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Quantifying the Effects of American Football Shoulder Pads on Reach Distance and Player Perception of Comfort and Fit

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Ron Jadischke is employed by Xenith, the industry partner responsible for supplying the sports equipment used in this study. Xenith had no influence on the outcome of this study. The other authors have no relevant financial or non-financial interests to disclose.

ABSTRACT

Background: The majority of sports equipment research to date has focused on their protective capabilities, and not on how they impact player performance and comfort while using them. **Objective:** The purpose of this study was to quantify the reach distances of players wearing different football shoulder pads and determine player perceptions of shoulder pad comfort and fit. **Methods:** Football players (n=10) underwent a standardized reach distance protocol comprised of three trials of repeated shoulder flexion, extension, abduction, horizontal flexion, and horizontal extension in each of the three shoulder pad conditions (no shoulder pad, standard shoulder pad, prototype shoulder pad). Player perceptions of shoulder pad comfort and fit, breathability, restrictiveness, and weight were also evaluated using a questionnaire. Reach distances were recorded using five GoPro Hero 9 cameras and analyzed using ProAnalyst®3D motion tracking software. **Results:** Reach distances were significantly affected during several movements, but especially in the vertical direction, for flexion and abduction, with mean differences between the prototype pad and standard pad of 10.3 cm and 23.1 cm, respectively ($P = 0.007$ and $P = 0.003$). Differences in reach distance were greater for the standard shoulder pad than the prototype shoulder pad on average. This indicates that the prototype shoulder pad was less restrictive, which aligned with what players reported. There was significantly more discomfort reported in the neck collar and armpit regions for the standard shoulder pad compared to the prototype pad. Participants also found the prototype shoulder pad to be lighter, and more breathable ($P<0.05$). **Conclusion:** These results provide manufacturers with valuable insights from a design standpoint, and offer athletes who are looking for superior sport protective equipment key evidence regarding shoulder pad performance, fit, and comfort.

Key words: Sports Equipment, Athletic Performance, Football, Motion Capture

INTRODUCTION

The three main focuses of sports protective equipment research are: studying the protective capabilities of equipment for attenuating impact forces and reducing injuries; documenting the effect sports protective equipment has on player performance, and; quantifying the comfort and fit of sports protective equipment (Virani et al., 2016; Kauffman et al., 2015; Brisbine et al., 2020; Duddy et al., 2012). Although each of these focuses are important, research on how protective equipment attenuates forces has dominated this field of study to date (Virani et al., 2016; Bartsch et al., 2012; Pain et al., 2008; Richards et al., 2016; Cecchi et al., 2019). Evaluations of how sports protective equipment impact player performance, as well as the comfort and fit of sport protective equipment, are relatively new and emerging concepts in the literature (Brisbine et al., 2020; Yu et al., 2019; Bailey et al., 2015; Brionnet et al., 2001; Gawlak et al., 2015; Golem & Arent, 2015).

There have only been a few studies that have reported on the effect that sports protective equipment has on athlete performance (Kauffman et al., 2015; Yu et al., 2019; Bailey et al., 2015; Golem & Arent, 2015; Frayne & Dickey, 2017; Frayne et al., 2019). Specifically related to reach performance, Frayne et al. (2019) studied the effects that shoulder pads have on the reach envelopes of hockey goalies. While the findings from this study provide important insights, the participants were sitting while they completed the reach envelope protocol, and their trunk was not secured. Therefore, it is not known what the contribution of the shoulder joints alone would have been to the reach envelopes while the shoulder pads were worn. Consequently, much work remains to document how shoulder pads in other sports and positions impact athletes' performances (e.g., how far they can reach). In addition, the development of a cost-effective and transportable set-up for testing shoulder pads would facilitate the assessment of shoulder pads on a broader scale,

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thereby benefiting manufacturers, players, and the sports science community.

