*Original Research*

# Influence of Baseball Catcher Mask Design, Impact Location and Ball Trajectory on Head Acceleration

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## ABSTRACT

*International Journal of Exercise Science 9(5): 567-575, 2016.* The general aim was to contrast accelerations caused by baseball impacts for different catcher mask designs. Study1 focused on impact locations for a perpendicular ball trajectory. Study2 examined perpendicular and oblique trajectories striking a single mask location. A 5.9 kg head model instrumented with a 3-d accelerometer recording at 512 Hz was mounted upright with springs in a shallow ball joint. A pitching machine fired a standard baseball at ~28 m/s for all tests. Transverse plane resultant peak acceleration was gathered from 5 trials in each experimental combination. In Study1, effects of mask design (T=traditional, H=hockey, and M=modified traditional) and impact location (high or low and center or lateral) effects were examined via 3x2x2 ANOVA. For Study2, design and ball trajectory effects were analyzed via 3x2 ANOVA. In Study1, the triple interaction was significant. For high/center collisions, T & H were 41% lower than M; for low/center impacts, H was 40% less than T & M; for high/side strikes, H was 33% less than T which was 32% less than M; and all 3 designs were equivalent for low/side contacts. T and H utilized different protection schemes. For T, energy transfer was reduced when equipment was displaced. For H, the more angled mask deflected the ball's energy. Both mechanisms were impaired for M. In Study2, no significant effects were identified. The trajectory conditions may have relied solely on the mask padding. Both the T and H designs offer protection, with the H performing somewhat better for the conditions tested here.

KEY WORDS: MTBI prevention, hockey versus traditional catcher masks, baseball impacts

## INTRODUCTION

Athletic participation at professional and amateur levels alike leads to numerous injuries (6, 15). Injuries to the brain is a topic of particular importance currently receiving a great deal of

popular media attention. A concussion (now referred to as a mild traumatic brain injury or MTBI) is defined as "a pathophyiological process resulting in functional neurological impairments, as a consequence of forceful biomechanical impacts directly on or transmitted to the head, neck or face" and can be affected by a myriad of different factors including sex, age, genetics, previous history, behavior, playing position, playing level, and protective equipment (7). The US Center for Disease Control and Prevention has estimated that 1.6 to 3.8 million brain injuries occur in sports and recreational activities annually (11) with 75% of these classified as MTBI. However, the CDC also acknowledges that these statistics are dramatically underestimated because most mild and moderate TBIs are not treated medically. Alarmingly, the rates of concussion among 10-19 year olds increased by nearly 100,000 annually between 2001 and 2009 (15).

The issue of sports-related MTBI is a hot current topic, but it goes far beyond professional football; indeed, the cascade of deleterious events begins during childhood sports participation (1). Learning and academic success is critical and essential for individual futures, as well as that of society as a whole. MTBI initiates a myriad of devastating short- and long-term consequences including, but not limited to: higher levels of loneliness, aggressive/antisocial behaviors, and lower self-esteem (1), deficits in the speed and accuracy of ability to switch attention and select relevant from irrelevant information, initial learning of verbal information and recall of verbal information (13), and slowed reaction time, sleep disturbances, and headaches (5). The huge number of these cases, coupled with the fact that they occur primarily among our youth underscores the importance of understanding this injury dynamic.

While most of the attention on sport MTBI is focused on American football, baseball catchers are also vulnerable. It is not uncommon for balls traveling at high speed to hit the catcher in the mask/helmet. In terms of athlete exposures (1 AE = one athlete participating in one practice or game), MTBI incidence has been reported to be 0.11 and 0.06 per 1000 AEs for high school softball and baseball players, respectively (12). In contrast, high school football MTBI incidence has been reported to be 4-5 times greater (7); the dramatic consequences of MTBI justifies its study in any sport endeavor. While most softball and baseball concussions arise from batters being hit by a pitched ball or fielders misjudging a ball they are attempting to catch, high school and college baseball catchers still receive 3.6% of these injuries (7), in spite of the protective equipment worn.

