

Validation of a Skin-Mounted Sensor for Measuring In-Vivo Head Impacts

Gunter P. Siegmund, Stephanie J. Bonin, Jason F. Luck, Cameron R. 'Dale' Bass*

I. INTRODUCTION

Head impacts in sport can cause concussions. A better understanding of the head mechanics related to these injuries can potentially improve player safety through rule changes, behavior changes, better equipment and immediate identification of potentially injurious impacts [1]. To achieve these goals, valid methods of detecting and measuring head impacts are needed. Some current sensors are integrated into helmets, mouthguards, earpieces and headbands, however some sports are played without this head-borne equipment and therefore a sensor that mounts directly to the head is needed. Here we evaluate the validity of a head impact sensor that adheres to the skin of the head and therefore can potentially be used in any sport.

II. METHODS

The test sensors (xPatch, X2 Biosystems, Seattle, WA) contained 3 linear accelerometers and 3 angular rate sensors. They measured 31x17x8 mm, weighed 9 grams, and are designed to adhere to the skin over the mastoid process using adhesive patches (Figure 1a). The xPatch records 100ms of data for each impact it senses >10g. Data were uploaded to a central server and post-processed using a proprietary algorithm to determine if the impacts were valid and to calculate various impact metrics, of which we evaluated peak linear and angular acceleration (PLA and PAA), and the azimuth (AZ) and elevation (EL) of the peak linear acceleration.

Validation tests were performed on 3 male cadaver heads (age=84±5yrs; mass=4.63±0.33kg; horizontal circumference=57±0cm) fitted with reference sensors rigidly fixed to the foramen magnum. The reference sensors consisted of 3 linear accelerometers ($\pm 2000g$, Measurement Specialties Inc., Hampton, VA), 3 angular rate sensors ($\pm 8000^\circ/s$, DTS, Seal Beach, CA) and an onboard data acquisition system (Slice Nano, DTS, Seal Beach, CA). Reference sensors and hardware weighed 0.51kg and were included in the head mass reported above. Sufficient neck tissues were retained and closed over the reference sensors to keep the skin taut and the skin edge away from the xPatches mounted over the left and right mastoid processes (Figure 1b). The heads were fitted into a Riddell Revolution Speed football helmet (size L) and subjected to free drops onto the forehead (FH), side (SD) and rear boss (RB) sites from heights of 3 to 142cm (Figure 1c,d,e). Reference signals were acquired at 50kHz with a hardware anti-aliasing filter. Test video was acquired at 5000 fps (Phantom v711).

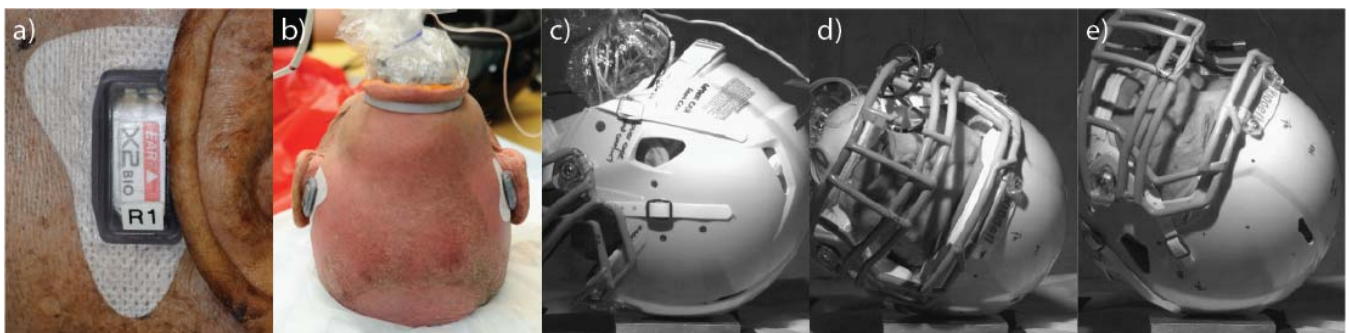


Fig. 1. a) xPatch adhered behind right ear, b) posterior view of inverted cadaver head with xPatches, c-e) helmet and head orientations for the forehead, side and rear boss impact sites.

Reference data were digitally low-pass filtered (300Hz [2]) and then resolved to the head center of mass. Angular accelerations were calculated from angular velocity using finite differences (1ms window). Reference direction was the direction of the peak resultant linear acceleration vector. xPatch directions (AZ, EL) were compared to the reference by calculating a spherical error ($\Delta AZ_i, \Delta EL_i$) for each test and then assessing if the 95th

*G.P. Siegmund, Director of Research, MEA Forensic, Canada (ph: +1 604 277 3040, fx: +1 604 277 3020, gunter.siegmund@meaforensic.com), S.J. Bonin, Biomechanical Engineer, MEA Forensic, USA; J.F. Luck, Postdoctoral Fellow, Biomedical Engineering, Duke University, USA; C.R. Bass, Associate Research Professor, Biomedical Engineering, Duke University, USA.

percentile confidence ellipse about the mean error included 0 ($\Delta AZ=0, \Delta EL=0$) for each impact site [3,4]. xPatch PLA and PAA validity, expressed as percent error, $PE=(xPatch-Reference)/Reference$, was assessed with a 3-way ANOVA for xPatch location (left,right), impact site (FH,SD,RB) and cadaver (C1,C2,C3) with repeated measures for xPatch location. Statistical analyses were performed with Matlab and Statistica using a p-value of 0.05.