It is also important to understand how the comfort and fit of sports protective equipment, such as shoulder pads, can impact player performance or perceived performance, as there is evidence to suggest players opt out of wearing recommended equipment if it is uncomfortable, too hot/not breathable, etc. (Brisbine et al., 2020). Moreover, improperly fitting pieces of equipment can have negative effects on player safety (Phillips, 2013). Following their assessment of force attenuation, Virani et al. (2017) asked participants about the comfort of two different models of hockey shoulder pads they were wearing (with and without an additional 2 cm thick foam pad over the deltoid). The questionnaire asked participants to rate the comfort of each shoulder pad on a scale of 1 (extreme discomfort) to 5 (extreme comfort). Although this provides a strong foundation for this type of research, the survey was specific to hockey players and was limited to one question regarding comfort. It did not include any questions regarding other comfort and fit-related measures such as the weight and breathability of the pads, or if there were any restrictions that would impact player comfort or fit.

Therefore, the purposes of this study were to; 1) create a standardized protocol that isolates movement to the shoulder joint and can be used to quantify the effects of football shoulder pads on player reach distance, using a transportable set-up; 2) determine if there are significant differences in player reach distances between football shoulder pad conditions, trial, and movement position, and; 3) determine players' perceptions of the comfort and fit of each model of shoulder pads.

METHODS

Participants and Study Design

Ten male current or former players (high school or university level) participated in this lab-based experimental study. Participants underwent a repeated-study design involving each of the three conditions. The order of the conditions was randomized for each participant. Participants had a mean (± 1 standard deviation) height of 183.3 cm (± 5.5 cm) and body mass of 107.1 kg (± 19.6 kg). Inclusion criteria were: current or former football players; free of shoulder pain, and; do not have a history of a significant shoulder injury that would affect range of motion. This research study was approved by the Research Ethics Board of the University of Windsor prior to the start of data collection, and participants provided written consent.

Equipment

Five GoPro Hero 9 cameras (2.7K resolution, 4:3 aspect ratio, 60 frames/s, shutter speed 1/480, vertically orientated) were used to record the movement sequence for each of the three experimental conditions (no shoulder pad, standard shoulder pad, and prototype shoulder pad). The GoPro lenses were modified (Back-Bone, Ottawa, ON, CAN) to have a fixed field of view of 47 degrees to eliminate lens distortion. A similar approach using GoPro cameras which have been modified in this way has been used to analyze football (Jadischke et al., 2019; Gyemi et al., 2021). Five LED lights were placed directly adjacent to or below each camera to illuminate the retroreflective markers on the participants – one on each middle finger, one on their helmet, and one on the stabilizing apparatus (described below). The GoPro cameras were manually synced using a flash of light that was introduced in the field of view of all cameras prior to each movement. A stabilizing apparatus was utilized that limited head and trunk movement (Figure 1) to isolate the contribution of the shoulder joint to players' reach distances during the reach distance protocol. The participants' heads were held in place by a head stabilization device, adjusted based on each participant's height and the width of their head while wearing their helmet, and a strap was tightened around the participants' hips and the stabilizing apparatus so that they were unable to bend at the hips.

The standard shoulder pads had a traditional shoulder pad design and were not specific to any player position. The standard pads had press-molded plates for a traditional shoulder pad fit (Figure 1) and weighed approximately 2 kg. The prototype pads had design features that were intended to increase range of motion, reduce discomfort, and improve breathability compared to the standard pads. Images and specific details of the prototype pads cannot be shared at this time due to the proprietary nature of the design in the marketplace. Different sizes of the standard and prototype pads were available to provide the best fit for each participant. Participants were measured and fit with appropriately sized pads based on the manufacturer's size charts before data collection. Participants were able to adjust the strap around the chest of each shoulder pad to modify the fit to their personal preference.

Protocol

Participants completed three trials of the movement sequence (Figure 2) including flexion (a), extension (b), abduction (c), horizontal flexion left arm (d), horizontal flexion right arm (e), and horizontal extension (f), in each of the three different pad conditions. The primary investigator who has un-

Figure 1. Stabilizing apparatus with hip strap and adjustable head stabilization device

dergraduate and graduate degrees in Kinesiology conducted the trials during data collection. This ensured that the correct movements were performed by participants. The order of the positions within the movement sequence, and the order of the pad conditions were randomized for each participant.

