Vastus and Patellar Protection with Range of motion Pad – Advanced Personal Protective Equipment for the Lower Body

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Abstract
The standard knee pad is considered the most ineffective personal protective equipment in the American football player's uniform. This study quantitatively and qualitatively assesses personal protective equipment for the lower body for U.S. football players against the VAPPR Pad (Vastus And Patellar Protection with Range of motion), the next iteration of lower body protection. The study consisted of player surveys, material drop testing, and Performance Drill testing including broad-jump, L-drill, pro-agility, and gait analysis with 138 participants in the initial survey and 25 men in the physical testing. Results of the Performance Drill Testing proved that unpadded players perform at higher levels than padded players; established no difference in performance between the unpadded players and players wearing the VAPPR Pad; and validated the VAPPR Pad's superiority to the standard knee pad.

Disciplines
Ergonomics | Operational Research | Sports Medicine

Comments

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INTRODUCTION

Football is the most popular game in the United States, and interest is growing. Player participation has increased over 16% at the collegiate level since the 2001-2002 season (58,090 in ’01-’02 : 69,643 in ’11-’12), and participation has been over 1 million at the high school level since documentation of participation began in 2006-2007 (NCAA participation, 2012; NFHS participation, 2012). Football is also the leading cause of sports-related injury, resulting in 8.61 injuries per 1000 athlete exposures at the collegiate level, and 4.36 at the high school level (Powell, 1999; Shankar et al., 2007). Given the physical nature of the game, these injury statistics are not surprising, and many pieces of personal protective equipment (PPE) have been introduced over the game’s history to guard against a variety of injuries. However, it is surprising that many football athletes are dissatisfied and prefer not to wear one customary piece of PPE; the standard knee pad.

Statistically, the most injured part of the body in football athletes is the knee, but a large majority of those injuries consist of tendon and ligament damage (Pritchett, 1982; Culpepper & Niemann, 1983; Shankar et al., 2007; Feeley et al., 2008). In fact, no research exists that seeks to quantify the number of injuries avoided by use of lower-body PPE. Due to the lack of specific injury data and the fact that the knee pad is a required piece of equipment at the high school and collegiate level, a more primitive understanding of the intended purpose of the knee pad was sought. Gerrard (1998) noted a concise definition of protective padding during his research into the effects of direct contact.

The most recent development in lower-body PPE was a device called a girdle, and its introduction moved past a technology patent that originated in 1941. McCoy’s (1941) original design implemented the use of a fabric pocket to hold the pad against the player and allow for removal following competition opposed to pads permanently sewn into game pants. The purpose for this design change was to allow for, “cleaning, repairing, or changing” of player equipment (McCoy, 1941). This function is no longer necessary as materials used in PPE have evolved as well. Most foams used for padding are closed-cell and do not absorb moisture (Ashby & Mehl Medalist, 1983).

Girdle design incorporates the compressive assistance of fabric to aid in muscular function and secure PPE to the player’s body (Arendsdorf & Stromgren, 1992; Walde-Armstrong et al., 1996). The foundation of the design removed the pads from a player’s game-uniform pants and placed them in a more compressive garment. In competition, lower-body PPE would remain in place within the tighter garment, allowing less restricted, natural movement of the lower limbs.
to occur. The girdle has been widely accepted as a standard piece of equipment at the collegiate and high school level, and a majority of college teams issue the garment to players as part of the uniform.

All competitive levels of football require players to wear certain protective equipment. Collegiate and high school players are required to wear the full set of lower-body PPE (NCAA rules, 2012; NFHS, 2012). This set includes tailbone, hip, thigh, and knee pads, and the girdle is the preferred method of abiding by this rule. Having outlined the development, intended purpose, and effectiveness of the girdle, it is imperative to note that the girdle does not incorporate the full set of lower-body PPE as shown in Figure 1.

