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Helmet Prototype Response Time Assessment using NCAA Division 1 Collegiate Football Athletes

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ABSTRACT

Background: With advances in concussion research, an increasing amount of resources are being allocated to advancing football helmet technology. **Objective:** This study assesses the claim that a new modified helmet prototype provides greater field of view for the user as compared to a commonly worn helmet by players. **Method:** The helmets—Riddell SpeedFlex and the modified helmet—were compared based on user response time while performing a response test task using the FITLIGHT Trainer system, actual helmet field of view blockage, users' subjective perception of field of view, and balance tests. Eighteen National Collegiate Athletic Association (NCAA) Division 1 American football student-athletes completed the response test task and questionnaire. **Results:** The results demonstrate evidence that the SpeedFlex helmet provided by the equipment staff significantly increases wearers' response times, $F(2,20) = 5.646$, $p < 0.05$. Also, while the quantification of the field of view perception was similar across helmet types, the student-athlete participants perceived the modified helmet to have significantly more field of view while performing the response test task, 1.56 v. 2.56; $p < 0.05$ for frontal vision and 2.83 v. 5.39; $p < 0.05$ for peripheral vision. **Conclusion:** In addition to the findings, this study also lays out a response time test protocol using the FITLIGHT Trainer system that can be used for assessment of response time testing of football and other helmets in future studies.

Key words: Helmet, Collegiate, Athlete, Response Time, Football

INTRODUCTION

Quick response times to visual stimulus are fundamental to athlete success in American football, hereafter the sport will be referred to as football. Response time has been proven as an indicator of differentiation between elite athletes and the general population as well as a key performance indicator within elite-level sports (Bhabhor et al., n.d.; Ghuntla, Mehta, Gokhale, & Shah, 2012; Hughes et al., 2012). Successful athletes must have high capacities for heuristic decision making (Hepler, 2015). Training visual-motor reaction time has become common practice in elite-level athletes (Appelbaum & Erickson, 2018) especially for football players because of the need to constantly read and react to their surroundings in training and game environments. While the football helmet is a required piece of equipment to protect players against head injuries such as concussions, research has investigated the mitigation of head impacts during game play. However, the effect these helmets have on an athlete's response time has not been addressed in current academic literature as football helmets are meant to protect players against head injuries. Concussions are a common form of head injury sustained in football (Baugh et al., 2015; Dompier et al., 2015). Currently, when considering football helmet design, concussion prevention is an important objective, and response time may be viewed as a skill strictly related to performance and not a function of the equipment. Recent studies have considered the effect of an improved athlete response time on incidence of concussion as well as soft tissue injury occurrence. The University of Cincinnati's football team reduced concussion occurrence by approximately eight concussions per 100 student-athletes by performing response time training (Clark et al., 2015). University of North Carolina evaluated student-athlete response time and found that low performers experienced far more severe head impacts than high performers (Harpham, Mihalik, Littleton, Frank, & Guskiewicz, 2014). These correlations are not just relevant to head injuries but also lower extremity soft tissue injuries (Wilkerson, 2012). The logic behind these findings is that if a student-athlete can react faster to his or her surroundings, he/she can brace

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for impact. The relationship between football equipment and performance has been studied before (Gdovin et al., 2018), but the author found nothing that studied football helmets influence on stimulus response. To the authors' knowledge, the only known investigations for helmet influence on stimulus response were studies for a ski helmet which did not affect stimulus response and a motor cycle helmet which had a minimal effect upon response time (Bogerd, Walker, Brühwiler, & Rossi, 2014; Ruedl et al., 2011; Ružić et al., 2015). The fact that both articles were addressing common reasons people often use for not wearing helmets during the respective activities should be noted, as well as the fact that ski helmets and motorcycle helmets are rather minimalistic in nature comparatively to the design of a football helmet. At the very least, football helmets obstruct the user's field of vision by way of the facemask, but in most instances the shell of the helmet can also limit peripheral view. This study addresses the helmet's limitations of the athlete's field of view, as well as the assumed correlation of field of view and effective response time.

Eighteen National Collegiate Athletic Association (NCAA) Division 1 football student-athletes participated in and completed this study. The purpose of this research is to measure the effect of a football helmet on the user's response time by comparing response times of the student-athlete wearing no helmet, a Riddell SpeedFlex helmet, and a modified prototype helmet. The SpeedFlex helmet was selected as the baseline football helmet by the research team via guidance from the Mississippi State University (MSU) football equipment staff as it represents the most commonly used helmet for the student-athletes at the university. The modified helmet is a proprietary prototype helmet created and studied by faculty (not represented by researchers on this project) at MSU and Liberty University (LU) (Johnson et al., 2016; Rush, Prabhu, Rush, Williams, & Horstemeyer, 2017). The intended purpose of this helmet is not to expand the field of view by the student-athlete but to increase protection against concussions. However, given the unique design shape provided by the shell and facemask combination, the modified helmet was provided to this research group under the pretext that multiple users of the modified helmet—including former student-athletes current playing in the National Football League (NFL)—perceived a greater field of view while wearing it. This prototype helmet design is unique in that the facemask is inset in the shell around the view portal which is unique to most helmets where the facemask bolts onto the outside of the shell. Due to the proprietary nature of the modified helmet, the exact design specifications cannot be provided in further detail in this paper.

FITLIGHT Trainer is a wireless reaction system comprised of LED lights controlled by a computer tablet. The FITLIGHT Trainer has previously been used in research settings (Fischer, Stone, Hawkes, Eveland, & Strang, 2015; Jensen, Rasmussen, & Grønbæk, 2014; Rauter et al., 2018; Slater et al., 2018). Given the use of the FITLIGHT Trainer to measure response time in peer-reviewed literature, one of the goals for this study was to create a standard protocol to measure response times with the FITLIGHT Trainer while wearing a helmet—this could include helmets of any kind, not just football helmets. In addition to response time, the student-athlete's balance was also assessed while performing the FITLIGHT Trainer test using a force plate. Balance is the ability to maintain the center of gravity, minimizing sway, to stay upright and steady (Chander et al., 2014; Winter, 1995). Balance is a key performance factor for athletes and is necessary for competition (Davlin, 2004). ACSM (American College of Sports Medicine) includes balance performance as one of the components of fitness in their guidelines for physical fitness (Chander et al., 2014; McKeon & Hertel, 2008). Moreover, the effect of helmet use in relation to the user's ability to minimize sway statically and dynamically, while performing a FITLIGHT Trainer response time test activity, was examined. The assumption that reduced field of view might have an effect on balance was based off of human's reduced ability to balance when their eyes are closed (Shim, Steffen, Hauer, Cross, & Ryssegem, 2015). Lastly, the student-athlete's subjective perception of the helmets' obstruction of their field of view was studied by means of a questionnaire.

