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Efficacy of Softball Face Masks at Reducing Linear and Rotational Head Acceleration

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ABSTRACT

This research study looked at the efficacy of infield softball face masks at reducing concussion risk. The primary goal of this research was to contrast head accelerations experienced during softball impacts for different brands of softball face masks. In order to achieve this goal, a surrogate headform equipped with different brands of face masks was impacted at a constant impact location and ball speed. The resulting headform accelerations (linear and rotational) were collected with a Vernier accelerometer upon each impact and analyzed. The results of the study showed that all tested brands of face masks were successful at reducing head acceleration severity. Moreover, significant differences in performance were observed between the different brands of face masks. One can conclude from this research that particular brands of face masks can more effectively reduce concussion risk because they better reduce head acceleration values. Due to the study results, softball players may have a better understanding of face mask performance, which could lead to higher mask implementation in the sport and an overall reduction in softball-related concussion occurrence.

Introduction

Many organized sport teams are currently available for young athletes. Across these different activities, a persistent concern over injury risk exists. One commonly occurring injury is a concussion, which is a form of traumatic brain injury caused during a head impact that transmits an excessive amount of force to the brain (Daneshvar, 2011). Concussions have been studied extensively in the field of sports injury, and researchers are aware that the consequences can be long-lasting. Concussions have been shown to negatively affect memory, concentration, and reaction time; this form of brain injury may also cause chronic headaches and sleep disturbances (Bratsis, 2013; Siu, 2016). The Centers for Disease Control and Prevention (CDC) estimates that around 3.8 million concussions occur in sports and other recreational activities each year (Siu, 2016). When considering the negative effects of concussions, it is important to examine the causes of this injury within individual sports.

One specific sport where concussion risk is a concern is softball. It is estimated that around 4,700 softball-related concussions are treated in emergency departments nationwide each year (Strickland, 2019). However, this number may be considerably low; many concussions in the sport go unreported and untreated because athletes often underestimate the severity of head injuries and fail to seek medical attention (Jett, 2021). The most common cause of concussion in softball occurs when a defensive player known as an infielder is struck by a batted ball (Gessel, 2007). More specifically, injury surveillance data has reported that impact from a batted ball accounts for 61.2% of all concussions in the sport (Jelsema, 2015). The threat of concussion occurrence in softball poses reason for concern, as sports medicine researchers have found that this injury may be a risk factor for long-term cognitive impairment and mental health problems (Manley, 2017). As a result of this concern, softball players have adopted a specific type of protective equipment known as an infield softball face mask to help reduce the risk of injury.

The popularity of softball face masks has recently increased; however, there is currently an insufficient amount of research on face mask effectiveness. Due to this overall lack of analysis, there are no national requirements obligating softball players to wear face masks (Morris, 2018). Consequently, many of these players do not wear masks while playing in defensive positions, which is where the majority of concussions occur in the sport (Gessel, 2007). This lack of requirements causes great controversy in the softball community, as many people argue in favor of the permanent implementation of face masks. The United States Consumer Product Safety Commission (CPSC) reported that about 36% of all injuries in softball could be significantly reduced with the use of safety equipment (Morris, 2018). Providing a better understanding of face mask efficacy could allow for higher face mask implementation and contribute towards this reduction in injury. In order to settle the controversy and reduce uncertainty about the efficacy of softball face masks, additional research is needed to help determine whether or not this protective measure is effective at reducing the risk of injury for softball players.

Literature Review

Concussive Accelerations

In previous studies determining the effectiveness of helmets in sports, researchers have relied on knowledge regarding the cause of concussions. A concussion ultimately occurs during a head impact when there is a change in acceleration that causes the head and brain to move rapidly back and forth (Graham, 2014). Due to this movement, the brain collides with the skull and damages brain cells (CDC, 2014). The purpose of a face mask is to reduce this movement by limiting the energy transferred to the head during a softball impact (Daneshvar, 2011). Face masks are designed to do this by absorbing the impact energy and displacing it over a larger area (Sone, 2017).

Previous research across different sports evaluating the effectiveness of helmets have analyzed changes in the head acceleration values that cause a concussion. The two main acceleration values involved in a concussion are linear head acceleration, which occurs in a forward and backward direction, and rotational head acceleration, which describes the side-to-side twisting motion of the head (Graham, 2014). Although these two head responses can occur independently, researchers have reported that concussions are most common when they occur simultaneously (Graham, 2014). The higher acceleration values a head experiences, the more likely a concussion is to occur. Therefore, helmets that are better at reducing head acceleration values also better reduce concussion risk (Morris, 2018).