The 'Football Shoulder Pad Comfort and Fit' questionnaire created and used for this study was derived from the questionnaires used by Dotti et al. (2016), Kaplan & Okur (2012), and Virani et al. (2016) for assessing the thermal comfort of back protectors, thermal comfort of sports garments, and comfort of hockey shoulder pads during checking, respectively. Following each shoulder pad condition, part one of the questionnaire was completed. The first three questions asked the participants if they found the pads restrictive, breathable, or heavy on a 5-point Likert scale. The last questions in part one required "yes" and "no" responses from participants regarding whether they felt any discomfort associated with any of the regions covered by the shoulder pads (e.g., neck collar, chest bottom, armpit, shoulder). If participants indicated any discomfort, they were asked to rate this discomfort on a 5-point Likert scale. They were also asked to describe the discomfort more specifically (e.g., itchy, scratchy, tight, prickly, sharp). Following the entire reach distance protocol, part two of the questionnaire was completed which included open-ended questions regarding what participants liked and disliked about the two shoulder pads.

Video records were converted into image sequences for each movement and input into ProAnalyst® (Version 1.6.0.2., Xcitex, Cambridge, MA, USA) to enable marker tracking. Clips of the same movement from two different camera views were tracked and paired with the calibration. The dependent variable of reach distance was measured for each of the conditions for every position in the movement sequence. The maximum value in the X (anterior), Y (medio-lateral), and Z (vertical) directions were determined for every position, trial, and condition. The marker on participants' helmets was used to determine if the participant moved relative to the stabilizing apparatus. Overall, the participants' heads did not move in any direction during the reach distance protocol. Therefore, reach distances were determined relative to the marker on the stabilizing apparatus, with the exception of the Z values which were taken relative to the ground (Figure 3).

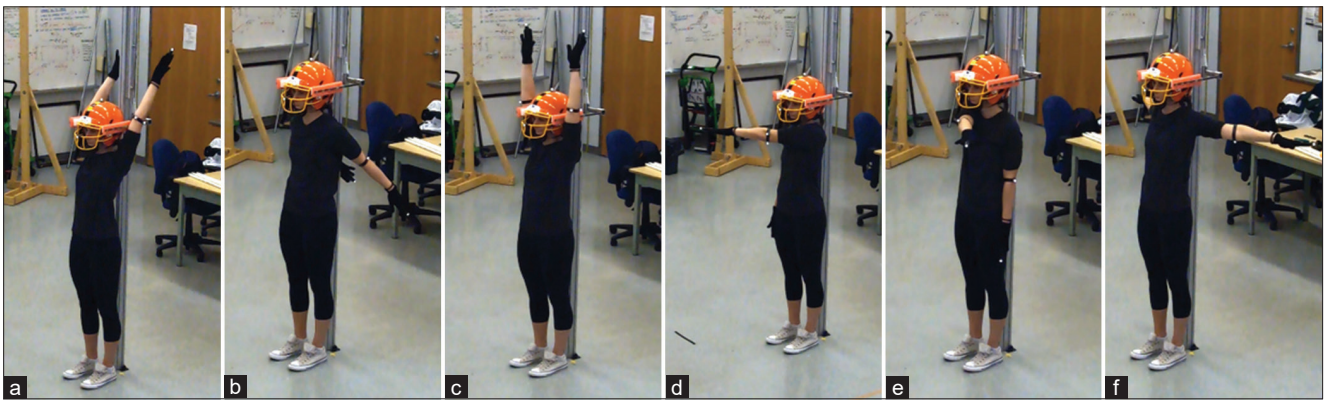

Figure 2. Images illustrating the movement sequence . (a) flexion (b) extension (c) abduction (d) horizontal flexion left arm (e) horizontal flexion right arm (f) horizontal extension