Head acceleration (linear and/or rotational) is a standard measure used to quantify the impact severity and injury potential. However, identifying the critical threshold for MTBI has proven to be a challenge because the contexts and methodologies range widely (8) and individual tolerances may range even more. The average linear acceleration leading to MTBI in the NFL was 98 g based on artificial models. For military personnel volunteers, injury resulted under conditions ranging from 42 – 80 g (17). Zhang, Yang, and King (2004) reported that there was an 80% chance of MTBI from an acceleration of 106 g, and Guskiewicz and Mihalik (2011) reported that levels above 70-75g's are presumed to elicit MTBI. While the impacts faced by baseball catchers are clearly less frequent and intense than those of football players, the dire

consequences of multiple MTBI events (10) does underscore the importance of catcher mask function.

There are two fundamental designs of catcher's masks currently in use. The traditional version is comprised of a padded mask with a harness running over and behind the head atop a skullcap helmet. The newer "hockey style" variety (inspired by gear worn by ice hockey goalies) unifies the helmet and mask components. It is clear that catcher masks are designed primarily to guard against serious fracture and contusion injuries to the face, head and eyes. The main protective mechanism of catcher equipment is that it distributes the force of a ball strike over a greater area via the padding incorporated in the mask and helmet. The padding also protects by reducing the magnitude of the peak impact force. It does so by increasing the deceleration time of the ball collision and by absorbing some of the kinetic energy of the ball through semi-permanent deformation.

The lead investigator's personal experiences using both styles of equipment suggest that there is another potential protective mechanism available with the traditional mask design. It is common for ball-to-mask impacts to dislodge or eject the traditional mask from the face and head. This is prevented by the full coverage of the hockey style design. Impacts causing an ejection often seemed to be less severe and better tolerated. The dislodging of the traditional design is evidence that a good portion of the ball energy was removed from the system which could better protect the brain. Our review of literature found many studies that examined ball collision consequences with and without protective equipment (2-4, 14, 16, 18, 20), but none that directly contrasted different designs, considered the ejection consequences explicitly, or examined different ball trajectory effects. These studies do reveal that most of the conditions tested resulted in accelerations below MTBI threshold levels, but as presented earlier, catchers do experience a meaningful proportion of these cases and the consequences are potentially catastrophic. The primary purpose of this project was to compare and contrast the effects of catcher mask design on acceleration measures caused by ball impacts. To provide further detail about mask functionality, we considered additional independent variables and developed a two-part study. In Study 1, the consequences of four impact locations were added and for Study 2, the influence of two trajectories were added.

**METHODS**

*Protocol*
Human testing for this project was impractical, so a head model was constructed. A plastic mannequin head (male) filled with a combination of ballistics gel, wood and lead approximated the physical characteristics of a human head. Human body models (19) indicate the head and neck constitute 8% of total body weight. Our model weighed 5.9 kg, which projects to a 73.9 kg person. The center of mass was at the tragus of the ear, which also matches anthropometric estimates. The head was mounted as a shallow ball joint to allow 3-d rotation and springs were integrated to mimic muscle tension. While the technical sophistication of our model was minimal, its response to impacts appeared to be fairly lifelike (e.g., rotation about all 3 axes were evident following some impacts). It is interesting to note that many more

sophisticated projects incorporate a horizontal sled apparatus that does not allow any form of rotation response (18). It appears reasonable that any differences measured in the experiment could be attributed to the different equipment designs.
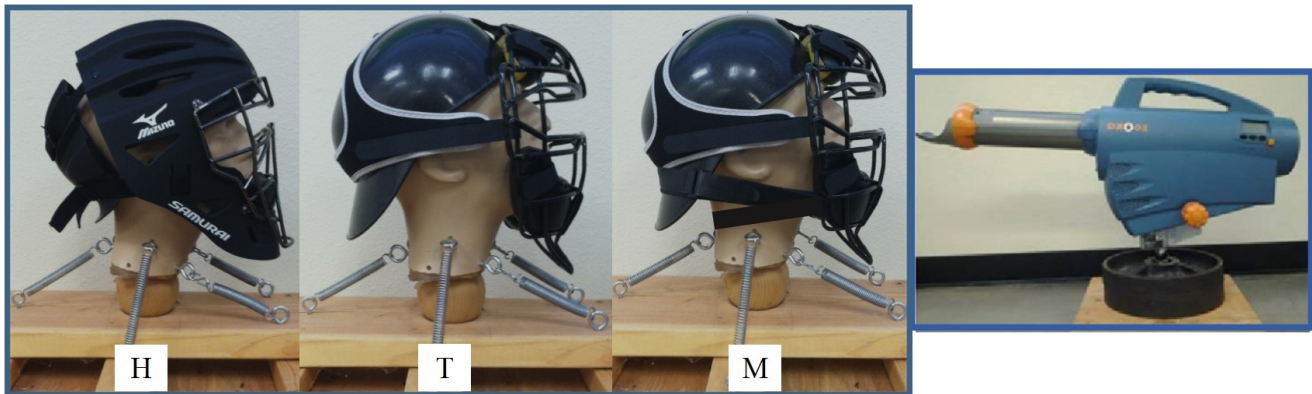


