Comprehension and Selective Visual Attention in Play-calling Signage in NCAA Division 1 Football: A Comprehensive Literature Review

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ABSTRACT

Background: The huddle in American college football has been replaced by hand-signals, play-cards, and other forms of nonverbal communication to deliver information from the sidelines to the field. These communication methods serve a dual-purpose of capturing the student-athletes' attention while perplexing the opposition. **Objective:** The purpose of this study is to apply cognitive engineering concepts toward the improvement of signage and play-calling such that coaches can more effectively transmit information to players on the field during competitions. **Methods:** This comprehensive literature review investigates strategies for successful visual play-calling systems in sports communication. Collaboration occurred with a National Collegiate Athletic Association (NCAA) Division 1 football coaching staff to understand communication processes on field. Existing literature related to visual language processing, selective attention, and signal comprehension were compiled for recommendations. **Results:** Research findings suggest positive correlations between speed, clarity, and simplicity of signage in addition to effective sideline communication. The results of this review can be used to develop guidelines that increase the accuracy and speed of play-calling during games, such as clearly designed imagery and simplified play calls; coaches may establish strategies that are consistently understood by student-athletes. **Conclusion:** In addition to the findings, this study also identifies visual communication methods and mediums that can be used in any sport or work field where transmitting and comprehending information from a distance is critical for task completion.

Key words: Sports, Communication, Visual Acuity, Attention, Comprehension, Reading

INTRODUCTION

Jamie Collins and Natalie Durand-Bush (Collins & Durand-Bush, 2016) conducted a study of coaching strategies within team sports. The study indicated seven primary function of a coach: (a) Nurture Individual Attributes, (b) Optimize Team Attributes, (c) Communication, (d) Foster Structural Team Processes, (e) Maintain Individual Regulation Processes, (f) Manage Team Regulation Processes, and (g) Establish Context.

Of those seven functions, communication represents the primary task of a coach during an actual game (aside from the general strategy). The game time environment introduces severe limitations on the communication between coaches and players. The limitations require the use of a messenger similar to the childhood game of telephone or sideline signals such as posters or hand gestures.

American college football coaches have increasingly relied on the use of poster boards in recent years. The introduction of poster boards allows teams to eliminate the huddle and increase the speed of the offense (Kadar, 2015). This trend originated with Oklahoma State University, was popularized by Chip Kelly while at the University of Oregon, and has spread across the nation (Hruby, 2011). Between the 2018 and 2019 football seasons, Mississippi State University (MSU) used poster boards like the graphics shown in Figure 1. These boards display images and items popular with the student-athlete roster at the time and will exhibit different meanings when shown to the players on the field. For example, the pictures may have no meaning but the predominate colors of blue and yellow in the upper left-hand corners of both posters could indicate the formation in which
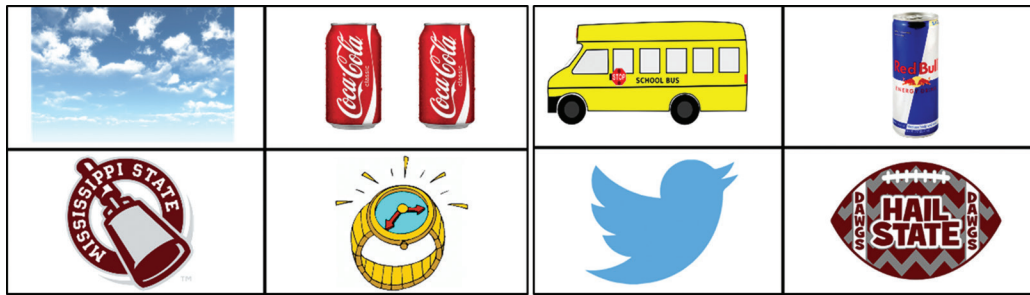
Figure 1. Example play cards recreated from (Hicks et al., 2019). (Clip art courtesy of: http://clipart-library.com.)

the student-athletes should align themselves defensively. The quadrants in which MSU-specific nomenclature such as the cowbell and the Hail State may be an indication of which side of the field to line up in a heavy formation. The number of cans in the upper right-hand corner may indicate a number more so than a drink brand or color. Or, as can sometimes be the case, the poster boards may mean absolutely nothing at all and could simply be used as a distraction for the opposing team (Hicks et al., 2019). Hand signals are still a critical means of communication, as each coach using hand-signals on the sideline during competition may be communicating a specific action to a specific set of players on the field. The poster board component of the signal call allows the coaches to communicate one or multiple points to the entire team at once while each group of associated player skill positions receives their own individualized communication via the hand signals. Yet despite the wide adoption of this communication technique, no previous studies have evaluated this method to provide recommendations for play-calling signage improvements within the context of the game of American football played at the collegiate level, The purpose of this article is to close the gap in literature by providing a detailed listing of recommendations in communication methods and mediums used by coaches to transmit information to the student-athletes on the playing field during competitions.

While the use of play cards is often associated with Chip Kelley's coaching tenure at the University of Oregon (from 2007 to 2012) and Oklahoma State University is given credit for the communication concept (Hruby, 2011), the overall effectiveness of these cards has not been openly studied. To this point, the use of play cards has existed primarily as a fashionable or trend-setting method of communication in college football. Each team is working to implement the newest trend while also creatively communicating information that is challenging for the other team to view and decode its meaning.

The research effort detailed below strives to apply cognitive engineering knowledge to the usage of sideline communications in college football. The research effort sets forth the goal of determining design characteristics and best practices associated with sideline signal implementation. The intended result is to develop guidelines that increase the accuracy and speed of play calling during game time. To reach this goal, the research team asked five questions about primary aspects of sign usage:

- Q1: What visual elements should appear on football signage?