Thus, this study attempts to answer the following five research questions. (a) Do student-athletes perceive the modified helmet to have a greater field of view than the SpeedFlex helmet? (b) Does the modified helmet provide less field of view blockage than the more commonly used helmet, the SpeedFlex Helmet? (c) Does wearing a football helmet (compared to a no-helmet baseline condition) impact an NCAA Division 1 student-athlete's response time and/or balance using the FITLIGHT Trainer response time test? (d) Does the modified football helmet affect the student-athlete's response time and/or balance as compared to the com-

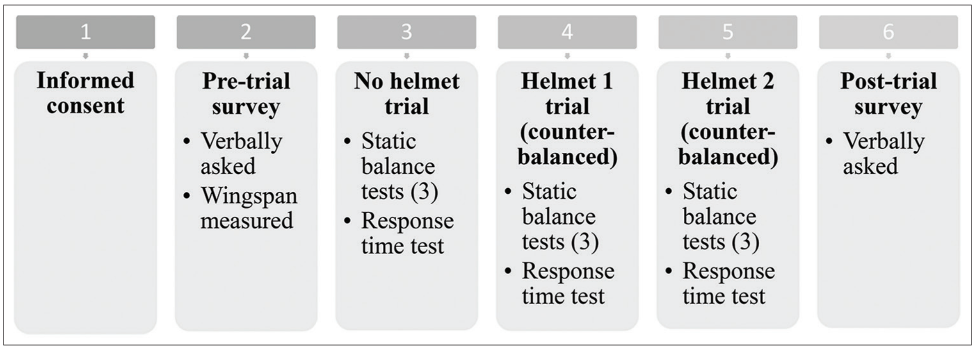

Figure 1. Procedural Protocol Flowchart. Where helmet 1 and helmet 2 are the modified helmet and the regular helmet

monly used SpeedFlex Helmet? Lastly, (e) does the student athlete's perception of greater field of view correspond to faster response time?

The null hypothesis is that no difference in response time variables will occur when measured between any of the conditions (no helmet, SpeedFlex helmet, or modified helmet). Secondly, the null hypothesis includes that there will be no difference in balance variables, measured field of view variables, or perceived field of view variables in this study and that there will be no correlation between any of the aforementioned variables.

METHODS

Participants and Design

The empirical research conducted in this study consistent mostly of experimental methods and a survey. The independent variable in this study was the helmet condition (denoted as no helmet, SpeedFlex helmet, modified helmet). The dependent variables were users' (a) response time while performing a response test task using the FITLIGHT Trainer system (including measuring elapsed time from the moment the FITLIGHT Trainer light was activated to the moment the participant deactivated the light), (b) objective helmet field of view blockage, (c) subjective perception of field of view measured by survey question responses, and (d) sway measurement variables provided by balance tests.

Due to the elite nature of football student-athletes at the collegiate level and their extremely time restrictive schedule, successfully recruiting NCAA Division 1 athletes can be challenging. The goal of the research team was to simply test as many of the student-athletes as possible based on which of them were interested and had permittable schedules. Given that this study took place in the football practice complex, the schedule from the football strength and conditioning staff allowed for the recruitment of up to 20 football participants. Participants were recruited during their regularly scheduled workout commitments. Researchers were present to explain the research study and answer any questions. Through the recruitment efforts, 19 NCAA Division 1 football male student-athletes volunteered but only 18 completed the research protocol in its entirety. One student-athlete did not complete the entire study due to other time commitments. Institutional Review Board (IRB) approval was given prior to the start of this study. Informed consent from all participants and permission to participate in the study from the head coaching staff, strength and conditioning staff, and athletic training staff were obtained. All student-athlete participants were injury free and cleared for participation by all relevant team staff.

Instrumentation

The football helmets that were used included a Riddell SpeedFlex helmet and a prototype helmet (modified helmet) designed via research projects at MSU and LU. The helmets had two different types of facemasks. The researchers understand that this could be considered a confounding variable, but the mask on the prototype was critical to the design and the institution could not provide a similar mask for the Riddell, so the most common facemask on the provided Riddell helmet was used. While the student-athletes may have had different facemasks on their own personal helmet that they used during competition, based on their position played, the same Riddell facemask was used for all participants in order to avoid introducing a confounding variable. The helmets used were appropriately fitted to the participants using increased or decreased air in the helmet pads and by adjusting the chin strap so that both helmet types correctly fit all student-athletes. The FITLIGHT Trainer reactive light system was used to measure participant response time during the response time tests. AMTI AccuGait was used in conjunction with BioAnalysis to perform balance tests as well as evaluate the ground reaction forces of the participants during the response time test. IBM's SPSS v24 was used to perform all ANOVA's and other statistical analysis.

Procedures

Participants reported to the laboratory and were verbally asked a series of pre-trial questions that provided demographic and contextual factors (e.g., age, years of experience in organized football, whether or not they had uncorrected 20/20 vision)., then the response time and balance tests were explained in detail to the participants based on the approved IRB protocols. The participants completed three trials of the experiment, one for each helmet condition (no helmet, SpeedFlex helmet, and modified helmet). Each participant was given a participant code. Even number participants performed the trials in order: (a) No helmet, (b) Modified helmet, (c) Regular (SpeedFlex) helmet. Odd number participants performed the trials in order: (a) No helmet, (b) Regular helmet, (c) Modified helmet. This was done to mitigate any order effect concerns. Each trial consisted of three static balance tests (Chander et al., 2014) and one FITLIGHT Trainer response time test (Fischer et al., 2015; Jensen et al., 2014; Rauter et al., 2018; Slater et al., 2018). After completing these tasks, the participants were verbally asked post-trial questions that consisted of the subjective field of view blockage ratings for each helmet. The total time of the experiment (outlined in Figure 1) was approximately 20 minutes per participant.

Response Time Test

Ten FITLIGHT Trainer lights were positioned in a semi-circle around a point of origin located on the back-middle of the force plate where the participant was to stand. Poles, extenders, and FITLIGHT clips were used to position the lights around the point of origin. The poles were placed in five positions with each pole located 1m away from the origin point at 0, 45, 90, 135, and 180 degrees as visualized in Figure 2a. The distance of the poles from the back center of the force plate was based off average arm length. The participants had to reach their hand within a 10 cm radius of the light to deactivate it. The distance of 1 m was set such that a wingspan of 1.83 m could easily extend and deactivate the lights within the 10 cm light response radius all without requiring the participants to lean. While every participant had a 1.83 m or greater wingspan, the goal of the study setup was to have a consistent distance and not one that catered to each individual student-athlete given the large variance in player sizes. The poles were positioned this way to record responses from 10 zones of vision: upper and lower zones of right peripheral, rightmost frontal, central frontal, leftmost frontal, and left peripheral. Upper and lower zones were created through the placement of four- and six-foot lights on each pole (Figure 2b).