The knee pad is excluded from the girdle design and is still incorporated into the football uniform via fabric pocket as introduced by McCoy in 1941. Perhaps this exclusion has remained unaddressed because the NFL has not required players to wear these pieces of equipment. In fact, many skill position players (those positions which require speed, agility, and overall movement more than repeated physical collisions) choose not to wear any lower-body PPE. For most of them, performance now on the field trumps the concern for safety over the long term, and going without lower-body PPE has become the norm. Making the decision to go without lower-body PPE was the player’s choice in the NFL until recently, but collegiate athletes did not have similar freedom. Instead, an adaptation to the equipment rule has led to the current state of the player uniform at this level. The choice to go without lower-body PPE is not a choice players are allowed to make, and assessing the knee pad as part of the uniform is critical. The complete rule listed in the NCAA Football Rules and Interpretations guidebook for 2011-2012 (NFHS rules) states: “Knee pads must be at least ½-inch thick and must be covered by pants. It is strongly recommended that they cover the knees. No pads or protective equipment may be worn outside the pants.”

VAPPR Pads

It has been shown that the standard knee pad design has not progressed along with other pieces of PPE in the game of football, and players at multiple competition levels are dissatisfied. At the professional level, some players risk injury and compete without the knee pad in an effort to improve performance. Collegiate players have modified the use of their knee pads in an identical effort. In either case, the standard knee pad does not satisfy all user requirements, and therefore, a new design must be created. This new design must meet two basic criteria: 1) PPE must not inhibit player performance; 2) PPE must provide equal or greater protection than the standard knee pad. Meeting these two design criteria, a Vastus And Patellar Protection with Range of motion (VAPPR) pad has been developed based on direct feedback from football athletes and further evaluated.

The authors hypothesize:

H1: A player wearing no lower-body pads has a performance advantage over a player wearing standard lower-body pads.

H2: No difference in performance exists between players wearing VAPPR pads and those competing unpadded.

H3: VAPPR pads are superior to standard knee pads.

METHODS

Player Surveys

In order to gain user perspective, a survey was constructed with the intent of generating a research hypothesis focused on standard knee pad design. Accordingly, this survey consisted of a series of YES/NO questions followed by an open section in which to elaborate and describe the reasoning behind the initial response. The survey also collected information about player age, height, weight, and position in order to link potential response trends to certain positions. A total of 138 participants completed the survey (part of which, asked if the players had made alterations to their kneepads and, if so, asked the participants to describe the alterations made and their intended purpose), of which 65 competed at the collegiate level and 73 at the high school level.

Drop Test

A common method for evaluating the effectiveness of a protective pad is by executing a material drop test (Hrysomallis, 2009). Although the VAPPR pad design was created by simply altering the shape of the existing pad, the drop test was performed to ensure no material property changes had occurred. An 8.5kg striker 4.5 cm in diameter was dropped from a height of 5 cm on both the standard knee pad and VAPPR design. Both drops were performed without warming up the material as high frequency impacts to the knee pad do not commonly occur during competition. Peak impact force from the striker was measured, and a smaller force correlates to more energy absorbed by the pad. For the standard knee pad, peak force was 24.14 g; and for the VAPPR design, peak force was 23.92 g. The similarities in felt impact demonstrate that the absorption properties of both pads are effectively identical.

VAPPR Pad Design

Testing for the VAPPR Pad, seen in Figure 1, was performed in two phases. For Performance Drill testing, subjects performed a series of standardized football performance drills under three different padded conditions (unpadded, standard, VAPPR). Following the drills, subjects completed a survey regarding their experience during the testing. During Gait Analysis testing, subjects performed a series of 5 yard bursts under identical padded conditions.

Performance Drill testing: Wartburg College

10 men (age: 21 ± 1 years, height: 72 ± 3 in. (182.9 ± 7.6 cm.), mass: 200 ± 26 lbs. (90.7 ± 11.8 kg)), free from injury for at least 12 months prior to participation, served as subjects. Informed consent was obtained prior to any testing procedures. During testing, each subject was outfitted with a full set of lower-body football performance apparel including: girdle with hip and tailbone pads, thigh boards for insert, knee
pads for insert, and game pants. After going through a dynamic warm-up, the participants performed a series of football performance drills while outfitted with three padded conditions: 1) Girdle Only; 2) Girdle, Thigh Boards, and Standard Knee Pads; 3) Girdle, Thigh Boards, and VAPPR Pads. Participants were allowed to rest to recovery between exertions. Performance drills completed during the experiment included: Broad Jump, L-Drill, and Pro-Agility. Listed below are descriptions of the three drills taken from the NFL Combine “Workouts and Drills” (2013) website:

**Broad-jump.** The Broad-Jump is used to test an athlete’s lower-body explosion and lower-body strength. The athlete starts out with a balanced stance, and then he explodes out as far as he can. The drill tests explosion and balance because the landing must be made without motion.