- Q2: Should the signage contain one or multiple visual elements?
- Q3: Should coaches provide additional or redundant information to the players to confirm receipt of the messages?
- Q4: What effect do environmental factors (e.g. noise, stress, time constrain) have on signal comprehension?
- Q5: What effect do training and attention have on signal comprehension?

METHODS

Study Design

To properly address these research questions, a literature study design was utilized along with feedback from coaching staff practitioners who are familiar with all communication methods utilized within the NCAA Division 1 American football and the National Football League (NFL).

Collaboration with Coaching Staff

To better understand how play-call signage is executed on the field, the research team met with the quality control coaches from the participating university who defined the signal-sending methodology currently used at many American football programs where an up-tempo football offense is commonly executed. These coaches are subject matter experts (SMEs) in card- and hand-based signals given their experience at multiple Division 1 football programs. The SMEs demonstrated for the research team how play-calls are distributed on the field and received by the student-athletes and answered all pertinent questions about the current process throughout the analysis. Additionally, the project team was permitted to observe live play-call signage usage during football spring practice to understand the communication dynamic from both the coaches on the sideline and the student-athletes on the field. The purpose of the interactions with coaching staff was to formally educate the research team on the process of football signal calling including familiarization with the interactions between the coaches and players, the positioning and usage of the signage and signals, and, most importantly, the sports-specific language used. The intended outcome of these interactions was keywords and search terms generation that would be used during the comprehensive literature review process.

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Literature Search

The project team utilized a comprehensive literature review approach to identify key concepts that influence the ability of coaches to communicate with players on the field through nonverbal methods. A systematic literature search for digitally available references was undertaken using the following key terms: "arm gesture communication", "attention analysis", "coach communication in game", "football", "gesture industrial communication", "gesture language", "hand signals communication", "military hand signals", "pictographs", "pictography", "salience in sports", "sign strategy", "signage", "signage and comprehension", "signal detection", "signals in a loud or chaotic environment", "signage in athletics", "sports", "sports communication", "sports management", "telegraphy", "visual communication", "visual communication noise", "visual comprehension", "visual cryptography", "visual image processing", "visual language processing", "visual message communication", and "visual perception".

Combinations of these words were used to systematically conduct the search from the following web databases: Google Scholar, SPORTDiscus and EBSCO. The literature search was conducted from February 2019 through April 2020, and citation tracking of key primary and review articles were managed using Mendeley. The resources collected span the years of 1970-2020.

Data Extraction and Analysis

The articles were evaluated with respect to their suitability and relevance for the desired context based on the problem statement described above. Applicable publications were further studied for inclusion in the analysis. A study was only included in the comprehensive literature review if it fulfilled the following requirements:

1. Full-text article available and in English.
2. Existence of a control group or condition.
3. Performance or effect of an intervention was quantified and described.
4. Participants' level of comprehension as a result of a selective attention and/or visual attention strategy was reported.

The literature was reviewed to determine the effectiveness of the recommended strategies. The key concepts were examined in detail and compared to the current methodologies employed by coaches on college football teams based on SME feedback provided throughout the process.

RESULTS

Study Selection

A total of 54 sources were selected for inclusion in the report. Of those sources, 13 contained information related to signage design (Q1). Six sources covered the effects of multiple images (Q2). Nine answered the question of signal reception confirmation (Q3), one of which also provided information for the first research question and another that provided research for the last question. Fourteen provided

insights regarding the effects of stressors (Q4) and 12 addressed training and player attention (Q5). Figure 2 visualizes the research article review process.

While the subject matter of this report concerns the application of the information in a sports setting, only 33% of the sources were directly related to sports. Behavioral and emotional studies accounted for 30% of the references. Additionally, a total of 15% of the articles addressed sign language. Engineering studies (industrial and human factors) accounted for 12% of the information. The remaining 10% of the articles were deemed irrelevant. Figure 3 demonstrates a graphical representation of the breakdown of the article composition by category.

Synthesis of Results

Q1: What visual elements should appear on football signage?

Since the 2007 season, the use of play cards has permeated college football (Hruby, 2011). The symbols and pictures vary widely, often referencing pop cultural topics such as Rick Ross, Kenny Powers, Red Bull, turtles, Gatorade, or crying Michael Jordan (Kadar, 2015). The images are chosen by the student-athletes and coaching staff to ensure the image and signal meanings are more rememberable while also making interpretation difficult for the opposing team who
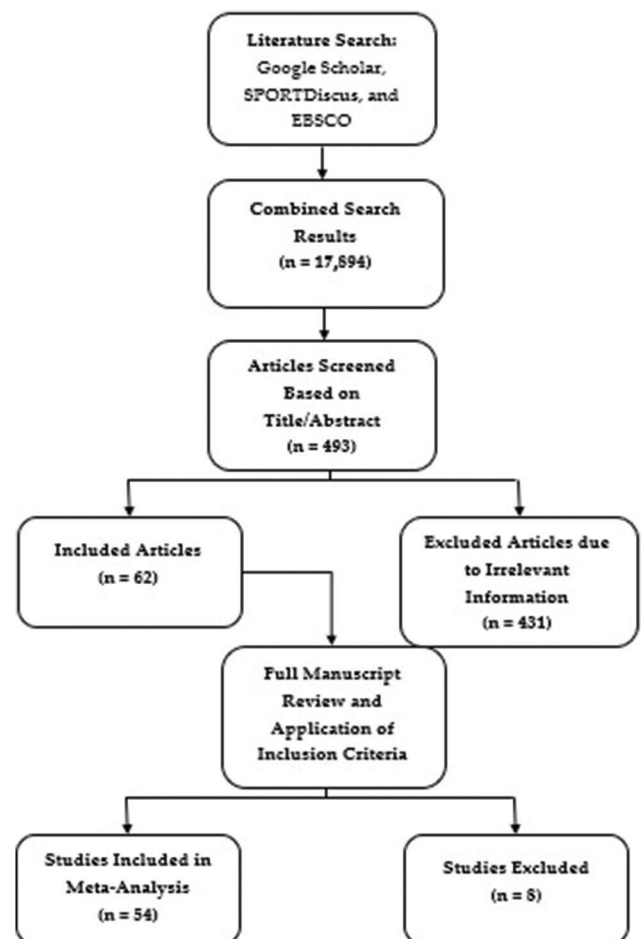
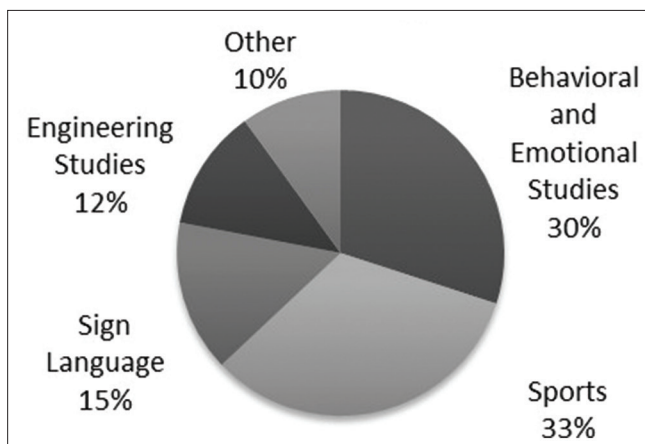**Figure 2.** Flow diagram of article selection