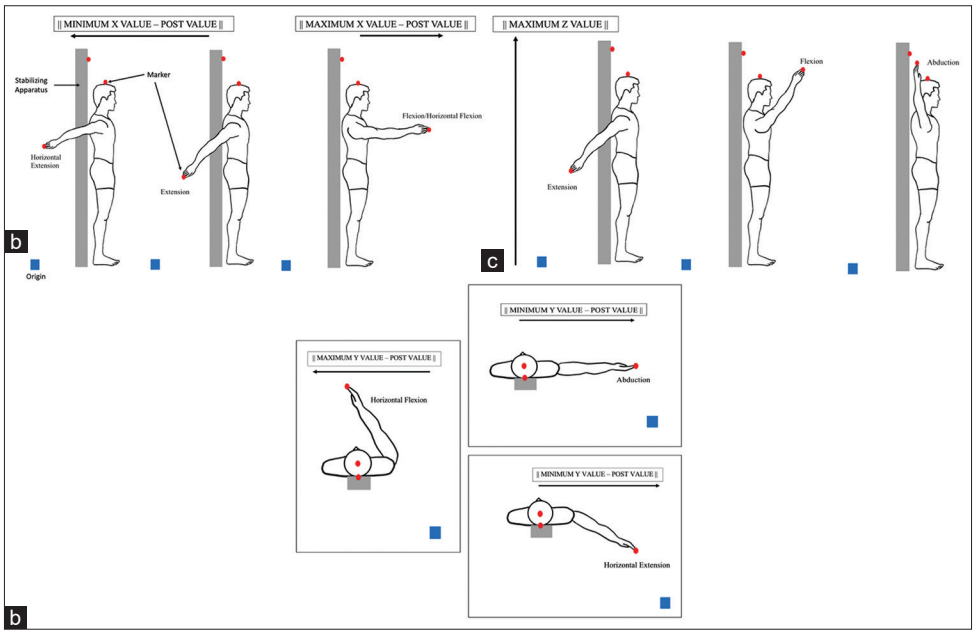

Figure 3. A Schematic diagram illustrating how the reach distance values were derived. The X direction (a), Y direction – Superior view (b), Z direction (c)

Statistical Analysis

For a sub-sample of three participants, a paired samples t-test revealed that there were no differences in reach distance between the left and right upper extremities for every direction ($P > 0.05$). A sub-sample was tested because the upper extremity movements on the left and right sides were symmetrical. By showing that there were no differences in reach distances between the two sides, analysis time was reduced considerably. Consequently, the full analysis was completed only for the right upper extremity. A Three-Way Repeated Measures Analyses of Variance (ANOVA) was performed on the dependent variable maximum reach distance (cm). The independent variables were trial, condition, and movement.

RESULTS

The differences in reach distance between the three trials were not statistically significant. Therefore, reach distances were collapsed across trials in subsequent analyses for each direction. The no shoulder pad condition allowed for 9.0 cm more extension reach distance in the X direction than the standard shoulder pad ($P = 0.007$) (Figure 4). Furthermore, the prototype shoulder pad allowed for a significantly greater reach distance in extension than the standard pad, with a mean difference of 7.0 cm ($P < 0.001$). In horizontal extension, the no shoulder pad condition had a significantly higher mean reach distance than the standard shoulder pad (a difference of 11.4 cm) ($P = 0.025$). The only significant differences in the Y direction were noted in horizontal flexion, whereby the no shoulder pad condition allowed approximately 12.6 cm more reach distance on average than the standard shoulder pad ($P = 0.002$).

In flexion for the Z direction, participants reached 17.3 cm further on average than when wearing the standard shoulder pad ($P = 0.008$) (Figure 4). The prototype shoulder pad enabled a significantly greater mean reach distance than the standard shoulder pad, by 10.3 cm ($P = 0.007$). Significant differences existed between conditions for the extension movement in the Z direction, with the prototype shoulder pad condition resulting in reach distances 4.7 cm greater on average than the standard shoulder pad condition ($P = 0.02$). During abduction in the Z direction, the no pad and prototype pad conditions resulted in mean reach distances that were 25.2 cm ($P = 0.005$) and 23.1 cm ($P = 0.003$) greater than the standard pad condition, respectively. There were no significant differences found between the no pad condition and the prototype shoulder pad condition for all directions.

Participants found the prototype shoulder pad significantly more breathable, less restrictive, and lighter, than the standard pad. There were significant differences in discomfort expressed between the two types of pads in the neck collar and armpit regions. Nine of the 10 participants found no discomfort in the neck collar while wearing the prototype shoulder pad, whereas only three participants reported the same after wearing the standard pad ($P = 0.031$). Ten participants and four participants reported no discomfort in the armpit region for the prototype shoulder pad and standard shoulder pad, respectively ($P = 0.031$). The most common descriptors of discomfort for these pads were “tight”, and “rigid/stiff”, as they were reported in 66% and 33% of responses. The frequency of discomfort descriptors in each specified region of the pad and the frequency of characteristics participants liked and disliked for each shoulder pad type can be seen in Figure 5 and Tables 1 and 2.