**L-drill.** The L-Drill tests an athlete’s ability to change directions at a high speed. Three cones in an L-shape are used in this drill. The athlete begins in a three-point stance at the starting line, goes 5 yards to the first cone and back. Then he pivots, runs around the second cone, runs a weave around the third cone (which is the high point of the L), changes directions, and returns around the second cone through the finish.

**Pro-agility.** The Pro-Agility tests an athlete’s lateral quickness and explosion in short areas. The athlete starts in the three-point stance, explodes out 5 yards to his right, touches the line, goes back 10 yards to his left, left hand touches the line, pivot, and he turns 5 more yards and finishes.

Running drills (L-Drill, Pro-Agility) were timed via stopwatch by two judges in order to limit variability associated with hand-timing. The Broad-Jump was measured to the nearest quarter inch as is customary for the drill. For all performance drills, participants completed two trials under each padded condition resulting in 18 total trials. During the experiment, a participant’s padded conditions and performance drill order followed a counterbalanced design. In doing so, variability due to fatigue or insufficient warm-up could be mitigated. After performing the drills, participants completed a follow-up survey regarding their testing experience. The follow-up survey incorporated design criteria collected from the initial player survey mentioned earlier in the section. Questions were constructed to gather quantitative and qualitative feedback from participants concerning their satisfaction with the knee pads worn during testing.

**Gait Analysis testing: Iowa State University**

15 men (age: 23 ± 3 years, height: 71 ± 2 in. (180.4 ± 2 cm.), mass: 186 ± 28 lbs. (84.4 ± 12.7 kg)), free from injury for at least 12 months prior to participation, served as subjects. Informed consent was obtained prior to any testing procedures. Each subject was outfitted with a full set of lower-body football performance apparel as listed in the Performance Drill testing section, and identical padded conditions were used. A series of anthropometric measurements were taken from each subject, 17 retro-reflective markers were correspondingly placed on anatomical landmarks of a participant’s right leg and pelvis. Following anthropometry and marker placement, a dynamic warm-up was completed before testing began.

During the Gait Analysis, subjects performed a 5 yard maximum speed burst across a force platform, starting from a three-point sprinting stance. Participants were allowed to rest to recovery between exertions. Five bursts were performed for each of the four padded conditions. The order of padded conditions used for the bursts followed a counterbalanced condition design. During each burst, marker position was collected at 200 Hz using a Vicon motion system, and ground reaction force (GRF) data was collected at 1000 Hz by the AMTI force platform.

**Data processing.** Times and distances collected from Performance Drill testing were entered into a JMP table for statistical analysis. For each participant, an average score (time or distance) was used for each drill under all three padded conditions. To achieve this, the stopwatch times were averaged, and the two trials of each drill were averaged. The result was an average score for each padded condition during the three performance drills.

Marker positions and force platform data collected during Gait Analysis testing were processed using MatLab. Both marker positions and force platform data were smoothed using a zero-lag, low pass (20 Hz) Butterworth filter. All kinematic and kinetic variables were analyzed during the right leg stance phase for movement in the sagittal plane. Ideally, all 17 markers would be present during the stance phase, but redundancy is built into the marker set to accommodate for any that are missing. Only four markers are required to perform calculations for each segment: pelvis, thigh, leg, and foot. Anthropometric measurements were used to estimate segment masses, moments of inertia, and center of mass locations for the four segments (which are assumed to be constant). All calculations followed principles of inverse dynamics with rigid body assumptions (Vaughan et al., 1992; Ko & Badler, 1996). Resulting variables associated with effective sprint start acceleration were entered into a JMP table for statistical analysis.

For both phases of research (Performance Drill and Gait Analysis testing) an ANOVA with repeated measures was chosen to determine if any significant differences existed between padded conditions. Counterbalanced experimental
design ensured independence, resulting data followed a normal distribution, and sphericity assumptions were met. If significance existed from the ANOVA testing, Tukey’s HSD test was used to investigate paired differences between padded conditions.

**RESULTS**

Of all respondents, 40% indicated they had made alterations to their standard knee pads, and all went on to describe the alterations made. The level of detail in the responses to the two questions allowed for a comprehensive design hierarchy to be created. Eleven knee pad design traits were then categorized into three low-order design themes: **Fit**, defined as size of the pad, thickness, and ability to be worn on the knee; **Shape**, defined as area of the pad, type of padding, and position of the pad on the body; and **Performance**, defined as flexibility of the pad and ability to function normally while wearing the pad.