Figure 3. Categories of articles included

are often tasked with stealing the signals during the game. The cards and hand signals work together to quickly communicate the next play. However, the choice of images has not been reviewed to increase accuracy and speed of interpretation.

Words, characters, and numbers: While the most entertaining card examples are images, some of the signs include words, numbers, and characters. Craib and Imbesi (2015) conducted a literature review to better understand how people read written language. They discovered that, when presented with written language, individuals will first discern the individual letters, combine them to form words, then reorder the text as if the words were spoken (Craib & Imbesi, 2015). By using magneto- and electroencephalography (MEG/EEG) across seven different word processing experiments, Schmidtke et al. (2017) demonstrated the timeframe of the neural activity associated with the multistep process of word recognition. The initial categorization begins between 140ms and 170ms after introduction of the word while complete understanding of the word concludes between 200ms and 250ms after introduction (Schmidtke, Matsuki, & Kuperman, 2017). By comparison, MEG and functional magnetic resonance imaging (fMRI) responses from participants to 92 different objects images displayed identified that categorization of images begins as early as 56ms for human faces and as late as 190ms for nonhuman faces (Cichy, Pantazis, & Oliva, 2014). Furthermore, when words are combined with images and graphics, the observer processes the separate components simultaneously, switching back and forth between each element of the composition in an effort to understand the meaning of the combination of the elements (Craib & Imbesi, 2015). Rapid task switching results in a time penalty added to the combined task times and is associated with the individual tasks due to the process of mentally changing perspectives for each task (Wickens, Hollands, Banbury, & Parasuraman, 2013). Therefore, the inclusion of words slows the signal interpretation process.

Pictures and icons: Through the same literature review, Craib and Imbesi (2015) identified that observers prefer photographs over illustrations. The preference stems from a desire for authenticity. The photograph presents the viewer with an uninterrupted recording of a moment in time. The image

shows a scene as it appeared before the camera without interpretation (Craib & Imbesi, 2015). In contrast, a comprehensive cross-cultural study looking at male and female toilet signage identifies the need to distill the core concept of icons or pictogram images down to the simplest representation possible (Ciochetto, 2003). Design studies used to assess iconic information during wayfinding and directions to unknown locations have found that the simplicity of the image directly correlates to the speed of interpretation by decreasing ambiguity (Park, 2013). The simpler the visual, the faster the interpretation. Moreover, communication through signage is most effective when the sign depicts or prompts the observer to action, based on a well-learned behavior (Meis & Kashima, 2017). This insight was identified during a study by Meis and Kashima (2017) to understand more about perceived effectiveness of well-known and unfamiliar signage used depict actions. Unfamiliar signage was better perceived with clearer intent of the action being depicted. Additionally, through the development of a theoretical model of "how simple human communication systems might have first arisen and evolved", researchers document that proper universal interpretation of a sign occurs most readily when the sign depiction is non-arbitrary (Lister & Fay, 2017). Therefore, the use of simplified iconology directly resembling the object or action leads to increased accuracy of interpretation with poster board signage for play calling.

Background colors: Sporting events occur in an atmosphere awash with colors and images. These sights and sounds represent signal noise, distracting the observer from proper identification and interpretation of the signals. Visual separation from the background improves signal salience. Using a study design where eye-tracked participants reviewed multiple signage treatment options, advertising researchers found that light colors attract attention more readily than dark colors. Moreover, colors with a higher contrast from the background increased viewer awareness (Breuer & Rumpf, 2014). Additionally, results of both advertising effectiveness and childhood communication studies demonstrate that using background colors neither increase nor decrease image identification performance over a white background (Breuer & Rumpf, 2014; Thistle & Wilkinson, 2017). Thistle and Wilkinson (2017) found no statistically significant advantage of using a white background when working with children performing symbol arrangements (Thistle & Wilkinson, 2017). Therefore, the images should be surrounded with light-colored backgrounds such as white, pale yellow, or pink to visually separate them from the environment by increasing salience. However, adding a light-colored background will not improve image identification, just ability to see an image.

Q2: Should the signage contain one or multiple visual elements?

In the context of college football, images and displays are used to signal a play call during a game to inform student-athletes of information pertaining to their strategy. Sometimes multiple images are displayed on each image board; however, only one of the images on the board may be "live,"

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at any given time while the other images on the board are simply a distraction for the other team attempting to steal the signal calls. Other times, multiple display may be used with single images, with only one board being considered "live" with the other picture boards being irrelevant to the play. This distinction is important in this research because, while the number of images in sports signaling is not prevalent in research literature, the use of single or multiple displays are prevalent.