The lights were numbered 1 – 10 and split into two position groups, high and low. Even numbers were low and odd numbers were high. Low lights were positioned at 4 feet above the ground and high lights were positioned 6 feet above the ground (Figure 2b). The lights "activated" by turning red, and "deactivated" when the participant's hand was waved in front of the activated light, turning the light off. The lights activated in a random order that was set for each helmet condition (i.e. the light order for every participant wearing the modified helmet was the same, but the order of the no helmet trial differed from that of the modified helmet and the SpeedFlex helmet conditions). Each individual light activated five times over the course of trial. In total, 50 lights activated during each trial. The random order was set by a random number generator and once a light had five activations, the light was no longer added to the randomized order; three orders were created. No light sequence was repeated to the same participant, but each participant completed the same light sequence for each condition. During the test, a light would activate, the participant would respond by putting his hand close to the light, the light would deactivate, then a one second delay would give the participant time to return to the ready position, eyes forward and hands at the sides with knees and elbows slightly bent, and prepare for the next light activation. The force plate measured postural sway using center of pressure (COP) excursions while the participant completed the response time test.

FITLIGHT Trainer response time was defined as the time difference between the light activation and the light deactivation by the participant. The response data set consisted of 2700 data points (response times for 18 participants, completing three helmet conditions, interacting with 10 lights, five times per light). The data was cleaned using RStudio (Version 3.5.2; 2019). After examining the outliers, determined by the 1.5 IQR (inner quartile rule), a filter removed seven response times that were less than 250 milliseconds. These included all the lower outliers because they were determined to be too fast for a human response time and were likely recorded due to light malfunctions. The higher outliers were kept in the data set because they were determined to be real response times from the student-athletes. Thus, the data set was analyzed with 2693 response times. Data was examined further using Wilks' Lambda as a test statistic to ensure that the data was approximately normally distributed. SPSS v. 24 (IBM, 2019) was used with all data sets to create a three-way [helmets(3) x lights(10) x repetition(5)] repeated measures ANOVA, $\alpha = 0.05$, to evaluate the null hypothesis that there is no difference in response time between helmet conditions. Sphericity was examined in order to use the assumed test values, and a pairwise comparison was also generated for all sets using a Bonferroni correction. RStudio was used for data manipulation and generating all graphs.

Blockage Quantification

To quantify the field of view blockage of each helmet, a picture was taken using an Insta360 Air camera from within each helmet. The camera lens was positioned half-of-an-inch below the top brim of the shell, flush with the padded lining within the football helmet, and centered between the lateral sides of the shell. The 180-degree version of the photos were edited in Adobe photoshop with a combination of the auto select, manual selection, and fill tools to change every pixel that included helmet and facemask to black coloration and every pixel that included viewing space to white coloration. Additionally, Photoshop was used to create crops of specific field of views that were as follows: Whole image, left and right 1/4th of the image, and a 1296x432 pixel image from a centered view starting from the top brim of the helmet; 1295x432 was the capture from the brim to the facemask to the edges of the peripheral of the modified helmet. Once the photos were edited, ImageJ was used to quantify the pixels that were black vs the number of pixels that were white. These numbers were compared to achieve a blockage percentage for each football helmet type.

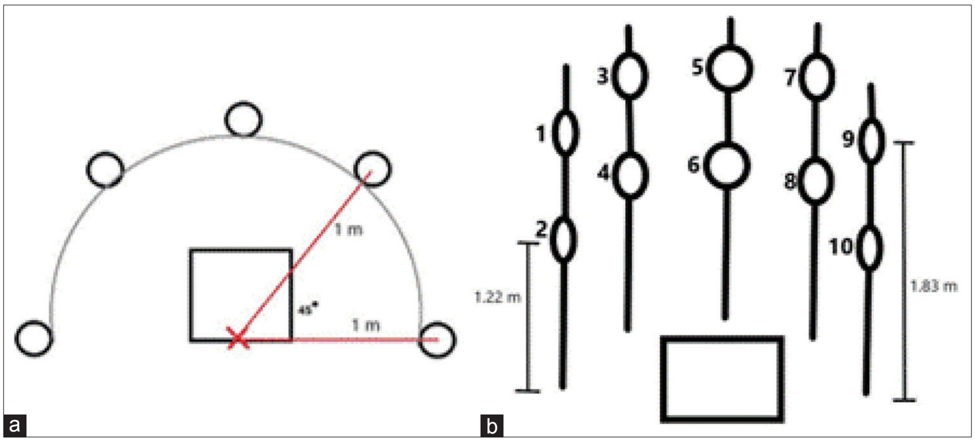

Figure 2. (a and b) Diagram of FITLIGHT Trainer set up, overhead and front views. The square represents the force plate with the back middle serving as the point of origin. Each circle represents a pole with two lights, one at 1.22 m and another at 1.83 m

Static Balance and Dynamic Response Time Balance Test

A static balance test (SB) in bilateral stance was given that consisted of having the participant step onto the force plate, finding an arbitrary spot in front of them to focus on, and standing as still as possible for 20 seconds. A dynamic balance test (DBT) was also assessed while the student-athlete performed the FITLIGHT Trainer response time test explained in a previous section (2.6). Three variables were assessed to quantify balance: anterior/posterior sway displacement, medial/lateral sway displacement, and 95% ellipsoid sway area.

Postural sway was quantified using COP excursions during both the SB and DTB condition. Based on the raw data from COP excursions, the BioAnalysis software from AMTI was used to derive dependent postural sway variables that included 95% ellipsoid sway area (95% EA) (cm^2), Anterior-Posterior (A/P) sway displacement (cm) and Medial-Lateral (M/L) sway displacement (cm). These postural sway variables hold an inverse relationship with balance performance, in that the smaller the postural sway variables are, the better the balance performance and postural stability during the balance testing conditions.

Statistical Analysis

A three [Helmet (No Helmet vs. SpeedFlex Helmet vs. Modified Helmet) by two [Balance Test (SB vs. DTB)] repeated measures ANOVA was used to analyze balance dependent postural sway variables individually that included 95% ellipsoid sway area (cm^2), A/P sway displacement (cm) and M/L sway displacement (cm). If a significant interaction was identified, then main effect significance was ignored, and the significant interaction was followed up with simple effects comparisons with a Bonferroni correction. If only main effect significance was identified, it was followed with post-hoc pairwise comparisons using a Bonferroni correction. All statistical analyses were performed using $\alpha = 0.05$.