Previous studies have suggested that a concussion can occur when the head experiences linear acceleration above 80 gravity units (g's) and rotational acceleration above 2,500 rad/s^2 (Siu, 2016). However, the exact injury threshold at which a concussion occurs is currently debated because researchers are unsure about how much of the brain needs to experience damage to produce a concussion (Graham, 2014). As a result, the exact acceleration values that cause concussions are uncertain, which restricts the ability to predict a concussion during head impacts (Graham, 2014). In other words, it is currently difficult to accurately predict the occurrence of a concussion, but head acceleration values can still be compared to the suggested threshold to help provide an approximation of concussion risk.

Helmet Efficacy in Baseball and Other Sports

Relatively few studies have been conducted to specifically assess infield softball masks' ability to mediate head impacts. The majority of research evaluating the efficacy of helmets has been conducted in other sports, such as baseball. Previous research in baseball has examined whether the design of a catcher mask affects its ability to reduce concussion risk. One such study compared different styles of catcher masks by using a Hybrid III headform, which is commonly referred to as a crash test dummy (Laudner, 2014). The researchers placed the helmets on the headform and impacted them at different locations and velocities. After each impact, linear and rotational acceleration values were recorded and later used to determine which style of mask best reduced the force of the impacts. Once multiple trials were conducted on each helmet, it was concluded that there are differences in catcher mask performance based on design (Laudner, 2014). Other similar studies in the sport have also utilized the same experimental research design to examine the efficacy of different helmet styles (Siu, 2016). Overall, these catcher mask studies have shown that there is an 85% reduction in the head acceleration values that lead to a concussion while wearing a catcher mask as opposed to not wearing one (Morris, 2018). However, this finding is specific to baseball catcher masks, which offer greater protection than softball face masks due to structural differences. As a result, additional research is needed to determine how well different softball face masks will reduce head acceleration values.

In the past, a great deal of similar research has been conducted in different sports including football, hockey, and soccer. However, different findings exist across independent studies. While many studies have shown that wearing a helmet reduces the risk of obtaining a concussion, other research has opposed this finding (Delaney, 2008). One such study tested head acceleration values during football-to-head impacts on a surrogate headform. Linear and rotational accelerations were recorded during impacts with and without headgear, and no significant difference in head acceleration was found between the trials (Withnall, 2005). Similar conclusions were reached in another review of helmet efficacy where researchers concluded that overall higher rates of helmet implementation were not associated with lower concussion incidence (Sone, 2017). In other words, some studies have found that wearing a helmet provides little-to-no better protection against concussion than not wearing one. Since previous research has shown that helmets may not always be effective at reducing concussion risk, it is important to determine whether softball face masks provide protection against concussive accelerations for softball players.

Face Mask Efficacy in Softball

Out of the few studies examining softball face mask efficacy, multiple have compared softball face masks of different materials to determine whether plastic or metal masks are more effective at reducing injury risk. Each of the examined studies showed that metal softball masks outperformed plastic ones (Morris, 2018). In a study assessing facial fracture risk, plastic face masks were much more likely to experience damage upon impact. More specifically, softballs projected at the plastic masks were able to contact the surrogate headform due to the plastic bending, which allowed for greater acceleration to be transported into the headform (Morris, 2018). Based on these previous findings, metal masks would also most likely provide the greatest protection against concussion. For this reason, metal face masks were the only type assessed in this study.

Another important study in the field identified a significant gap in research: “The ability of fielder’s masks to attenuate concussive accelerations is not well established” (Strickland, 2019). More research is needed to assess how softball face masks specifically reduce the head acceleration values that lead to concussion. This current gap in research leads to the question: Which brands of metal infield softball face masks are most effective at decreasing concussion risk by reducing linear and rotational head acceleration? A face mask’s ability to reduce head acceleration may be the greatest form of defense for avoiding concussion; therefore, an increased understanding of different face masks’ performance will help determine the benefits of wearing them (Morris, 2018). Prior to conducting the study, it was hypothesized that there would not be statistically significant differences in head acceleration values between the different brands of face masks tested because they were similar in design and material and therefore were assumed to provide similar protection.