While images are a great medium for conveying information, they also have the ability to be misleading for a task (Schnotz & Bannert, 2003). When working with university students in scenarios that included interpreting text with pictures and text only, Schnotz and Bannert (2003) found that task-inappropriate images interfered with mental model construction. Also, using comic strips with unstructured and structured story panels to compare participant understanding and reaction time, researchers discovered that the narrative grammar associated with visual-graphic mediums requires the combination of both meaning and sequential structure (Cohn, Paczynski, Jackendoff, Holcomb, & Kuperberg, 2012). Therefore, paying attention to details when assigning an image or graphic to a meaning is critically important in poster board design for play calling. For example, in Figure 1, if the image of a school bus is intended to inform the student-athletes of the word "yellow," then the bus color needs to be distinctly yellow instead of orange or white. Additionally, a display which has a succession of images can give the sense of time passing across them (Cohn, 2010). McCloud (2000) proposed his concept that "sequential images are guided by a notion that 'time = space'" and, through the use of multiple combinations of story panels and sequential image comprehension, Cohn (2010) confirmed that this theory can be true but only when images are "thought of as the union of conceptual information that is grouped via unconscious hierarchic structures in the mind" (Cohn, 2010; McCloud, 2000). Multiple images on a poster board play call should clearly tell a cohesive story when related or the images should obviously have no connection when not related.

When working with displays, especially technological ones, the trend is that "more real estate" is preferred because it allows more information to be presented (Bi & Balakrishnan, 2009). The preferred trend of larger monitors identified by Bi and Balakrishnan (2009) extends from an older study when desktop workers began to transition to multiple screens. A software tool developed to monitor single monitor users and multiple monitor users confirmed that with increased "window visibility" comes the users desire to fill said space with information (Hutchings, Smith, Meyers, Czerwinski, & Robertson, 2004). Therefore, the display itself should be as enlarged as conveniently possible (within the confines of NCAA or stadium specific requirements) for optimal clarity. However, an issue experienced by the coaching SMEs as they increased the "real estate" of their own poster board signage was that the size of the display would begin to block the line-of-sight of the fans attending the football games. Given the location of where these signage boards were held, the visually impacted fans were often prestigious

university donors sitting in front row seats. These donors would then contact the Athletic Director who would then instruct the coaching staff to lower the signs. The signs would be lowered and then the student-athletes on the far side of the field could no longer clearly see the image identifying the signal call. After all, donors and sponsorships account for large amounts of money especially in the world of NCAA Division 1 universities (Chen & Reams, 2013). In learning from this example, there are other, often unconsidered, limiting factors when making signage boards larger.

Q3: Should coaches provide additional or redundant information to the players to confirm receipt of the messages?

Hand signals: Coaches and players have been communicating through hand signals long before the introduction of poster board signage to the football sidelines. Even with the addition of signage, teams often still rely on gesture based signaling (Hruby, 2011). The coaching SMEs who participated in this study indicated that they must use a combination of both poster boards and hand gestures to convey more complex information. They indicated that poster boards are good for certain components of information while hand gestures are better at communicating others. The SMEs agreed with communication and artificial intelligent design literature stating that gestures successfully transmit meaning and emotion when viewed in the proper context and connected to cultural meaning (Behoora & Tucker, 2015; Cash & Maier, 2016). However, when the gesture lacks cultural shorthand status (i.e. a new gesture that may be created for a football play call), the employment of motions that directly represent the item or task has been found to increase the interpretability and learnability of the gesture (Kapalková, Polišenská, & Süssová, 2016). Kapalková et al. (2016) performed a study with two-year-old's assessing two nonverbal mechanisms, pictures and gestures, for learning new words; gestures were found to be the better way to support new word learning. Furthermore, a sign language recognition study by ten Holt et al. (2009) found that observers can identify a hand sign from only a portion of the sign. A hand signal consists of three distinct parts, the preparation, the stroke, and the retraction. The stroke or actual gesture was always interpretable. The study also demonstrated that the start of stroke motion was often enough to recognize the sign. However, the researchers also found that observers identified the sign from the preparation movement at a rate greater than chance. The results demonstrated two major factors leading to preparation movement identification: when the shape of the hands was unique (other than a fist or flat-handed), and the starting point of the stroke was distinctive (ten Holt, Van Doorn, de Ridder, Reinders, & Hendriks, 2009). In a separate study involving dolphins well versed in sign language, researchers found a correlation between the size of the gesture and successful interpretation. The smaller the spatial extent of the gesture the more difficult the gesture was to interpret (Herman, Morrel-Samuels, & Pack, 1990). Therefore, the use of descriptive hand signals that have unique hand shapes, distinctive beginning positions, and large movements can be

used to compliment the use of physical signage in order to provide deeper, more detailed meanings to the play call.

Confirmation of received signal: In the fast-paced game of college football, hand signals and play boards may be used in favor over traditional huddles to relay information to all team members and maximize playing time. Based on SME descriptions of hand-based communication from the sideline to the student-athletes on the field, the signals are brief, lasting only 3-6 seconds and are slightly faster at 2-4 seconds when repeated. After receiving the signal, the players' first action is to quickly align in the formation that has been signaled. Any additional information to confirm the receiver received the signal could delay the play of the game and reduce the amount of game time allotted to run more plays (the key to most up-tempo offenses). Every student-athlete on the field receives the visual signal even if it may not pertain to them. Therefore, it would be a futile effort and time-consuming to routinely include additional information to confirm receipt of the signal by each student-athlete on the field.