RESULTS

The 18 student-athletes who participated had an age range of 18-22 years (mean: 19.94; SD: 1.35), a weight range of 176-322 lbs. (mean: 231.94; SD: 44.57), a height range of 1.75-1.96 m (mean: 1.87; SD: 0.069), and a wingspan range of 1.78-2.06 m (mean: 1.88; SD: 0.091). The participants included defensive and offensive linemen, defensive backs, a linebacker, wide receivers, quarterbacks, and a tight end. The participants had experience playing football that ranged from 6-15 years (mean: 11.05; SD: 2.78). Additionally, sample size was also determined to match previous literature, specifically testing NCAA Division I Athletes (Chander et al., 2014).

FITLIGHT Trainer Results

The box and whisker plots below display response time in milliseconds grouped by condition in Figure 3 and grouped by light number in Figure 4.

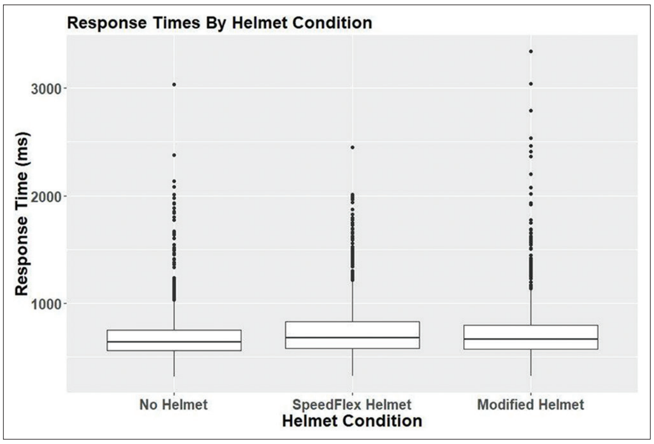

Figure 3. Boxplot describing all data collected, broken down by helmet condition; No helmet: lower quartile – 558, median – 635, upper quartile – 746; SpeedFlex helmet: lower quartile – 575, median – 672, upper quartile – 826; modified helmet: lower quartile – 568, median – 660, upper quartile – 794

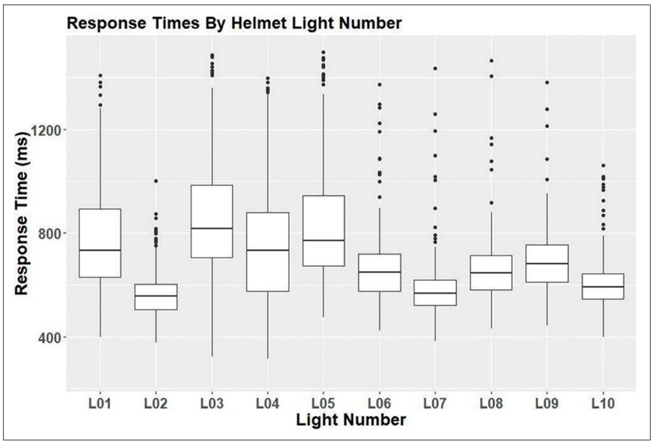

Figure 4. Boxplot of all data collected broken down by light number. Odd numbers were at 1.83 m. Even numbers were at 1.22 m. Lights 1 & 2 were at 0 degrees, 3 & 4 were at 45 degrees, 5 & 6 were at 90 degrees, 7 & 8 were at 135 degrees, and 9 & 10 were at 180 degrees

All Lights ANOVA

The three-way repeated measured ANOVA that was conducted to evaluate the null hypothesis that there is no change in NCAA Division 1 football student-athlete's response time when measured with no helmet, SpeedFlex helmet, and modified helmet when performing the response time test with the FitLight Trainer (N=2693) had three factors: helmet condition (3), light number (10), and repetitions for each light (5). The results of the ANOVA indicated a significant time effect for Helmet, $F(2,20) = 5.646$, $p < 0.05$. Thus, there is significant evidence to reject the null hypothesis. Furthermore, light number, $F(9,90) = 18.567$, $p < 0.05$ and the interaction between helmet and repetition (helmet*rep), $F(18, 180) = 2.565$, $p < 0.05$ were determined as significant.

Follow up comparisons indicated that only one pairwise difference was significant, $p < 0.05$ (between the no helmet condition, and the SpeedFlex helmet condition). The pairwise of the no helmet condition and the modified helmet failed to find a statistically significant difference at a p-value of 0.097. The pairwise of the SpeedFlex and the modified helmet also failed to find a statistically significant difference at a p-value of 1.000. Therefore, the researchers conclude that the SpeedFlex helmet did significantly affect the athletes' response times when compared to the athletes' performance while not wearing a helmet, but the modified helmet did not significantly affect the athletes' response times as compared to the no helmet condition.

Response Times Descriptive Statistics

The estimated marginal means response time for the no helmet condition was 0.659 seconds with a 95% confidence interval of 0.621 – 0.695; The SpeedFlex helmet was 0.737 with a 95% confidence interval of 0.683 – 0.791; and the modified helmet was a 0.724 with a 95% confidence interval of 0.658 – 0.791. Figure 5 shows the average times of the participants at all lights throughout each condition. The average response time for the right-side lights (7, 8, 9, 10) was 0.643, and the average response time for the left-side lights (1, 2, 3, 4) was 0.791.

As reported in the ANOVA results section of the light response times, the repetition number held significance. Figure 6 shows the steady increase of response time as compared to the order that the light was reacted to. The student-athletes, on average, trended slower as the test progressed.

Quantifying the Blockage of the Helmet

The SpeedFlex blocked 9% less than the modified helmet when considering the entire 180-degree photo. The SpeedFlex blocked 5% less than the modified helmet when considering the 1296x432 crop in the direct field of vision view. However, when only considering the outer ¼th edges of the 180-degree image, the modified helmet blocked 2% less than the SpeedFlex helmet. An example image of the SpeedFlex black and white edit can be seen in Figure 7.

Questionnaire Results

First, the participants were asked three questions regarding how they would rate their own vision in certain situations. One question asked the student-athletes how they would rate their vision compared to other football players (coded as 3 = better than most, 2 = about the same as others, 1 = worse than most). Respondents scored an average of 2.79 on this variable, suggesting that most of the participant sample believed their vision was better than the vision of other football players. The next question asked the participants how good their peripheral vision is in everyday life on a scale from 1 – 10 (1 = very poor, 10 = perfect). The average response to this question was an 8.32 indicating that most of the sample believed their peripheral vision was very good. The third question asked the participants how good their peripheral vision is on the playing field (1 = very poor, 10 = perfect). The average response for this question was 8.11, indicating that most of the sample believed their peripheral vision was very good on the playing field as well.

Prior to the experiment, participants were asked to rate on a scale from 1 – 10 (1 = not at all, 10 = very much) how much a football helmet affects their frontal and peripheral vision. The mean scores on these questions were 2.89 for frontal vision and 4.82 for peripheral vision, indicating that respondents felt that helmets impact their peripheral vision almost twice as much as they impact their frontal vision. Respondents were then asked to wear the modified helmet and a regular football helmet to participate in the experiment.