Methodology

The primary goal of this study was to evaluate the efficacy of different brands of metal infield softball face masks at reducing head acceleration. In order to achieve this objective, an experimental research design was used. The independent variable altered was the brand of face mask while the dependent variable was the resulting linear and rotational head acceleration values. This type of methodology was modeled off of previous studies in the field of sports injury identified earlier; it was the most commonly used setup and it provided quantitative data that allowed objective comparison of the face masks (Laudner, 2014; Morris, 2018; Siu, 2016).

HIGH SCHOOL EDITION
Journal of Student Research
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The use of human subjects was unethical for this project due to injury risk, so a surrogate headform was needed. While previous concussion-related studies utilized professional Hybrid III test dummies, this device was not available for this study due to a limited budget. As a result, a head model was constructed (Fig. 1). A styrofoam head was attached to a tripod wig stand and secured with duct tape and wood. Although the technical sophistication of the headform differed to that of previous research, the response to softball impact seemed fairly lifelike. The Eerya Mannequin Head Tripod was specifically selected because of its designated head mount tilt. It allowed for 90° rotation in each direction as well as 60° tilt which closely resembled the movement of a human neck (Siu, 2016). Additionally, a hole was cut into the top of the styrofoam head so an accelerometer could be inserted and secured inside. The Vernier Go Direct Acceleration Sensor was chosen because it was specifically designed for use in helmet impact tests and could connect to a computer wirelessly via bluetooth to display the results in real time (Vernier, 2019). The device did not measure the head impact force directly, but it instead measured the desired linear and rotational acceleration values of the headform in response to softball impacts (Graham, 2014).

Figure 1. Surrogate headform. A head model was constructed using a styrofoam head and tripod wig stand.

Six brands of infield softball face masks were analyzed: Mizuno, Schutt, EvoShield, Markwort, Champro, and Rip-It. Each of these masks, which were similar in design and metal material, were selected because they were analyzed based on brand rather than specific design features. Each mask had foam padding and adjustable head straps to properly fit them onto the headform with the padding aligned on the chin and forehead. Once positioned correctly, zip ties were used to secure the face masks to the headform. They were wrapped around the exterior of the face masks to ensure the masks would not fall off of the headform. This action was not believed to have an effect on the results of the study because the zip ties did not provide any additional protection to the head. Instead, they ensured that the masks stayed in the proper position during testing to allow for increased accuracy when measuring the head acceleration values.

Line drive impacts were analyzed in this study, meaning the ball did not come into contact with the ground before striking the headform. Line drives were chosen because they were more predictable and accurate to replicate than bouncing balls (Morris, 2018). A First Pitch Baseline pitching machine was used to project Rawlings 12-inch softballs at the headform. The machine was set at a constant speed of 55 miles per hour for each trial. This speed was selected based on the average female high school softball player's batted ball velocity of 24.6 ± 0.51 meters per second, or about 55 miles per hour, in order to provide a real-life scenario condition (Morris, 2018).

In order to determine the control linear and rotational acceleration values, bare-head impacts were conducted on the headform. This control trial was necessary so the masked trials could later be compared to it and show the reduction in head acceleration values. Each trial was performed at the same frontal impact location at the center of the face between the eyebrows and nose, mirroring previous studies that used the same location to ensure that the maximum amount of energy was transferred from softballs into the masks (Eckersley, 2018). Six trials were conducted on each face mask to increase the accuracy of the impact data. During each trial, Vernier software connected to the accelerometer was used to record the magnitude of the linear and rotational acceleration of the head. The testing was repeated for each mask until all trials were completed.

Results and Analysis

A sequence of softball-to-headform impacts was conducted when the headform was both bare and equipped with different brands of face masks. The mean linear and rotational head acceleration values were calculated for each set of impacts by averaging the data. The bare headform had mean linear acceleration of 332.237 g's and rotational acceleration of 3,698.663 rad/s². These values indicate a high potential for injury without wearing a face mask because they exceed the suggested concussion injury threshold of 80 g's and 2,500 rad/s² (Siu, 2016). Three out of the six face masks also exceeded 80 g's, including the EvoShield, Markwort, and Champro brands, which indicates poor protection offered. No mask exceeded rotational acceleration of 2,500 rad/s².