Occasionally, and as necessary, a player could shout or nod their head to confirm they received the signal. Similarly, a player can throw up their hands in confusion to ask to have the signal repeated. However, these extra actions to transmit additional information would increase the amount of time before the team aligns in their formation. Rather than transmit additional information to ensure the signal was received, coaching efforts should focus on adequate training and practice to nurture skilled players and improve their selective attention and signal comprehension. A study performed using tennis players found that more skilled athletes are able to demonstrate a global perceptual strategy and pick-up dynamic information across different body areas rather than from a single source (Cañal-Bruland, van Ginneken, van der Meer, & Williams, 2011). If football student-athletes should miss the signal call, they may be able to follow cues from their teammates and identify the formation that all the players are assembling in. Likewise, Cañal-Bruland et al. (2011) also found that more experienced tennis players showed significant decrements in performance when the other players' arms were perturbed. Therefore, unfamiliar or difficult to assess movement could actually hinder more experience players from following cues of team mates and of the opposition in order to appropriate guess the signal call.

In the game of football, no additional information is necessary to confirm what the signal receiver thinks they are seeing. However, there are several strategies that could be used to improve selective attention and comprehension that warrant consideration, including adequate training and practice. These are discussed in response to Q5.

Approaches to improve information transmission and comprehension: The receipt of the visual signal does not stop at the eye and requires perception and recognition of the signal to comprehend the information and translate this input into a rapid decision about which action to take (Miller, Clapp, & Coordination, 2011). How much information is received depends on the number of possible signals, the probabilities of the possible signals, and the constraints and context of the situation (Wickens et al., 2013). Since

there are multiple coaches signaling, with each separately transmitting different pieces of information about the play-call, communicate the plays can take time. The use of picture boards could work better if student-athletes have an easier time associating an image to an action than remembering hand signals. However, a tremendous amount of effort and coordination is required to first identify the correct poster boards among a stack of several giant poster boards and be quick enough to have them displayed.

Keeping visual hand signals as simple as possible so they can be relayed to the student-athletes while providing the most specific information in the fastest amount of time, is an important strategy to increase information transmission found in an experiment with both novice and expert basketball players (Laurent, Ward, & Williams, 2006). Likewise, integrating direction into the play name helps to improve processing efficiency and reduce the amount of information presented based on feedback from the football coaching SMEs. Both recommendations reduce the mental workload and amount of memorization required.

Q4: What effect do environmental factors (e.g. noise, stress, time constrain) have on signal comprehension?

Noise: When college football offenses take the field in a large stadium, the arena fills with noise generated by yells, claps, and sometimes even cowbells if the team is playing MSU at Davis Wade Stadium in Starkville, MS. Fans feel as though they are providing their defense an advantage by interfering with the offense's ability to communicate. But are they?

Increases in environmental noise increase relative arousal, as has been shown in numerous studies over the years focusing on sleep experiments, mental arithmetic, and office noise respectively (Corcoran, 1962; Frankenhaeuser, Marianne; Lundberg, 1974; Loewen & Suedfeld, 1992). However, noise-induced arousal has not been shown to decrease task performance or attentional selectivity. In fact, performance on simple primary tasks has been repeatedly shown to increase with noise levels (the benefit of arousal on complex task performance is less clear.) Peripheral tasks, however, may suffer; this is the result of increased attentional selectivity, or focus, during increased psychological arousal (Hockey, 1970a, 1970b). For signal callers and signal receivers, less complex communication methods or more experienced signal transmitters and receivers will reduce the task complexity and potentially eliminate any noise-induced detriment to performance. Scientific evidence provided by Hockey (1970a, 1970b) on attentional selectivity supports the likelihood that experienced athletes actually perform their tasks better (including receiving signals) under noisier environments, lending credence to the reputation of certain student-athletes being "clutch" or always on target.

Stress: Helton and Garland (2006) found is a study of complex tasks, reading comprehension and land navigation orienteering, that participants were likely to report (via the Short Stress State Questionnaire; SSSQ) worry as the likely cause of cognitive slips (Helton & Garland, 2006). Worrying uses cognitive resources to imagine possible failure outcomes (possibly a useful process under certain decision-making

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circumstances). Worry therefore distracts from the primary task which, for this study, is receiving play call information from a poster board.

Anxiety has also been shown across numerous studies to decrease attentional control (Derakshan & Eysenck, 1998; Eysenck, Derakshan, Santos, & Calvo, 2007; MacLeod & Donnellan, 1993; MacLeod & Hagan, 1992). Tests involving Corsi blocks (Berch, Krikorian, & Huha, 1998) have shown that anxiety decreases performance only to the extent that it occupies the central executive (Eysenck & Payne, 2005).

Thermal stress has been shown to exhibit a significant impact on cognitive performance. Interestingly, the greatest effects are typically on perceptual performance (as compared to psychomotor performance and cognitive tasks). There is a greater impact on speed than on accuracy. In a thorough meta-analysis review, thermal stress has been found to begin at ambient temperatures above 85° F or below 52° F, with pronounced effects only occurring at extremes well beyond those limits (Hancock, Ross, Szalma, & Florida, 2007).

Time Constraints: Per feedback from the coaching SMEs who assisted in explaining the game of football and the use of signage, they detailed their experience with student-athletes' time-based perceptions. For example, many football student-athletes making the transition from high school competition to collegiate competition express "how much faster" the college game is played. The student-athletes are faster, more precise in their execution, and have adopted skillsets that lead to better distraction, evasion, or physical contact. When new freshmen enter a Division 1 NCAA football program, they are often trying to catch up to the speed of the game. A few seasons into the program and more so by the time the student-athletes reach their senior season, they often mention the opposite effect where the game seems to "slow down" for them during competition-based critical execution moments. The researchers for this study used an autoethnographic frame and can confirm this concept as the last four authors include a former MSU football player, a member of the MSU coaching staff, and two football strength and conditioning coaches, respectively. The concept that "time slows down," perceiving events during competition take longer than they did, or "it was all a blur," the perception that events moved faster than the ability to perceive and understand them. In either case, there is not strong evidence that student-athlete performance was either reduced or enhanced, but instead that, when stressed and fully loaded, the human brain ceases keeping up with time temporarily (Hancock & Weaver, 2005). Instead of positive effects (time slowing down), the effects of this are generally negative (losing track of time). Imagine a scenario where a football player waits too long to look over to the sideline to receive the play call information because he thinks he still has time to get in position on the playing field. This effect can lead to errors in the timing of signaling, distributing, and executing a football play.