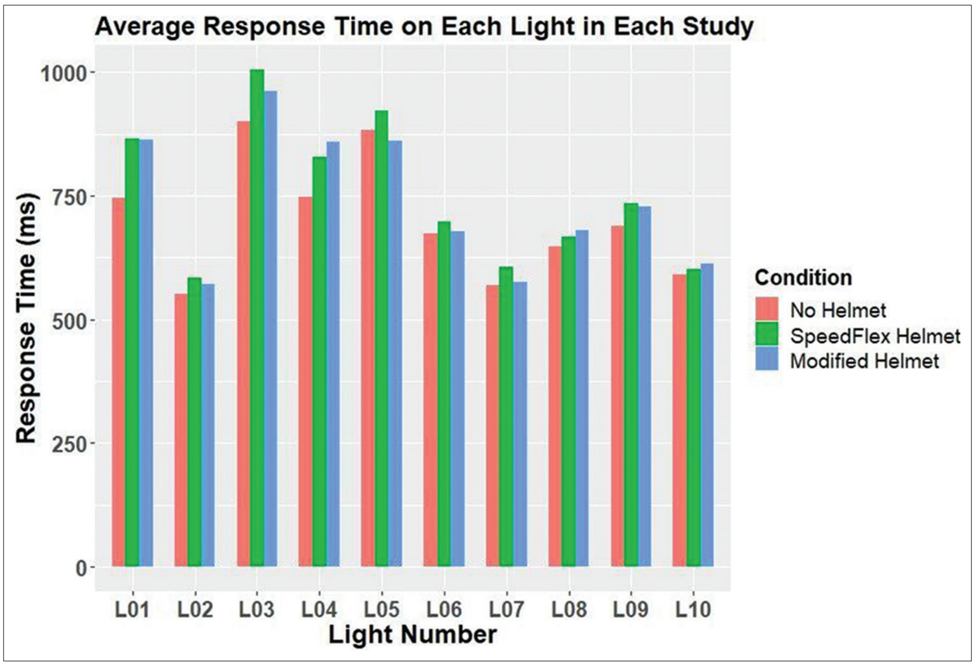

Figure 5. Shows average times at all lights through all conditions. Speed Flex and the modified helmet were found to not be significantly different, but no helmet was shown to be significantly different

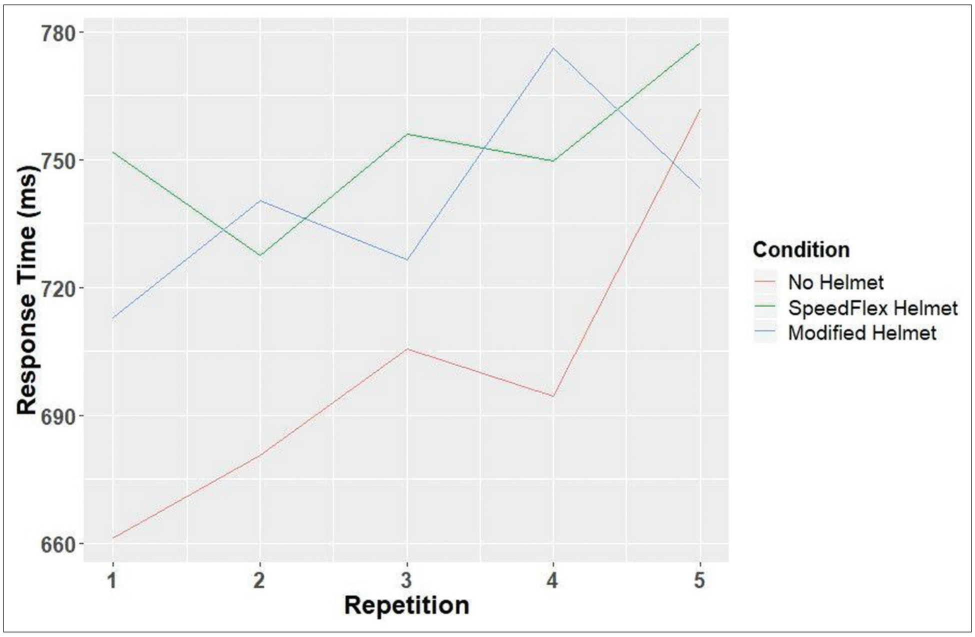

Figure 6. This graph shows the average response time by order of repetition where 1 is the student-athlete's first repetition with each light and 5 is there last repetition with each light

Figure 7. SpeedFlex blockage, black and white edited image (with circled areas indicating potential points of peripheral blockage as compared to the modified helmet)

Table 1. Perceived Impact of Helmet on Frontal and Peripheral Vision

Visual Impact	Pre-test Response	Modified Helmet	Regular Helmet
Frontal Vision Impact (1 Not at All to 10 Very Much)	2.89[2]	1.56[1,3]	2.56[2]
Peripheral Vision Impact 1 Not at All to 10 Very Much)	4.82[2]	2.83[1,3]	5.39[2]

[1]Significantly different from pretest (p<0.05) in same helmet condition in a paired samples t-test. [2]Significantly different from modified helmet (p<0.05) in same helmet condition in a paired samples t-test. [3]Significantly different from regular helmet (p<0.05) in same helmet condition in a paired samples t-test

After the experiment was complete, respondents were asked to rate the impact of each helmet on their frontal and peripheral. Responses to all three sets of questions are presented in Table 1.

Respondents reported that the modified helmet impacted both their frontal and peripheral vision significantly less than both the regular helmet and their pre-test response. After testing the modified helmet, the average response for perceived impact on frontal and peripheral vision were 1.56 and 2.83 respectively. Perceptions of the regular helmet were not significantly different than pre-test perceptions. This implies that the modified helmet makes it easier for student-athletes to see both in front of them and peripherally.

To determine whether the respondent's vision significantly impacted their perceptions of their frontal and peripheral vision, we conducted a series of independent sample t-tests. The results of the independent sample t-tests contrasting perceptions of respondents with corrected 20/20 vision and uncorrected 20/20 vision regarding their ability to see with different helmet types are presented in Table 2. The results suggest that there is a significant difference between corrected and uncorrected 20/20 vision in four of the nine situational questions the participants were asked. Those with uncorrected 20/20 vision scored significantly higher than student-athletes with corrected vision on how their vision compared to the vision of other football players (1.29 v. 1.00; $p < 0.05$), their peripheral vision in everyday life (8.9 v. 6.8; $p < 0.05$), and their peripheral vision on the playing field (8.5 v. 7.0; $p < 0.05$). The uncorrected 20/20 vision group also scored significantly lower in terms of how much a regular football helmet impacted their frontal vision (1.9 v. 4.4; $p < 0.05$).