Each mask resulted in decreased head acceleration from the bare-head impacts; however, there was a large range in values between the face masks. The EvoShield face mask resulted in the highest linear acceleration at 201.242 g's, while the lowest occurred in the Mizuno mask at 40.902 g's. In the rotational direction, the highest acceleration resulted in the Champro mask at 2385.964 rad/s², and the lowest resulted in the Schutt mask at 260.236 rad/s². These large ranges in head acceleration values indicate significant differences in performance between the brands of face masks. Table 1 displays the mean head acceleration values for each face mask.

Table 1. Average linear and rotational head acceleration.

Face Mask:	Mean Linear Acceleration	Mean Rotational Acceleration
None (Bare-head)	332.237 g's	3,698.663 rad/s²
Rip-It	68.823 g's	1,846.630 rad/s²
Mizuno	40.902 g's	330.616 rad/s²
Schutt	77.798 g's	260.236 rad/s²
EvoShield	201.242 g's	2,047.098 rad/s²
Markwort	127.644 g's	1,711.865 rad/s²
Champro	134.096 g's	2,385.964 rad/s²

In order to determine the extent to which each mask reduced head acceleration values, a comparison was made between the face mask and bare headform impacts using the percentage reduction formula (McIntosh, 2002), Eq. (1). The outcome of this equation represented the percentage to which each face mask reduced head acceleration. A higher percentage reduction is associated with increased protection being offered by a face mask.

Equation 1: Percent Reduction $= \frac{x_1 - x_2}{x_1} * -100$

The percentages in reduction for linear and rotational acceleration were analyzed independently because both values were measured in different units. The brands that demonstrated the greatest percentage reduction in each type of head acceleration were considered most effective because they limited the force of the softball impacts to the greatest extent. Table 2 displays the percent reductions in linear and rotational head acceleration for each face mask. The greatest linear acceleration reduction was the Mizuno face mask at 87.689% while the greatest reduction in rotational acceleration was the Schutt face mask at 91.061%. When all of the data was averaged together, the face masks decreased linear head acceleration values by 67.367% and rotational acceleration by 61.327%.

Table 2. Calculated percent reduction in linear and rotational head acceleration.

Face Mask:	Linear % Reduction	Rotational % Reduction
Rip-It	79.285%	50.073%
Mizuno	87.689%	91.061%
Schutt	76.584%	92.964%
EvoShield	39.428%	44.653%
Markwort	61.580%	53.717%
Champro	59.638%	35.491%
Overall	67.367%	61.327%

Discussion

The data demonstrated that all masks were successful at reducing head acceleration values since they resulted in decreased values from the bare-head impacts. This finding corresponds with previous studies that found higher helmet use reduced concussion occurrence due to the protection offered to the head and brain (Morris, 2018). Although some of the tested face masks exceeded the concussion threshold for linear head acceleration, none exceeded the threshold in the rotational direction. A likely explanation for why this occurred was that all impacts were conducted straightforward at a frontal location, which would not cause as much rotational acceleration as an angled or side impact would. The lack of high rotational acceleration is important to consider because previous research has suggested that concussion is most likely to occur when both acceleration responses occur simultaneously (Graham, 2014). Additionally, high linear acceleration alone has been found to be a poor predictor of concussion (Siu, 2016).

Variation in head acceleration values between the different masks was significant, indicating notable differences in performance between brands (Morris, 2018). This finding refuted the original hypothesis, which was that all masks would perform similarly due to their similarities in overall design features. An explanation for this result is the specific design for each brand of mask. Although the masks were similar in design and materials, there were slight differences in their structure, padding, density, and other factors that may have contributed to variability in performance. Additionally, although the chance of concussion was not calculated, previous research implies that masks that greatly reduce head acceleration will also better reduce the risk of concussion (Morris, 2018). This finding relates to how well a mask absorbs and disperses the impact energy, reduces the energy transferred to the head, and limits the head's movement and brain's contact with the skull (CDC, 2014). Therefore, masks resulting in lower head acceleration can be labeled as most effective. Considering these factors, the Mizuno and Schutt face masks could be considered most effective at reducing head acceleration values and the risk of concussion in this study.