Q5: What effect do training and attention have on signal comprehension?

Training and practice: Each hand gesture or play call poster board has a specific meaning to each player position to form the choreography of a larger play. A similar literature review study led by members of this research team details the differences in communications requirements for each football defensive position in regards to reaction time (Reid et al., 2020). Learning poster board image meanings along with hand signals and remembering what each image plus hand gesture combination means is akin to learning another language. Signals must always be used in practice. Currently, student-athletes receive two-to-three days of exposure to a new signal before using it in a game. This practice improves search, recognition, or both. Consistency and training play an important role in formulating the correct mental models for receiving the signals and producing faster reaction times (Wickens et al., 2013). In a study with college-level American football players, mindfulness training was shown to have benefits on sustained attention to response task outcomes (Rooks, Morrison, Goolsarran, Rogers, & Jha, 2017). Based on a study using surveying techniques to assess nonverbal communication across multiple sports, training was shown to lead to fundamental changes in the way the teams communicated as both non-verbal and verbal were used equally and in unison (Novitaria M & Subarkah, 2018).

Skill-level differences in sensitivity to visual information extend to detecting deceptive information as was shown in a study of novice and expert participants using video to gauge a rugby player's movements based on deceptive movement or the ability to discriminate between the true signal and noise or false signals (Jackson, Warren, & Abernethy, 2006). In another study using novice and skilled soccer players, highly skilled participants were found to demonstrate greater sensitivity in differentiating genuine and deceptive actions in a signal detection analysis study (Jackson, Barton, Ashford, & Abernethy, 2018). Based on research found using tennis players, this gap between novice and expert players could be due to highly skilled players using information from distributed sources whereas less-skilled players are more reliant on local sources of (potentially deceptive) information (Ward, Williams, & Bennett, 2002). Skilled players were able to differentiate genuine and deceptive actions even when limited information is available, for example when only the lower body or upper body gestures were visible (Jackson et al., 2018). During a study using novice, intermediate, and expert boxers, eye tracking, and video of opponent activities, a correlation was found between level of expertise and subjects' visual strategy, response accuracy, and reaction time (Ripoll et al., 2018). The ability to exert interference control is an important factor in the performance of college football players during a study by Wylie et al. (2018) that assessed their "interference control" during an age matching control variant of the Eriksen flanker task. Collegiate football players have been shown to lead to better response execution speed compared to controls (Wylie et al., 2018) and better response times in general being a critical element for mitigating injuries (Shelly et al., 2019).

An conceptual framework designed through the outcome of a literature review using reward learning was predicted to modify the attentional priority of a stimulus, allowing it to compete more effectively for selection (Anderson, 2013).

This mechanism of attentional selection is uniquely driven by learned associations between stimuli and rewards. A study utilizing participants searching for color-based targets driven by the motivation of a monetary-based reward showed that visual search for a salient target is slowed by the presence of a task-irrelevant item that was previously associated with monetary reward during a brief training session (Anderson, Laurent, & Yantis, 2011). The authors suggest this type of reward training might reflect knowledge of situational probabilities of the respective actions or an assessment that there are greater costs associated with missing a deceptive action. This reward learning method is one strategy that could be considered for incorporation into training and practice to enhance attentional priority of a signal. A monetary reward, obviously, would be a violation of NCAA rules but the Industrial Engineering concept of gamification has been identified as a successful rewards-based system within other NCAA Division 1 football programs (Luczak, Burch, Lewis, Chander, & Ball, 2019). During an extensive interview process, Luczak et al. (2019) found that strength and conditioning coaches and athletic trainers across numerous collegiate and professional teams were using gamification, " taking typical elements of games and competitions and applying them to other areas of activity," and turning training elements into competitive environments by using the already driven attributes of student- and professional athletes to improve the learning culture (Luczak et al., 2019). The coaching SMEs aiding in this study mentioned the culture of their current team was already using gamification concepts is two key areas: (a) the teaching of the importance of hydration and (b) maximizing player performance output evaluation during competitive jump tests (Burch et al., 2019).

Despite training and practice, it is not uncommon to have a signal mix up by a student-athlete once or twice during a game. There may be instances where a student-athlete simply forgets or confuses signals. This may be due to the student-athlete not taking the time to learn the signal or not being focused on the game. Strategies to improve selective attention and comprehension, such as gamification, can help to mitigate the chances of this occurring.

Strategies to increase selective attention: The importance of selective attention and comprehension in signal detection has significant implications for perceptual training protocols. Attention selects which aspects of visual inputs are brought to awareness (Anderson et al., 2011). A team's coaching staff may use (a) multiple signalers to convey the cadence, formation, and play name through hang signals; (b) other signalers to provide fake signals; and (c) additional signalers to each hold up a picture board. Designated signalers have the objective of conveying information to the players on the field, all while keeping the information hidden from the other team. Selective attention plays a critical role in the visual processing of the signals being conveyed and to minimize the occurrence of errors and mix ups between the true and fake signals.