**Figure 1**. Illustration of hockey (H), traditional (T), modified traditional (M) and pitching machine used in the project.

Three masks (shown in Figure 1) were used in testing: (a) a hockey (H) style version (Samurai G4, Mizuno, Norcross, GA), (b) a traditional (T) two-piece mask and skull cap version (FM25LMX, All-Star, Shirley, MA), and (c) a variation of the traditional which was modified (M) by adding two straps (one passing behind the neck and the other placed just above the bill of the helmet) to prevent mask displacement subsequent to the ball impact. With this modification we sought to elucidate specific protection mechanisms associated with mask ejections. A baseball pitching machine (ZS740, Zooka Sports, Redmond, WA) donated to our lab was used to shoot the ball at the masks (Figure 1). The speed was selected as a percentage of full power, with outgoing velocity displayed on a digital readout. Actual ball velocity at the 100% setting was verified in pilot testing from the elapsed time between infrared photocell interruptions placed 1.50m apart (63501IR/54060, Lafayette Instruments, Lafayette, IN). A standard collegiate baseball (0.146 kg) was fired at 100% (28.2±1.2 m/s, ~58 J of kinetic energy) with the pitching machine placed 2.5m from the head-form for all tests.

Inside the head-form, a cavity and platform were created to accept mounting of a 3-d linear accelerometer (X250-2, Gulf Coast Data Concepts, Waveland, MS) to digitally record (512 Hz) the impact responses. This platform was oriented with the horizontal (transverse) plane of the head. The anterior-posterior and medial-lateral linear acceleration vector signal recordings were added to obtain the horizontal plane resultant acceleration and the peak from each trial was identified for analysis (Figure 2). Rotational acceleration was not examined.

Study 1 examined effects of impact location (high/low vertically and center/side horizontally) for ball trajectories that were orthogonal to the frontal plane of the headform. Study 2 used a mid-level, slightly lateral to the mid-line impact location and focused on the effects of ball trajectory angle (perpendicular or oblique to the frontal plane). The head-form base was rotated 40° so that the trajectory was approximately orthogonal to the curvature of the H mask

at the intended impact location. These combinations are illustrated in Figure 3. Five trials were taken for each experimental combination.
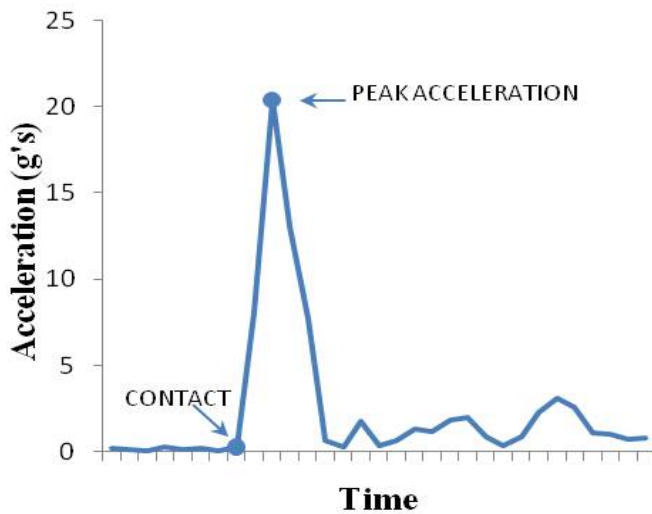


**Figure 2.** Exemplar resultant acceleration record.



**Figure 3.** Ball/mask impact location and trajectory detail.

*Statistical Analysis*

For Study 1, the effects of mask design and impact location and their potential interactions on head accelerations were analyzed via a 3 (T, H, M) x 2 (high, low) x 2 (center, side) repeated measures ANOVA ($\alpha=0.05$) with Fisher post hoc tests applied when indicated. For Study 2, the effects of mask design and ball trajectory angle and their potential interactions on head accelerations were analyzed via a 3 (T, H, M) x 2 (orthogonal, angled) repeated measures ANOVA ($\alpha=0.05$) with Fisher post hoc tests applied when indicated.