III. INITIAL FINDINGS

The xPatch sensed all impacts, but classified 49% as invalid (FH 65%, SD 23%, RB 39% invalid). Invalid impacts were biased towards higher severities, with 80% of the 64 impacts above 80g (as measured by the reference) classified as invalid. Despite these misclassifications, we used all impacts in our statistical analyses. xPatch direction was significantly different from the reference only at the FH site, with mean absolute errors of $29 \pm 18^\circ$, $36 \pm 13^\circ$ and $41 \pm 21^\circ$ at the FH, SD, and RB sites respectively when pooled across left/right conditions and cadavers (Figure 2a,b,c). xPatch overestimated PLA by $64 \pm 41\%$ and PAA by $370 \pm 456\%$ across all tests. All ANOVA terms were significant, and post-hoc testing revealed different PEs between the three cadavers, between the three impact sites, and between the left and right xPatches for some combinations of cadaver/impact-site.

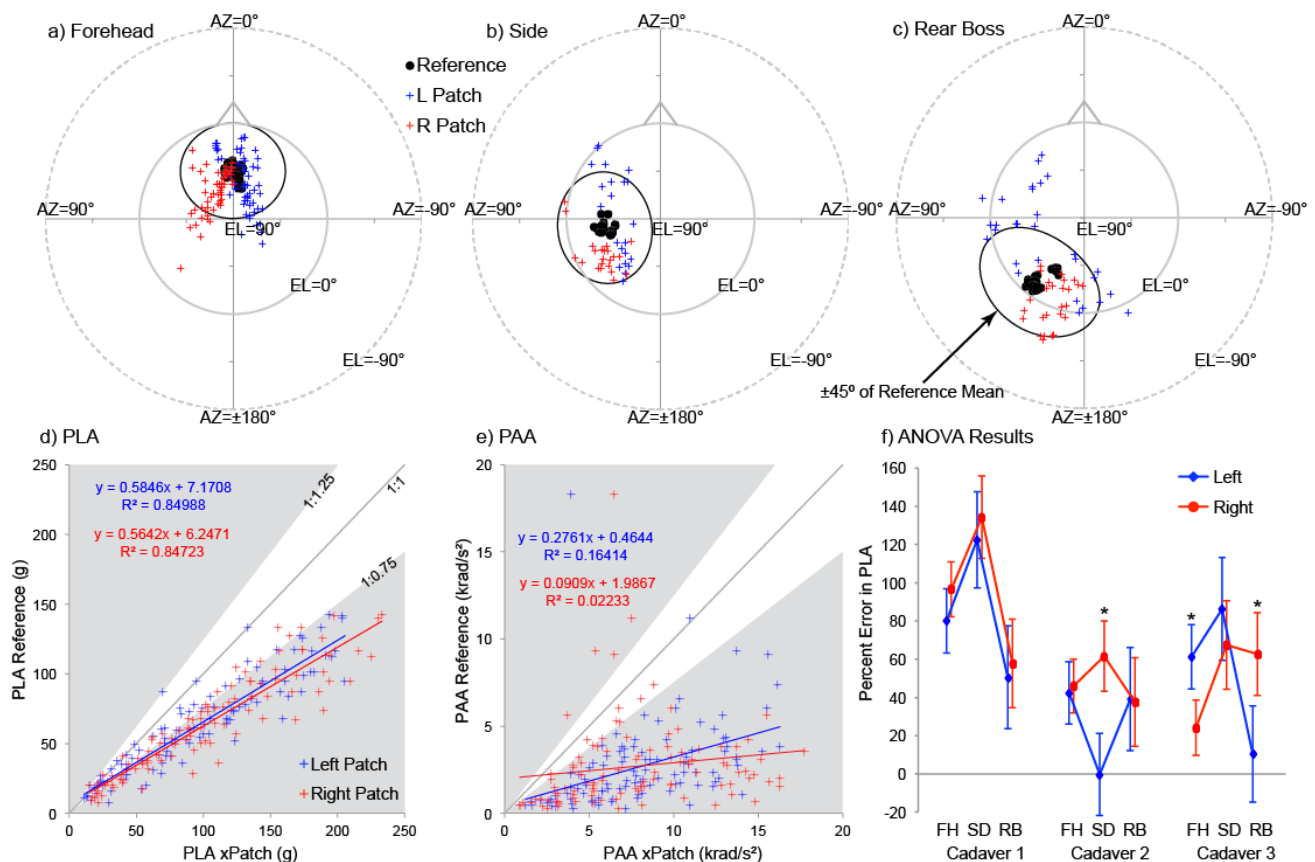


Fig. 2. a-c) Impact direction for the Forehead, Side and Rear Boss sites, d-e) pooled peak linear and angular acceleration, and f) summary of ANOVA results (error bars = 2xSE; * significant left/right differences)

IV. DISCUSSION

Our preliminary results show the xPatch overestimates peak linear acceleration and that this overestimation varies between cadavers, impact sites and left/right sensors. While the linearity of the pooled PLA data may still be useable for population estimates of acceleration exposure, the angular acceleration data are not similarly graded and are likely not useable. Impact direction distributions are relatively wide and differentiating between impact sites within the pooled data may be difficult. Overall, the xPatch results should not be used to estimate the direction and magnitude of a single impact, but may be useful for analyzing large populations of exposures if the errors related to site, left/right position and skin response are appropriately accounted for in the analysis.

V. REFERENCES

[1] Pellman, Neurosurg 2003, 53:799-814. [2] Newman, J Biomech. 2005, 38:1469-81. [3] Fisher, Statistical analysis of spherical data. Cambridge University Press, 1993. [4] Leong, J Neurosci Methods 1998, 80:191-200.