DISCUSSION

To the authors’ best knowledge, the current study is the only one to date to assess the reach distances, comfort and fit associated with football shoulder pads. The methods presented herein resulted in a standardized protocol that allows for reach distances to be quantified in a repeatable manner using a transportable set-up. Reach distances were significantly affected during several movements, but especially in the vertical direction. There were no significant differences between the prototype shoulder pad and the no pad condition. Differences in reach distance were greater for the standard shoulder pad than the prototype shoulder pad on average. This indicates that the prototype shoulder pad was less restrictive, which aligned with what players reported. Participants also found the prototype shoulder pad to be lighter, and more breathable. Significant differences in discomfort between shoulder pads were only noted in the neck collar and armpit regions.

Significant differences were found between shoulder pad conditions for several movements in different directions. This is contrary to the findings of Frayne et al. (2019) who assessed reach envelopes while wearing different hockey goalie shoulder pads. One possible explanation for this discrepancy is that the current study provides a standardized methodology not seen previously. Frayne et al. (2019) did

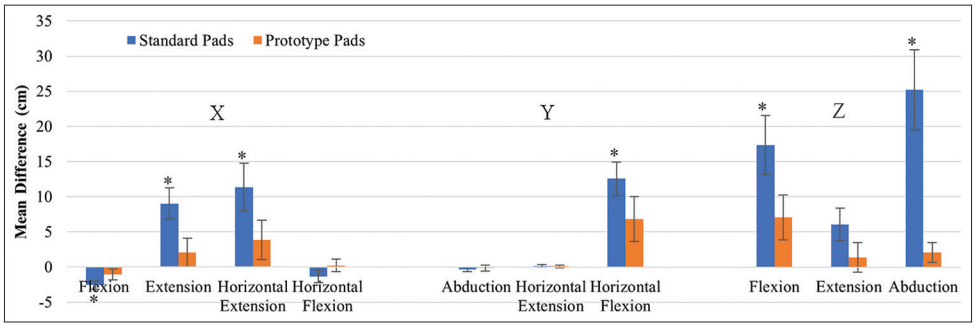

Figure 4. Mean (±SE) difference (cm) in reach distance between the no shoulder pad condition and the two pad conditions

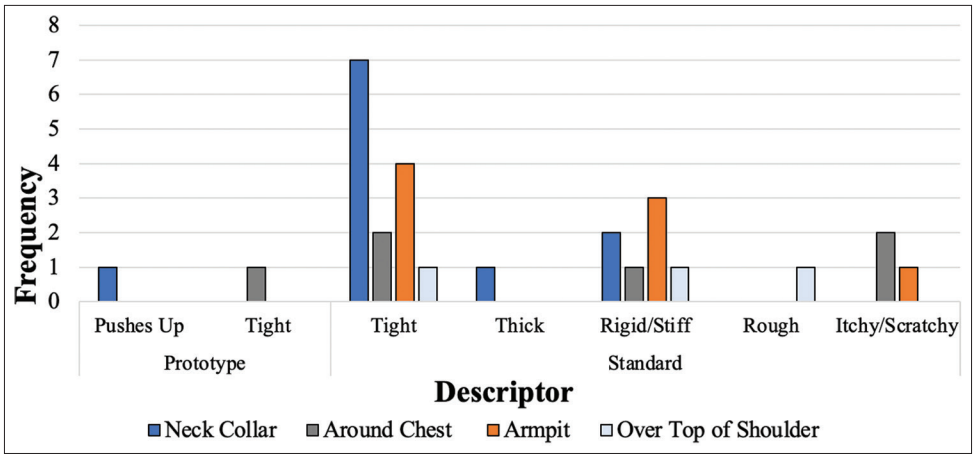

Figure 5. Frequency of discomfort descriptors made by participants for each shoulder pad region and each shoulder pad type

Table 1. Frequency of characteristics that participants liked for each type of shoulder pad