Force Plate, Postural Sway ANOVA

For 95% EA, a significant main effect for Helmet, $F(2, 34) = 5.297$; $p = 0.021$, and for Balance Test, $F(1,17) = 109.043$; $p < 0.0001$, and a significant interaction, $F(2, 34) = 5.853$; $p = 0.017$, was identified (Figure 8). A simple effect comparison for the significant interaction revealed that during DTB, the modified helmet had lower 95% EA compared to no helmet condition. A main effect for only the Balance Test existed for A/P sway displacement, $F(1, 17) = 100.805$; $p < 0.0001$ (Figure 9), and M/L sway displacement $F(1, 17) = 128.831$; $p < 0.0001$ (Figure 10), with no significant main effect for Helmet and no significant interaction. Post-hoc pairwise comparisons revealed that SB had significantly better balance compared to DTB.

DISCUSSION

The previous studies searched for research detailing the impacts of peripheral view from inside of a football helmet versus the response time of the wearer when performing a reaction-based task such as the FITLIGHT Trainer (Bogerd et al., 2014; Ruedl et al., 2011; Ružić et al., 2015). Research was found that identified response training as a means to reduce concussions for football players (Clark et al., 2015). Additional studies validated that lower performing football players suffered from increased head trauma (Harpham et al., 2014). While improved response time was linked to improved safety, no studies were found that researched different football helmet types and changes in football player response times. The purpose of this research was to investigate that connection and determine if football helmet design—from a peripheral view perspective—can have an impact on player concussion safety through improved response time to reaction-based assessments. The results from this current study expand upon previous results by demonstrating football helmets in general do significantly increase response time and that helmet shell and facemask configuration created a significant change in perceived peripheral

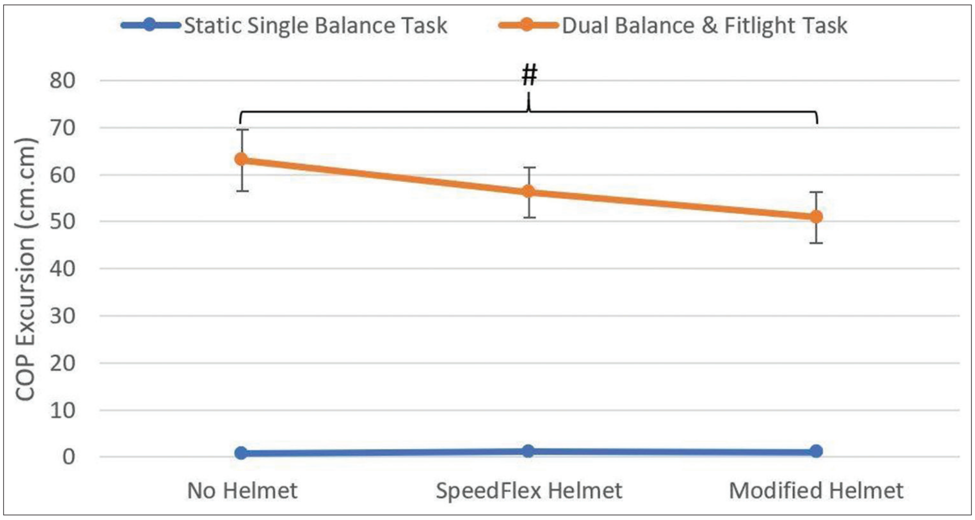

Figure 8. 95% Ellipsoid Sway Area (95% EA) for three helmet conditions (No Helmet, SpeedFlex Helmet, Modified Helmet) during Static Single Balance Task (SB) and Dual Balance and FITLIGHT Trainer Task (DTB).
represents significant difference between helmet and bars represent standard errors

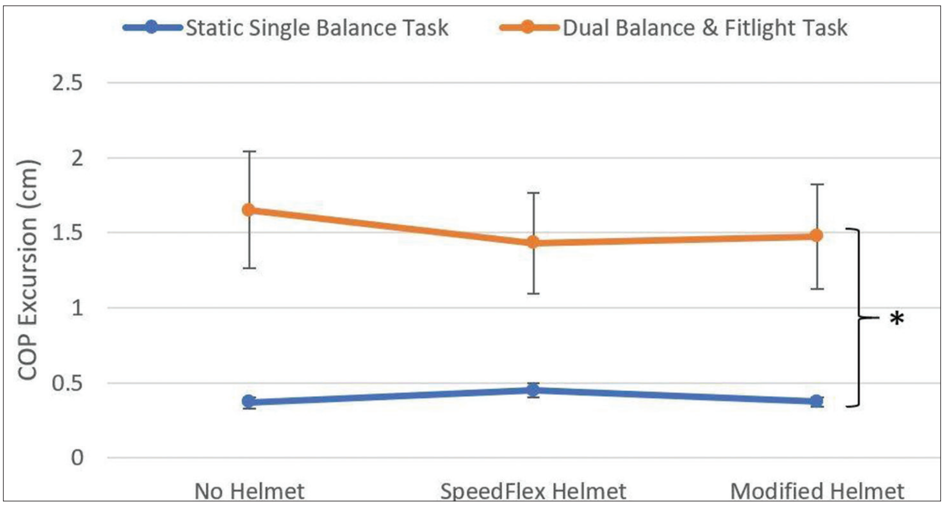

Figure 9. Anterior-Posterior (A/P) Sway Displacement for three helmet conditions (No Helmet, SpeedFlex Helmet, Modified Helmet) during Static Single Balance Task (SB) and Dual Balance and FITLIGHT Trainer Task (DTB).
*represents significant difference between balance tests and bars represent standard errors

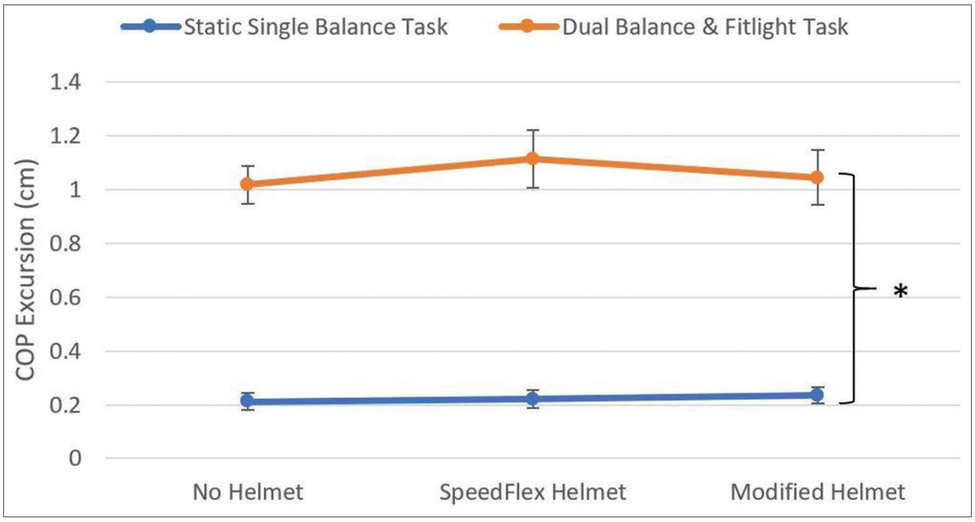

Figure 10. Medial-Lateral (M/L) Sway Displacement for three helmet conditions (No Helmet, SpeedFlex Helmet, Modified Helmet) during Static Single Balance Task (SB) and Dual Balance and FITLIGHT Trainer Task (DTB).
*represents significant difference between balance tests and bars represent standard errors