Once the visual signals (both real or "live" and fake) are relayed by the designated signalers, the student-athletes must be able to detect that the signal is present, identify the characteristics of the signal, and recognize the type of signal. Salience (how much the area of interest stands out from the background), effort (scanning difficulty), expectancy (contextual cues), and value (importance of information) all have an impact on selective attention (Wickens et al., 2013). To their benefit, the results of one study comparing the reading-based comprehension abilities of low- and high-income adolescents after engaging aerobic exercise have suggested that aerobic exercise improves selective visual attention and reading comprehension (Tine, 2014). However, under stress from the noisy and physical exhausting game environment, the student-athletes may lose attentiveness to peripheral stimuli and demonstrate attention narrowing, or perceptual tunneling. Change blindness (not noticing when something changes) and intentional blindness (failure of attention even if something is visibly seen) may also occur (Wickens et al., 2013).

One way to improve divided attention performance is through redundancy. Having the signal repeated twice may sufficiently achieve signal detection. If necessary, the signal may be repeated a third time if a student-athlete on the field throws his hands up in confusion. Another way to improve selective attention is through stimulus discriminability (Wickens et al., 2013). In a study where computer animations of highly exaggerated tennis serves were used to train participants, results showed that exaggeration can be used to make some actions more recognizable (Pollick, Fidopiastisô, & Braden, 2001). Lastly, spatial proximity is also crucial in optimizing selective attention. Coaching SMEs stated that, through experience, they have learned that the signalers should face the football players on the field such that they are positioned in a straight line at the line of scrimmage. The ability for all student-athletes on the field to see the sidelines for the signal is critical.

DISCUSSION

Summary of Evidence

The previous analysis presents detailed explanations of the theories and evidence contained within the body of knowledge of academia. In the interest of increasing the speed and accuracy of the communication of the ideas within this report, the following section provides recommended best practices for increased speed and accuracy of communication through hand signals and signage during a sporting event. This information was shared with the quality control coaches who participated as consultant SMEs for this comprehensive literature review.

Signage should avoid words when possible (Craib & Imbesi, 2015). As shown in Figure 4, the design should consist of simplified iconology directly resembling the object or the action (Lister & Fay, 2017; Park, 2013). The intent of Figure 4 is to demonstrate different signs representing the same information but provided with simpler and simpler imagery that can be more quickly interpreted (from left to right in the figure). The most complicated visual is a written one that requires more time to comprehend and process whereas the less complicated image represents an action. Whether that action

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is to be taken by the football player or is meant to represent something else, the goal of Figure 4 is to explain that simple images are better. Additionally, sufficient background space in solid white or a contrasting color to the dominant color of the environment should be provided around the image (Figure 5) to visually separate it from the environment (Breuer & Rumpf, 2014). Moreover, the trade-off between comprehension time and amount of information to convey should be considered when implementing multiple images. A single image conveys less information but in a timely manner while multiple images convey more information but require more time to comprehend (Ward et al., 2002). However, hand signals are preferred over signage (Kapalková et al., 2016) when conveying certain elements of the play call. When used, hand signals should be descriptive (Kapalková et al., 2016), incorporate large movements (Herman et al., 1990), include unique hand shapes, and employ differing beginning positions when possible (ten Holt et al., 2009) as demonstrated in Figure 6.

No confirmation (form of understanding) from the student-athletes on the field is necessary. The additional communication effort to confirm the receiver received the signal could delay the play of the game and reduce the amount of game time allotted to run more plays. Instead, selective attention and comprehension can be improved through training and practice (Ripoll et al., 2018), redundancy (repeating signal), spatial proximity (ensuring all players can see the sidelines for the signal), signal discriminability (exaggerated motions) (Pollick et al., 2001), and simplification of the number and type of signals to be memorized (Laurent et al., 2006).

The game-time environment can be filled with environmental stressors. The most noticeable to the crowd is noise level. Contrary to the belief of the 12th man (a Texas A&M University football tradition), noise can increase performance. Noise increases arousal, and, in turn, arousal increases focus and performance on primary tasks (Corcoran, 1962; Frankenhaeuser, Marianne; Lundberg, 1974; Loewen & Suedfeld, 1992). However, the performance increase may be more significant on simple tasks than on complex tasks. Moreover, arousal decreases performance on peripheral tasks (Hockey, 1970a, 1970b). Consequently, student-athletes who are more experienced or proficient will likely find operating in a noisy environment easier than less experienced athletes.

Unlike the noise of a crowd, thermal stresses are less predictable. Thermal stresses occur at temperatures above 85° F or below 52° F. Thermal stress shows a strong correlation with reduced performance, with the most pronounced effects on perception. Among perception tasks in both high and low temperatures, speed and accuracy were both reduced, with the greatest effect on speed. The effects increase exponentially as temperatures exceed the "comfortable" bounds. Therefore, more time should be allotted to the communication of plays (Hancock et al., 2007).

Perceptual abilities are impacted by stress, mainly to the degree that they monopolize cognitive resources. These cognitive burdens are known as worry and anxiety. Worry

Figure 4. Words slow interpretation. (Clip art courtesy of: http://clipart-library.com)

Figure 5. Sufficient background space and color. (Clip art courtesy of: http://clipart-library.com)

Figure 6. Large hand signals with unique starting positions and distinctive motions. (Clip art courtesy of: http://clipart-library.com)

involves mentally simulating failure scenarios. This process reduces performance by substantially occupying cognitive resources (Helton & Garland, 2006). On the other hand, anxiety is usually associated with divided attention and multi-task performance. Anxiety may reduce perception performance, but only to the extent that secondary tasks utilize the central executive function of working memory (Eysenck & Payne, 2005). Practice often reduces the effects of both stressors. When a process or response is practiced sufficiently, it becomes "automatic", allowing the student-athlete to break out of the cognitive spiral (Jemmy & Easvaradoss, 2018).