Standard Shoulder Pad	Frequency	Prototype Shoulder Pad	Frequency
Nothing	3	Not Restrictive	8
Good Protection, Sturdy, Works Well, Thicker	4	Smaller	3
Comfortable	1	Comfortable	5
Belt Buckle Strap	1	Not Hot	1
Good Fit	1	Light	4
		Softer	1
Total	10		22

not secure participants' trunks during their reaching protocol, which could have masked any differences in range of motion at the shoulder joint between pad conditions. The stabilizing apparatus utilized in the current study addressed this limitation. The lack of head movement reported herein shows that the reach in all movement directions using the stabilizing apparatus was isolated to the shoulder joint. Furthermore, the mean coefficients of variation across all movements and directions were 6.3%, 8.4%, and 8.4%, for condition 1, 2, and 3, respectively. Coupled with the fact that there was no main effect of trial, the protocol was quite reliable overall.

There were significant differences reported between the standard pads and the prototype pads for flexion and abduction in the Z direction. The prototype pad allowed for higher reach distances in abduction (23.1 cm) and flexion (10.3 cm) in comparison to the standard pads. These findings have meaningful practical implications. For example, the diameter of a standard size football is approximately 17 cm, which is less than the mean difference in reach distance between the prototype and standard shoulder pads for abduction in the Z direction (23.1 cm). This suggests that players may be able to make catches while wearing the new prototype shoulder pads that they would not be able to make if they were wearing the standard shoulder pad. Although the mean difference between the prototype and standard pad for flexion was not quite the diameter of a football (10.3 cm), it is still a considerable difference in reach in relative terms. Regardless, it is apparent that the prototype shoulder pad has the potential to positively impact a players' abilities to make or defend a catch in certain directions. However, the practical significance of this finding is limited to some extent by the relatively small sample size. Although the number of participants in the current study is consistent with what has been reported previously for similar work (Virani et al., 2016; Frayne & Dickey, 2017; Frayne et al., 2019), sample size and sample characteristics must be considered when interpreting and applying the results.

There were no significant differences in reach distance in the no shoulder pad condition compared to the prototype shoulder pad condition for any movement in any direction. Athletes' reach distances while wearing the standard shoulder pad were reduced. There is evidence to suggest that athletes will opt out of wearing important pieces of safety equipment because they feel that the equipment negatively impacts performance (i.e., is too restrictive) (Brisbine et al., 2020). However, this study showed that the prototype pads enabled the participants to reach to a similar extent in some directions compared to when they were not wearing pads at all. Practical implications such as these are encouraging from a design standpoint, as greater reach may translate into improved performance on the field.

The results for flexion and horizontal flexion in the X direction may seem contradictory to the other findings presented in this study, as they suggest that participants can reach further in the X direction with shoulder pads on compared to when not wearing shoulder pads at all. However, participants may have positioned their hands further out from their midline (as their baseline position) during the shoulder pad conditions (in the Y direction). This would have increased the reach distances they could achieve in the X direction when

Table 2. Frequency of characteristics that participants disliked for each type of shoulder pad

Dislikes			
Standard Shoulder Pad	**Frequency**	**Prototype Shoulder Pad**	**Frequency**
Neck Collar Tight	5	Weird	1
Straps Dig In	2	Too Much Padding	1
Bulky	4	Thin	2
Restrictive	4	Floppy	1
Uncomfortable	4	Straps Too Short	2
Large Shoulder Caps	1	Neck Discomfort in One Move	1
Stiff	1	Worried Pads are Not as Protective	5
Total		21	13

wearing shoulder pads. Furthermore, although these results were considered statistically significant, the mean reach differences were less than 2.6 cm for all condition comparisons. The mean uncertainty values in some cases for flexion and horizontal flexion in the X direction were as much as 1 cm, which may help to explain these findings.

Participants found the prototype shoulder pad to be significantly more breathable and comfortable than the standard shoulder pad. Better breathability may be attributed to the many holes in the material of the prototype shoulder pad that the standard shoulder pad did not have. The holes allow air to circulate through the prototype shoulder pad, and would therefore improve breathability and reduce heat build-up during play. Since this study was completed using relatively static tasks without a warm-up period, further assessments of shoulder pad breathability during dynamic tasks after warming up, or after play, may provide valuable design-related data that are more in line with what could be expected during practice or play conditions.