**RESULTS**

In Study 1, a significant triple interaction effect was identified (see Table 1). This required every experimental condition combination to be examined directly and precluded characterization of any primary effects. The means and standard deviations of each experimental condition are presented visually and numerically in Figure 4, organized to focus on the mask contrasts within each impact location.

For low-center impacts, the H mask acceleration was 38% less than the T and M designs (blended average of 24.4g). However, for the low-side collisions all three designs performed comparably (overall average of 12.4g). For impacts at the high-center location, the T and H masks performed comparably (blended average of 20.2 g) and were 38% better than M. Differences were apparent between all three equipment versions for low-center impacts; H demonstrated the lowest peak accelerations which were 33% lower than those of T, which were then another 32% lower than those of the M design.

For Study 2, there were no significant effects present (see Table 1 for details). The overall mean and standard deviation for peak acceleration was 22.7±0.4g.

**Table 1**. ANOVA results for Study1 and Study2.

| Source | F-Ratio | Probability |
|---|---|---|
| Mask, Vertical and Horizontal Impact Locations | | |
| M x V x H | 8.098 | 0.006 |
| M x V | 14.585 | 0.001 |
| M x H | 0.062 | 0.940 |
| V x H | 8.214 | 0.014 |
| V | 56.544 | 0.001 |
| H | 34.607 | 0.001 |
| M | 45.813 | 0.001 |
| | | |
| Mask and Ball Trajectory Angle | | |
| M x A | 0.590 | 0.574 |
| M | 0.113 | 0.892 |
| A | 1.542 | 0.240 |

*Note.* The abbreviations M, V, H and A refer to the Mask, Vertical and Horizontal locations and trajectory Angle factors, respectively. Degrees of freedom for the MxVxH and MxT interactions was 2,12. For all other interactions and main effects the degrees of freedom was 1,12.
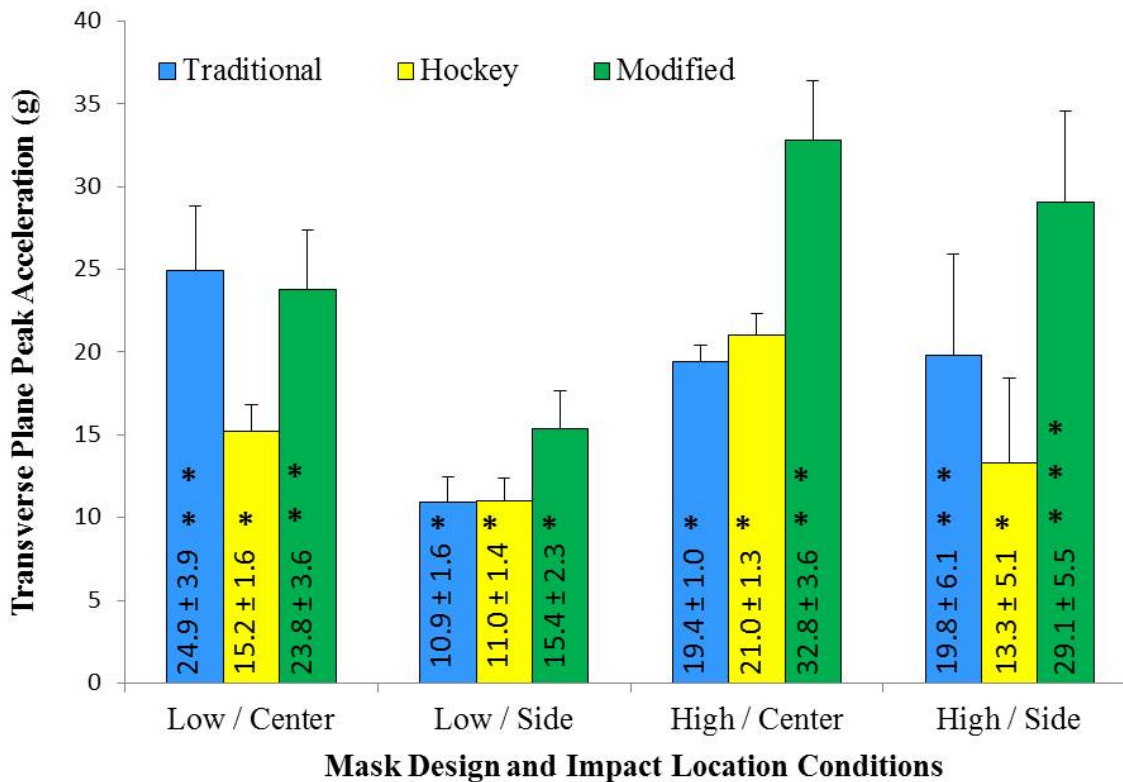