"Time slowed down" and "it happened so fast, it was just a blur", are both effects of stress on the brain. When faced with a sufficiently stressful situation (i.e. rigorous competition against a top opponent in front of 65,000+ spectators) which requires 100% of human mental capacity to manage, the brain temporarily stops doing non-essential things, including counting the passage of time. Since the individual is not actually thinking and responding faster in such a situation (they just feel like they are), the corresponding consequences are generally negative, losing track of time (Hancock & Weaver, 2005). Under time-sensitive situations such as executing a drive in a football game, this can have negative consequences. Stress can lead to a student-athlete's "mental clock" shutting down, and not allowing enough time to bring the team to the line and snap the ball. Practicing conscious referencing of the game clock will reduce the student-athlete's reliance on their internal clock.

When training student-athletes to improve their signal detection and recognition from a poster board, gamification is a proven method to utilize the competitive spirit of football players to reward improved comprehension. Gamification has been shown to change the mindset of a team culture while improving the understanding of importance of key concepts that the coaching staff wishes to impart on the student-athletes (Luczak et al., 2019).

Application for Coaching Practitioners

The game demands of football have been shown to change and evolve over time and with those demands, the players themselves have evolved (Shelly et al., 2020). These changes are driven by the need to remain competitive and winning out over the competition is simply the right mix of being better, faster, stronger, smarter, and more prepared. Just as training regimens have been modified to meet the demands of doing more with less, so too has all aspects of the game of football. Coaching practitioners in performance can utilize the information provided in this article to design and implement protocols that will build visual recognition abilities into their programming. For instance, when scouting opponents, the unique background colors of certain stadiums, jersey color, fan color patterns, etc. could all be considered. Visual processing exercises could be built into the training regimen such that the football players are being exercised from both a physical and a cognitive perspective. An example of this style of drill could come in the form of a reactionary conditioning drill where the coach has two sign colors,

one of which dictates a certain direction the drill should be performed to. This color-direction combination can be designed to reinforce the same protocols based on specific game planning and visual cues that will be utilized in an upcoming competition.

When training collegiate football players, the environment in which training occurs is often filled with external noise and other stimulus' that can lead to potential for distraction. For the coaching practitioner, incorporating visual cues such as hand signals designed for feedback would be advantageous. This type of cue-based practice will further boost the development of the team's non-verbal communication skills. For example, as a part of group training sessions in the weight room, the strength and conditioning (S&C) coaches could utilize a basic hand signal system aimed at providing common feedback loops. The S&C coach may cue the athlete to bring their chest up by tapping their chest and pointing "up," for instance while ensuring the messaging is clear such that no verbal communication is required. Further, most football weight room environments play music very loudly. The "natural" environment of the weight room does not bode well for verbal communication because the music volume is frequently high thereby enabling this non-verbal practice to be adopted. Another situation for the need for non-verbal communication practice is a result of the understanding by S&C coaches that thermal stress has an impact on cognitive performance. This awareness can be leveraged to promote visual training in high heat and humidity environments or post-training when the athlete has experienced an increase in psychomotor fatigue.

With time constraints of the NCAA football training schedule, frequently exposing the football player to these non-verbal signals, such as cards and hand gestures, will be beneficial for them individually and for the team. Skill acquisition in signal detection and processing would continue in both practice and the meeting rooms with the position coaches but these are other recommended options for implementing non-verbal training strategies. There are two forms of communication in football, verbal and non-verbal, and both must continue to evolve with the rest of the sport to remain competitive.

While this article focuses on the game of American football at the collegiate level, the NFL communicates play calls in a more verbal manner as players and coaches can converse using radio receivers in the helmet. One player on field for each team—one for the offense (the quarterback) and one player on defense (typically the defensive captain or inside linebacker)—is permitted to have an active radio receiver (Blair, 2016). While this communication medium reduces the need for signage or other non-verbal communication, the radio signal is terminated with 15 seconds left on the play clock (Goodell, 2019), leaving room for NFL teams still need play cards. Some examples include the defensive coaches using signage that signify which offensive personnel are in the game. Also, offensive line coaches occasionally use signs that signify which defensive front the lineman should anticipate. Regarding the signage contents in the NFL, mostly letters or numbers—consistent in size,

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color, and font—are displayed on white backgrounds with bold red letters and a thin black outline.

Both NFL offensive and defensive coaches have hand signals as well for the signage examples provided. Offensive coaches give hand signals signifying their own personnel in the game. This way, players who are on the field but not in that specific offensive or defensive configuration know to leave the field while the players on the sidelines hear the personnel, see the hand signal, and know to run out onto the field. Defensively, the non-verbal communication is very much the same. Lastly, if the radio communication to the players' helmets becomes unavailable for any reason, coaches resort to hand signals for play calls; and if any team's headset cease to work, the other team has to stop using their headsets during the game as well. This levels the playing field for NFL competitions such that no single team has a communication advantage over the other (Goodell, 2019).

CONCLUSION

To better understand the communication challenges of an American football team from a cognitive engineering perspective, the comprehensive literature review was conducted by first searching databases, criteria, and terms to guide the analysis based on interview feedback from NCAA Division 1 football quality control coaches. Then, reviews were conducted on available literature and summarized into relevant information for sports communication recommendations. The main questions which framed the research included an in-depth understanding of signage design, signal design, and the effects of environmental factors in a game environment as well as training and attention. The primary focus was to understand the best ways to send signals to student-athletes in ways which promote comprehension while using what is known about selective attention to coaches' advantage. The research points to several best practices for the implementation of signaling between the coaches and players. For example, comprehension is promoted by allowing team members to come up with the signs (familiarity) in addition to using large, distinctive, and unique movements to improve the salience of the signal (clarity). Additionally, ample practice before game time ensures strong habits for players to enhance their ability to combat the consequences of signal disturbances and attention narrowing. These practices are not hard fast rules but rather suggestions to keep in mind when designing communication methods. Overall, the results encourage the use of simple signage to convey complex messages. The quality control coaches who participated as SMEs for this study plan to take this information and supplement their existing play-calling strategies. Based on SME input, future efforts should include investigation through field studies of play-calling strategies appropriate for ensuring comprehension by college football student-athletes.

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