Participants reported that the neck collar region was more comfortable in the prototype shoulder pad condition. Although it is difficult to determine the exact reason for this, it may be because the prototype shoulder pad laid flatter on participants' bodies due to the flexibility of its design. The standard shoulder pad had a relatively stiff shell that may have caused the shoulder pad to shift upwards to the neck when participants reached above their heads, thereby increasing participants' discomfort ratings.

The most common descriptor of discomfort from participants was "tight", which was noted in 66% of responses. The most common "like" and "dislike" for the standard shoulder pad were "good protection" and "neck collar tight", respectively. Comfort and fit have previously been assessed using five-point Likert scales, visual analog scales, and various other questionnaire methods (Virani et al., 2016; Brisbine et al., 2020; Duddy et al., 2012; Yu et al., 2019; Bailey et al., 2015; Brionnet et al., 2001; Gawlak et al., 2015; Kaplan & Okur, 2012). The questionnaire used in the present study was broader in scope compared to others in the literature because it addressed breathability, weight, restrictiveness, discomfort in several specific regions, and general likes and dislikes. In the only other study on shoulder pads (hockey) to date, Virani et al. (2017) reported significant differences in comfort between the different shoulder pad conditions. Determining the discomfort associated with different shoulder pad regions provides manufacturers with specific details that would help with future designs. For example, based on the results of this study, manufacturers designing new shoulder pads should focus some attention on reducing the tightness of the neck collar area in order to improve player comfort.

The most common "like" of the prototype pad was that it was not restrictive; the most common "dislike" was that participants were worried that these pads would not provide as much protection as the standard pad they were used to wearing. On-field performance was not quantified or assessed in this study, and this may alleviate the athletes' concerns had they been able to wear the pads in competition. Participants' perceptions that the prototype shoulder pad was significantly less restrictive than the standard shoulder pad aligned well with the reach distance values – the prototype pad enabled participants to reach further than the standard pad for several of the movements tested. This addresses a key issue expressed anecdotally by players. How improved range of motion during typical use interacts with the protective capabilities of shoulder pads remains to be determined, but should be a primary focus of future testing efforts.

In addition to the limitations described above, others include the computational time and the lack of functional and task-specific testing required with the approach used in this study. ProAnalyst® (Version 1.6.0.2., Xcitex, Cambridge, MA, USA) requires considerably more time after recordings have occurred to obtain calibrated marker coordinates than more expensive and integrated motion capture software systems. By only providing a full analysis for the right hand, the amount of analysis time was reduced considerably. A sub-analysis of three participants (30% of the sample) showed that there were no significant differences in reach distances between the left and right hands in all movement directions. This finding is not surprising, given the bilaterally symmetrical nature of the movement sequences studied. However, future work on asymmetrical reaching tasks would need to assess both hands to best represent the movements studied. As this was a lab-based experimental study, it did not address functional and task-specific movements; in future studies this could be accomplished following practice or game play in the field. Furthermore, this study only eval-

uated two shoulder pad models designed for a single population. There are a significant number of shoulder pad designs on the market that have never been tested in this way. Future studies should also consider larger samples of participants to improve the generalizability of the findings and should assess the reliability of the questionnaire used to assess comfort and fit.

Reach distances determined using the methodology presented in this study were shown to be reliable and sensitive to the differences in shoulder pad designs. The implications of the results of this study are that this methodology could be used to assess other types of shoulder pads in the future, including those worn in other sports (i.e., hockey).

CONCLUSION

Research to date that assesses sports equipment focuses mainly on the protective capabilities of these pieces of equipment. Despite equipment impacting athletic performance and comfort and fit affecting user compliance and safety, literature in these areas of sport equipment research is severely lacking. Although specifics regarding the design of the prototype pad could not be provided, the standardized and relatively inexpensive methodology utilized in this study was able to show that there were significant differences in reach distance values between the shoulder pad conditions. Differences in players' perceptions of the comfort and fit of the two shoulder pads tested were also evident from the developed questionnaire. The combination of these results adds considerably to the very limited literature in this research area and suggests that the approach used could provide manufacturers with valuable design-related insights. In addition, the information gained about the specific pads tested could inform football players who may be looking for a performance advantage related to reach.

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