view. This study also contradicts previous studies specific to other helmet types such as ski and motorcycle helmets (Bogerd et al., 2014; Ruedl et al., 2011; Ružić et al., 2015) where minimal to no effect change in stimulus response and response time was found.

FITLIGHT Trainer Results

The ANOVA results suggest that SpeedFlex football helmet causes a significant difference in response time when compared to the no helmet condition, but the modified helmet/no helmet difference was proven to be insignificant. This alone differentiates football helmets from other types of helmets that have been studied previously (Bogerd et al., 2014; Ruedl et al., 2011; Ružić et al., 2015). Football helmets are not the same as motorcycle helmets or ski helmets, therefore the differences in function and environment need to be examined in order to understand why the ski helmets and motorcycle helmets appear to perform better than the SpeedFlex helmet did when compared to response performance while not wearing a helmet. Isolating the differences between ski, motorcycle, and football helmets can then lead to questions about form fitting function, thus providing a detailed explanation as to why football helmets performed worse on response time tests than ski and motorcycle helmets. It should be noted that while the difference between the regular helmet and the no helmet condition was found to be significant, the difference between the modified helmet and the no helmet condition was not found to be significant.

When considering only the response times that corresponded with the lights in the peripheral view, lights 1, 2, 9, and 10, the helmet results were similar to that of the total view, but the six-foot lights were significantly different than the four-foot lights (Figure 11), whereas light height in the frontal view did not seem to have any pattern pertaining to the differences in response time and placement. This suggests that the viewing zone of the six-foot level periphery as compared to the four-foot level periphery is significantly affected.

Another noticeable trend when looking at Figure 5 is that the average response is decisively lower on the lights positioned on the right side (7, 8, 9, 10) than the lights positioned on the left side (1, 2, 3, 4) except for light 2. The handedness of the student-athletes was data that was not recorded but may have been a reason for this difference is the student-athletes had a tendency to react with their dominate right hand.

The ANOVA results also revealed significant differences in repetition. These differences can be seen in Figure 6. The graph seems to present a linear trend of the participants getting slower over time. Their first repetition being faster than their last. This is likely due to a fatigue effect.

Helmet Blockage Percentage

When considering the results discussed in Section 4.1, the blockage percentage of each helmet was negligible as there was no significant effective difference between the SpeedFlex and modified helmet conditions. The added blockage observed by the modified helmet is due to the shape, style, and thickness of the facemask. The perceived added peripheral view can be attributed to less blockage when only considering the outer 1/4th of each image as discussed in the results section. To put into practical terms, the top of the facemask where the top bar connects to the front top of the helmet does not come into view of the wearer for the modified helmet; whereas most football helmets, including the SpeedFlex, have facemasks visible at the top corners of the viewing area (as indicated by the highlighted areas in Figure 7). The facemask is obviously a very important factor when considering field of view of a helmet and the study should only be considered as a comparison between the helmet and facemask combination that were used.

Questionnaire Results

The results of the questionnaire suggest that the student-athletes believe their peripheral vision is the same on the field as it

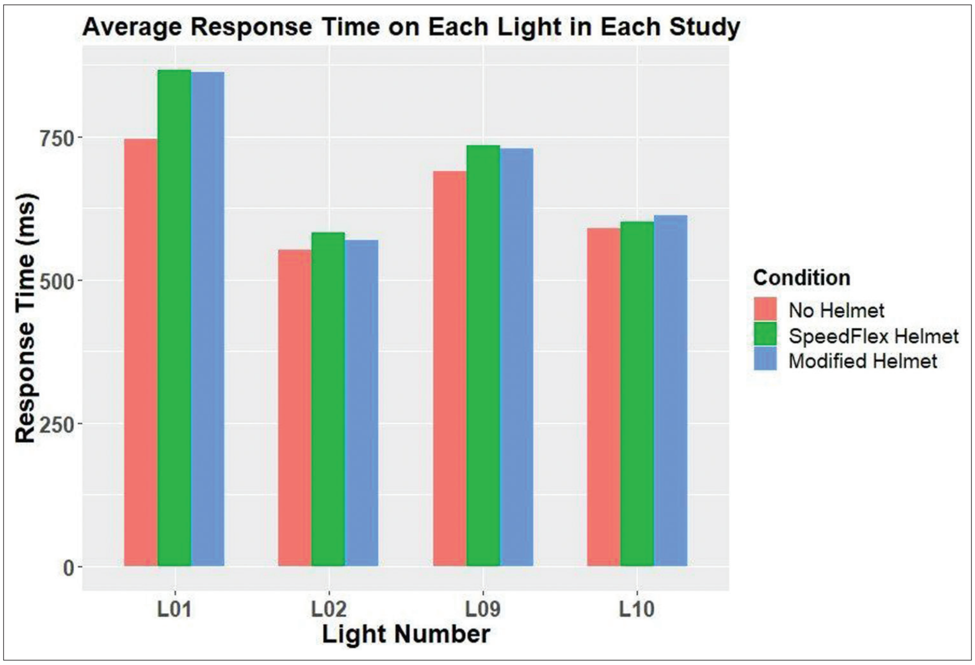

Figure 11. Peripheral lights 1 and 9 (six-foot lights) were significantly different than four-foot lights.
*Same as in data presented in Figure 5

