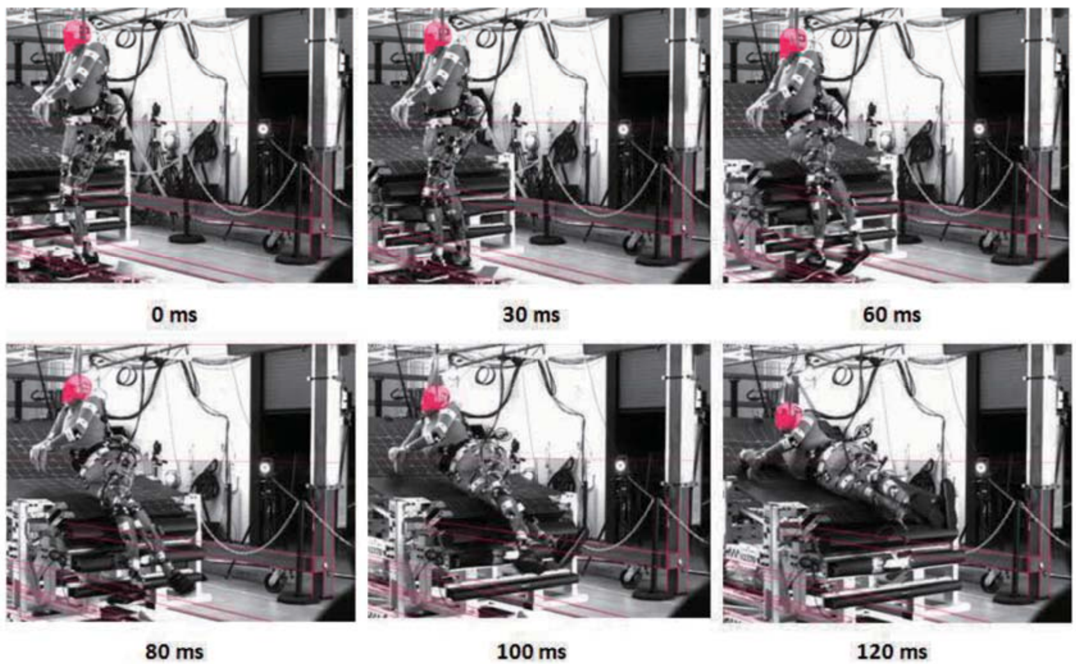


**Figure 4: A time lapse of the MBIM matching for one of the camera views.**

**RESULTS:** For head displacement, the RMS error was under 1 cm for displacements ranging from 2-34 cm, and <0.01-0.04 rad for head rotations ranging from 0.29-0.64 rad (Table 2). For velocities, the MBIM method yielded RMS errors between 0.14-0.26 m/s for change in head linear velocities ranging from 0.56-5.70 m/s, and 0.27-1.38 rad/s for change in head angular velocities ranging from 6.10-41.90 rad/s (Table 2).

**Table 2**
**The Root mean square error values for the MBIM measures compared to Vicon along with Vicon range of values.**

| | | Displacment (m) | Linear Velocity (m/s) | Rotation (rad) | Rotational Velocity (rad/s) |
|---|---|---|---|---|---|
| X | RMSE | <0.01 | 0.26 | 0.03 | 1.38 |
| | Vicon Range | 0 to -0.02 | -0.44 to 0.12 | -0.21 to 0.43 | -9.50 to 32.40 |
| Y | RMSE | <0.01 | 0.14 | <0.01 | 0.27 |
| | Vicon Range | 0 to 0.11 | 0 to 2.60 | -0.04 to 0.31 | -0.04 to 8.60 |
| Z | RMSE | <0.01 | 0.25 | 0.04 | 0.41 |
| | Vicon Range | 0 to 0.34 | 0.30 to 5.40 | -0.12 to 0.17 | -6.10 to 0 |

**DISCUSSION:** This paper set out to establish whether Model-Based Image Matching (MBIM) is suitable for estimating head kinematics in sporting impact events for which several camera views are available. This was done through application of the MBIM approach to a vehicle-cadaver impact experiment for which Vicon motion data was available as a well-established independent measure (Richards, 1999). The analysis showed that the MBIM process using three camera views was able to extract head position and orientation which were then used to infer linear and angular velocities with low errors. Application of the MBIM can therefore assist with a better understanding of concussion causation mechanisms as the method provides a more precise description of head kinematics when compared to previous video analysis methods (McIntosh, McCrory & Comerford, 2000; Pellman, Viano, Tucker, Casson & Waeckerle, 2003). Furthermore, this approach directly extracts three dimensional linear and rotational motion from video, while previous video approaches have been limited to linear motion only. An initial MBIM analysis using only two camera views yielded poor results when compared to the Vicon data and was therefore not reported in this study.

**CONCLUSIONS:** The Model Based Image Matching (MBIM) approach can be used to extract the linear and rotational position and velocity metrics of the head in a collision environment similar to that of a concussive impact in contact sport. Although the method is time-consuming and requires high quality video, the errors in the predicted linear and rotational kinematics measurements are small in this case. The results from this study indicate that the MBIM method is a useful approach for describing the kinematics of head impacts in sport when multiple camera angle videos are available. Future work will investigate the inter/intra rater reliability of the MBIM technique, and the ability to model direct head impact situations.

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