**Figure 4.** Peak accelerations for each combination of mask and impact location factor. Values on bars are mean and standard deviation for that condition. Asterisks indicate post hoc contrast outcomes; if bars have different numbers of asterisks, the differences were significant.

## DISCUSSION

We acknowledge that the simple head-form built for this project prevents direct comparison with other published reports. However, it did appear that the peak acceleration measures for the center-line impacts in Study 1 were very similar to published values (18) and any significant differences identified in this project can be logically attributed to the performance of the equipment. The additional straps added to the traditional design performed as intended and prevented displacement of the headgear which allowed for a clearer view of the ejection mechanism consequences for the traditional design.

The T and H masks differ in design and appeared to use different protection mechanisms, both of which appeared largely effective. The T mask capitalized on an ejection mechanism that removed energy that could be transferred to the brain as the equipment flew off the head. For the T impacts, we observed that the ball often dropped nearly straight down when the mask was dislodged. The H mask has a more angled shape and we noted that the ball often ricocheted off the H mask with a good amount of speed. This greater deflection of the ball would likely redirect its energy instead of allowing transfer into the head. For the M version, the additional straps prevented ejection and its flatter shape provided less deflection of ball energy, which combined the undesirable qualities of each standard mask. This was shown statistically for all but the low-side condition. Based upon the peak acceleration results in Study 1, it appears that both the T and H masks offer good protection, with the H version performing somewhat better overall when balls collided with the mask travelling orthogonal to the frontal plane.

In game situations, balls very frequently will strike the catcher at an oblique angle, which prompted our Study 2 effort. We identified no significant effects for the ball trajectory angle or design. Both trajectories may have been approximately orthogonal to the mask curvature which may have prevented T's ejection mechanism as well as H's deflection mechanism from operating. If this was the case, impact mediation and ball energy transfer would be influenced only by the mask padding, and since that element is consistent across designs, it would lead to the equivalent performance measures. The construction of the head-form, which allowed for longitudinal axis rotation subsequent to the ball impact, might also have influenced these results.

The peak accelerations measured in the study were well below the levels reported to have a high probability for producing MTBI. This suggests that the currently available catcher's gear functions reasonably well. An alternate explanation is that the ball speed used (~64mph) was inadequate. This was the maximum setting for the pitching machine and it was placed very close to the head-form, so the loss of speed for an actual pitch (about 10%) by the time it reaches the batter was minimized and represents what a 70mph pitch might produce. While this does not represent adult levels of play, it may be quite relevant for the youth baseball environment which has a larger number of participants. The smaller head mass of youth/children would give rise to greater acceleration values than those measured here and would represent greater risk levels. We also noted that advertising for catcher helmets

frequently emphasize light weight; while this would very likely facilitate playing performance, a heavier helmet would minimize the acceleration resulting from the impact. The H mask (1.29 kg) was approximately 30% more massive than the T mask (0.98 kg) which would necessarily result in smaller accelerations if the head-form was limited to pure linear motion responses as some studies have employed. Given the unique features of our test apparatus, particularly its rotational motion reaction, it would be inappropriate to speculate further about the mass consequences. It is also possible that ball impacts to the helmet, not the face mask, more often lead to MTBI for baseball catchers. Finally, we noticed significant deformations to the facemasks of both designs, which represents another energy absorption mechanism, and highlights the importance of inspecting gear regularly to ensure proper function is preserved.

## ACKNOWLEDGEMENTS

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