Table 2. Perceived Impact of Helmet (Mean Score) by Vision Correction

Questions	Corrected 20/20 Vision (*n*=5)	Uncorrected 20/20 Vision (*n*=13)
Pre-Trial Questions		
How do you rate your vision compared to other football players (e.g.,, Better than most, about the same, worse than most)?	1.0	1.29*
How good is your peripheral vision in general everyday life (on a scale of 1 to 10. 1 being Very Poor and 10 being Perfect)?	6.8	8.9*
How good is your peripheral vision on the playing field (same 1-10 scale)?	7.0	8.5*
How does a football helmet impact your frontal vision (on a scale of 1-10 with 1–Not at all and 10 – Very Much)?	3.6	2.6
How does a football helmet impact your peripheral (side) vision (same scale)?	5.8	4.5
Post-Trial Questions		
How did the regular football helmet impact your frontal vision (1-Not at all to 10-Very Much)?	4.4	1.9*
How did the regular football helmet impact your peripheral vision (1-Not at all to 10-Very Much)?	6.4	5.0
How did the modified football helmet impact your frontal vision (1-Not at all to 10- Very Much)?	2.2	1.3
How did the modified football helmet impact your peripheral vision (1-Not at all to 10-Very Much)?	3.2	2.7

* indicates t-statistic is significantly different between means ($p<0.05$)

is off the field during general everyday life events—meaning that the added stress of a competitive event did not change the student-athletes' perception of their peripheral vision. Additionally, they feel as though their peripheral vision is moderately affected by a football helmet. This indicates that, either the participants did not understand the context under which the question was asked, or they were not considering the blockage of their football helmet while answering the questions. More interestingly, student-athletes felt as though the football helmet had significantly more of an effect on their peripheral vision than their frontal vision. When comparing these results with the two separate ANOVAs, their perceptions were in line with the results of the response time study.

The student-athlete's perception of the helmets' impact on their field of views does not align with the response times results in this study. The modified helmet was perceived to impact frontal view less than the SpeedFlex helmet and perceived to impact peripheral view even less. Combining these results with the viewable area discussed in Section 4.2

suggests that 2% added peripheral viewing space increases the athlete's perception of peripheral viewing ability by a wide margin. Additionally, the data seems to suggest that the blockage of frontal viewing space by the facemask has no correlation of the perception of frontal viewing ability by the user. Furthermore, the added viewing space or the perception of added viewing space by these margins between the modified helmet and the SpeedFlex helmet did not significantly affect response times of the student-athletes, but the regular helmet did make response times notably slower when compared to the no helmet condition.

Michael Levy provided a list of important helmet design factors for football helmets in his paper, "Birth and Evolution of the Football Helmet," of which one was, "[…] good vision so that there is no restriction of peripheral vision." (2004). The combination of the results discussed in the previous discussion sections suggest that there is an inequality of vision, perceived and/or actual, when comparing the SpeedFlex helmet, modified helmet, and no helmet conditions. The importance of vision and response performance while playing sports is unquestionable (Bhabhor et al., n.d.; Ghuntla et al., 2012; Hughes et al., 2012), and this should be combined with the possible effect that response time has on concussion occurrence (Clark et al., 2015; Harpham, Mihalik, Littleton, Frank, & Guskiewicz, n.d.), thus providing significant evidence that vision and response performance are important variables that should be considered when comparing and testing football helmets.

Balance

Balance results comparing SB and DTB, supported previous literature (Chander et al. 2014; Winter 1995; Horak 2006) where, SB was significantly better than DTB, and SB results remained constant regardless of the helmet condition. The significant finding was the lower 95% ellipsoid sway area of the modified football helmet as compared to the SpeedFlex helmet. The student-athletes, when considering this balance variable, performed better when wearing the modified helmet compared to wearing the SpeedFlex helmet. This could be due to the perceived increase of field of view that was provided by the modified helmet or the objective measured increase field of view when considering only the periphery of the modified and SpeedFlex helmets.

Limitations

The modified helmet had minimal effect on response times as compared to the corresponding effect of the SpeedFlex. This is surprising considering that the responses on the questionnaires seem to suggest that the student-athletes perceived their vision was affected significantly less while wearing the modified helmet versus the SpeedFlex. The added viewing area/ability—whether real or perceptual—was not enough to enhance response times. Thus, does viewing area influence reaction to response stimulus at all? The football helmet was proven to affect response times when compared to not wearing a helmet, but was that due to another factor of the helmet that was not considered in this study? Interestingly, the 95% ellipsoidal sway area was determined have a significant difference when comparing between helmet conditions, where the no helmet condition had the greatest area of the three conditions and the modified helmet the lowest area. This does not correlate with the findings on helmet's effect on response time. Furthermore, when considering the perceived viewing area and actual viewing area, assuming the no helmet condition would have zero percent blockage and a perception of zero viewing hindrance, these findings do not correlate in a logical manner with findings presented in this study (field of view blockage, perceived field of view, and response times). However, it should be noted that the two other balance variables studied showed no significant difference between helmet conditions. Therefore, further studies should be done on the relationship between football helmets and static and dynamic balance.

Also, the number of participants limited the ability to analyze subgroups such as offense versus defense, upper versus lower classmen, and positions played. The intent of this study was to first determine if helmet peripheral view did in fact impact response time and if the test designed for this study would be a solid methodology for assessing helmets of all types moving forward. In order to effectively analyze if years of experience, game-based motivations, or position-related skillsets impact perception of peripheral view, additional participants will be needed—preferably across multiple teams due to differing approaches in coaching and training styles.

Future Research

Going forward, this study could be improved by doing a more robust "blockage percentage" quantification of the field of view from inside of a football helmet. Also, the effects of more, commonly used football helmets, as well as different combinations of shells and facemasks can be studied. Another future study would be to get more data from a larger pool of participants thereby allowing researchers to assess different experiences and skillsets as they pertain to perceived peripheral view and the positions played in football. This study does lay out a strong, repeatable protocol for response time testing of helmets of all types using the FITLIGHT Trainer, something that was lacking in prior literature, as well as offering evidence that the modified helmet currently being built by researchers does not have a significant negative effect on users' response times like it's current helmet counterpart, the SpeedFlex. The modified helmet also offers the perception of greater peripheral field by the wearers, the NCAA Division 1 football student-athletes.

CONCLUSION

The commonly used SpeedFlex football helmet significantly affected student-athlete response time compared to wearing no helmet. However, the modified helmet's effect on response time relative to the no helmet condition could not be concluded as significant. These findings are significant because of the aforementioned importance of response time in football as a key performance indicator and modifiable injury risk factor. Also, the fact that a helmet affects response time is in opposition with previous research performed on motorcycle and ski helmets. In summary, the tested football helmets did affect the participant's response time and 95% EA but not in the same manner. All other sway variables measured provided insignificant differences between helmet conditions. There was not a significant difference when comparing only the modified helmet and the SpeedFlex helmet concerning response time or balance. The prototype (modified helmet) had greater blockage overall when compared to the SpeedFlex helmet, due to the bulky nature of the facemask, but had less blockage when only considering the peripheral viewing space provided by the helmets. The student-athletes do perceive the modified helmet to have a greater field of view than the provided SpeedFlex helmet. However, the perceived greater field of view did not contribute to faster response times, nor did the difference in blockage percentage, frontally or peripherally.

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