During this study's headform-impact trials, a few noteworthy face mask responses occurred. The EvoShield face mask cracked upon the first impact. After the final impact, the front of the face mask completely detached. Additionally, a softball was able to lodge itself into the Mizuno face mask, making visible contact with the headform. If these responses occurred on a real athlete, more energy would transfer into the head, resulting in greater head accelerations (Morris, 2018). Since these responses could have caused outliers in the data, the head acceleration values for these impacts were not included in the analysis. However, these factors are important to consider when analyzing the safety and efficacy of softball face masks.

Limitations

Although this study analyzed the effectiveness of softball face masks, there are limitations that impact the generalizability of the results. The first limitation to acknowledge is human error. During the trials, the headform moved upon each impact and may not have been placed at the exact same angle each time, which may have altered the actual impact location for each trial and reduced the validity of the study. An attempt to minimize this error consisted of placing a wooden board in front of the tripod for the head to rest on in the same position each time. An additional limitation could have resulted from the simplicity of the headform. Although a constructed headform was most appropriate for the study, a real human head may respond differently to softball impacts than the styrofoam headform did. As a result, the ability to completely generalize this study's results to actual humans is limited. Another limitation to consider is the lack of analysis on all impact conditions. This study only tested one impact location and one ball velocity. Other impact types, locations, angles, and velocities can occur during real gameplay, so the ability to generalize the results of this study to a larger understanding of the effectiveness of the masks is limited. One final limitation to consider is how face mask deformation, such as cracks or dents, may have affected the head acceleration results. Although little visible deformation was noticed, the masks were impacted multiple times, which may have altered the impact results. However, face masks are reused in real-life gameplay, so it was considered acceptable to perform multiple impacts on each face mask. Each of these factors should be taken into account when assessing the overall effectiveness of the different brands of face masks.

Implications

All tested brands of face masks in this study were successful in reducing head acceleration values, with the Mizuno and Schutt mask decreasing linear and rotational acceleration respectively to the greatest extent. This new understanding holds many implications for future researchers and softball players. The results of this study can aid future research by providing a basis for face mask performance. Other studies assessing the efficacy of face masks can compare their results to the data from this study in order to see whether face masks perform consistently across multiple tests. Additionally, the outcome of this study holds potential benefits for softball players. The results can inform softball players about the benefits of wearing a face mask. Since the data showed that all tested brands were successful in reducing head acceleration values, softball players will have an increased understanding of each face mask's performance and may choose to wear a mask since it can help reduce the risk of injury. With increased mask implementation, there may also be an overall reduction in softball-related concussion occurrence.

Future Research

Future researchers are encouraged to address the limitations of this study in order to provide a better understanding of face mack efficacy. Since this study only assessed one impact condition that is not representative of all factors influencing face mask efficacy, future studies can test more impact locations, angles, and ball speeds that simulate diverse impact scenarios that may occur during real gameplay (Morris, 2018; Siu, 2016). This would allow for an increased understanding of face mask efficacy and injury prevention during real-life situations. Another suggestion for future research is to further analyze the impact of design on performance. Since the results of this study suggested major differences in performance between different brands of face masks, future researchers can address why these differences in performance may have occurred. Considerations of the relationship between face mask design and performance can allow face mask designers to alter specific features such as materials, weight, and head coverage in order to provide better protection to athletes (McIntosh, 2002).

Conclusion

Many differing viewpoints exist as to whether softball players should be required to wear softball face masks; however, a lack of analysis on their overall effectiveness at reducing the risk of injury has resulted in no national requirements for their use. This study aimed to provide a deeper understanding about which brands of metal face masks effectively reduce head acceleration values and concussion risk. The results of this study illustrated significant differences in softball face mask performance based on brand, which refuted the given hypothesis that each face mask would perform similarly due to their design similarities. While the original hypothesis was refuted, the research question about which brands of softball face masks reduce head acceleration values to the greatest extent was able to be determined from the data. The Mizuno face mask was deemed most effective at reducing linear acceleration and the Schutt at reducing rotational acceleration because they resulted in the highest percent reduction in headform acceleration values. The results of this study also indicated that the Mizuno and Schutt face masks were most effective at decreasing concussion risk because they reduced head acceleration values to the greatest extent. The findings of this study can be used as a basis for future researchers that further analyze the efficacy of softball face masks and in consideration for softball players when selecting a face mask to purchase and wear for protection against concussion.

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