Participants who completed the Performance Drills phase of the experiment were going through standardized assessments used at the highest level of competition in the game of football. All were trained in performance of the drills and practiced them on a regular basis. Times and distances achieved were organized by drill and corresponding padded condition. An ANOVA with repeated measures was then used to determine if any of the three padded conditions (unpadded, standard knee pad, and VAPPR pad) led to different results during the same performance drill.

For the Pro-Agility times (seconds), an ANOVA showed significant differences existed among the three padded conditions (F-Ratio = 7.92; Prob > F = .003*). Comparing means indicated that trials performed unpadded (Mean = 4.4, Std. Dev. = 0.21) and with the VAPPR pad (Mean = 4.4, Std. Dev. = 0.20) were significantly faster than those completed wearing the standard set of pads (Mean = 4.46, Std. Dev. = 0.23) given a confidence interval of 95%. A comparison of times achieved unpadded and while wearing the VAPPR pad in place of a standard knee pad did not show any significant difference.

For the L-Drill times (seconds), an ANOVA showed significant differences existed among the three padded conditions (F-Ratio = 6.17; Prob > F = .009*). Comparing means indicated that trials performed unpadded (Mean = 7.09, Std. Dev. = 0.32) and with the VAPPR pad (Mean = 7.118, Std. Dev. = 0.33) were significantly faster than those completed wearing the standard set of pads (Mean = 7.20, Std. Dev. = 0.31) given a confidence interval of 95%. A comparison of times achieved unpadded and while wearing the VAPPR pad in place of a standard knee pad did not show any significant difference.

For the Broad-Jump distances (inches), an ANOVA showed significant differences existed among the three padded conditions (F-Ratio = 7.10; Prob > F = .005*). Comparing means indicated trials performed unpadded (Mean = 102.65, Std. Dev. = 5.76) and with the VAPPR pad (Mean = 102.62, Std. Dev. = 5.36) were significantly farther than those completed wearing the standard set of pads (Mean = 100.93, Std. Dev. = 5.81) given a confidence interval of 95%. A comparison of distances achieved unpadded and while wearing the VAPPR pad in place of a standard knee pad did not show any significant difference.

**DISCUSSION AND CONCLUSION**

It is clear that the standard knee pad is an effective guard against injury, but effectiveness is not in question. What is clear from this research is that the functionality of the standard knee pad is poor, and the VAPPR pad provides greater or equal protection against injuries that occur from common impacts in the game of football. Although all variables followed a similar pattern to that found in the Performance Drills (unpadded and VAPPR performance superior to standard), not all differences were significant. Propulsive impulse was significantly different between padded conditions of the gait analysis, but the lack of significance in the other variables must be contemplated. Mechanically, the forces exerted by the athlete will far exceed those differences in ground reaction force, range of motion, or moment caused by a different pad set. However, in a game of inches, minor differences may become more evident during competition. Further biomechanical analysis is needed to fully understand why performance differences occur while competing under different padded conditions, but perhaps the answer is not entirely mechanical. Perceived differences will obviously exist for athletes under the different padded conditions and may lead to physical or psychological changes in gait or mentality that impact performance. Attempting to understand these physical or psychological changes should be the focus of future research.

Prior to this study, no published investigation existed regarding the impact that lower-body pads have on the football athlete. Personal experiences identified the standard knee pad as the most ineffective PPE in the football uniform, and further inquiry confirmed this belief. Player feedback indicated that a design flaw existed and also became the foundation for the creation of the VAPPR pad. With a new design achieved, performance and usability testing were
necessary to confirm an improvement of the knee pad. Performance Drill testing (1) proved the unpadded player performs at a higher level than the padded; (2) established that no difference in performance exists between an unpadded player and one wearing VAPPR pads; and (3) validated the VAPPR pad’s superiority to the standard knee pad.

In an attempt to further analyze these differences in performance, or lack thereof, a full gait analysis was undertaken. However, results from the small scale experiment indicated that no significant biomechanical differences existed as a result of the different padded conditions. Further research should be directed towards understanding biomechanical differences while competing under different padded conditions as well as considering potential psychological impacts that wearing different PPE have on athletic performance.

REFERENCES


