International Journal of Industrial Ergonomics 77 (2020) 102942

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: http://www.elsevier.com/locate/ergon

Reaction time assessment for coaching defensive players in NCAA division 1 American football: A comprehensive literature review

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ARTICLE INFO

Keywords:
American football
Reaction time
Sports
Signal detection
Response times
Decision making

ABSTRACT

This comprehensive literature review seeks to understand the contributing factors that impact the reaction time in decision making of collegiate level, American football players who play on the defensive side of the ball. The goal of this study was to work with National Collegiate Athletic Association (NCAA) Division 1 coaches to identify possible limitations and challenges for coaching staff to understand when training student-athletes to react to movement during game-time scenarios. Current literature focusing on football or other similar sports is limited; as such, this review gathers data across many fields of study and applies the findings to the reaction time in football players. This crossover of information was found to have a correlation to football as several individual decision-making factors were found to impact reaction time such as: cognitive fatigue, age, experience, player position, expectancy, uncertainty, and visual ability. These factors play a significant role in negatively increasing the reaction time for players, which thereby hampers the opportunity to stop the opposing team and impedes the continual positive progression of the football player. In addition to the contributing factors, the authors provided literature-based solutions to these issues which assist in achieving the highest performance of student-athletes.

Relevance to industry: This study highlights gaps in research related to reaction time in decision making. This study focuses on correlations of reaction time-based research to sports, specifically American football. However, the available, relevant information in cognitive fatigue, experience, uncertainty, and expectancy applies across all tasks in which information is gathered via observation.

1. Introduction

Minimal reaction time is a critical component to an athlete's success on the field (Burch et al., 2019). In the case of American football at the National Collegiate Athletic Association (NCAA) Division 1 level (known from this point forward simply as football), the faster the reaction, the more likely a student-athlete is positioned to make a play and to prevent injury (Engeroff et al., 2019). This is especially true for the defensive player who generally does not know what the offense is planning to do on a given play. The minimization of reaction time may also provide student-athletes with the needed edge to reach the next level of elite sports, of which a very small percentage are able to accomplish (Wylie et al., 2018).

This work is intended to gather existing research from across multiple fields where decision making is assessed and compile the findings into a comprehensive study on the factors which influence an individual's reaction time. Reaction time is defined as "the time that elapses between receiving an immediate and unexpected stimulus and reaction given to it" (Atan and Akyol, 2014). There are a number of factors that can change reaction time such as demographics variables like age (Atan and Akyol, 2014; Brychta et al., 2013; Obetko et al., 2019) and gender (Charkhandaz Yeganeh, Ebrahimi, Alimohammadi and Khalilzadeh Ranjbar, 2019; Lauridsen et al., 2012), physical factors such as condition (Hascelik et al., 1989) and fatigue (Sant'Ana, Franchini, da Silva and Diefenthaeler, 2017), environmental factors such as altitude (Dykiert, D., Hall, D., van Gemeren, Benson, Der, Starr and Deary, 2010), and stimulant or depressant factors such as alcohol, caffeine (Martin and Garfield, 2006), and nicotine (Day et al., 2007). Rest, sleep

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https://doi.org/10.1016/j.ergon.2020.102942
Received 18 July 2019; Received in revised form 23 February 2020; Accepted 27 February 2020
Available online 5 March 2020

deprivation, and general sleepiness beyond basic cognitive fatigue are also other factors that could impact reaction time (Vitale et al., 2018). General visual ability with speed in visual processing is another critical factor as well for reaction time and injury prevention (Feldhacker et al., 2019) as "mean human reaction time to a visual stimulus amounts to approximately 250 ms, with athletes showing lower values (Mańkowska et al., 2015). The importance of these determined factors is significant because research on the topic of reaction time is not often focused on sports and even more rarely on football. By compiling the existing knowledge into this work, the authors provide a starting point for further understanding and, in turn, reducing the factors which influence a player's reaction time. Also, for clarification, it should be noted that the time from stimulus to completion of the action, referred to as the response time, is not the focus of this work, as reaction time is the amount of time between when an individual receives a stimulus and simply begins the action (Shelly et al., 2019).

The goal of this comprehensive literature review was to determine how a defensive football player's reaction time changes based on the observation immediately preceding the signal compared to how much information the players were provided, priming their actions. Offensive football players generally receive some form of communication from the coaching staff regarding the play they are to execute. With knowledge of the play, offensive players line up in position, scan the defensive players of the other team, and mentally create a predetermined course of execution (Hicks et al., 2019). While defensive football players are given a base formation play call generated from the assumption of the coaching staff in terms of the offensive play about to be executed, they are still required to react to stimuli provided by the physical movement of the offensive players.

The available research directed the authors to address reaction time in defensive football players by focusing on key factors which impact their ability to recognize the offensive players and other contexts specific to the sport of football. These factors are a football-specific subset and include: position, cognitive fatigue, age and experience, uncertainty and expectancy (Atan and Akyol, 2014), and visual ability (Mańkowska et al., 2015). The findings of this work illustrate the complex interaction of sports and science. By gathering related information from many fields, a robust accounting of the sources of increased reaction time are provided and applied to defensive football players. As information identified through this effort was provided to the defensive football coaching staff at Mississippi State University (MSU) who intend to take the provided solutions and preventative measures and apply them during fall training camp.

2. Materials and methods

In order to provide a holistic view of the available materials related to this topic, a literature review was conducted to utilizing a repeatable methodology. The review was conducted in multiple publication databases via the guidance of the quality assurance coaches on MSU staff who are responsible for communicating play calls from the sideline to the student-athletes on the field. The literature search terms originated through interviews with the quality assurance coaches and were divided amongst the researchers according to the divisions of the identified decision-making factors. The terms were largely focused on literature pertaining to athletes and the related factors, diverging in some cases to directly related industry research (see Table 1 for details regarding database names, search terms, and article counts). Articles were evaluated by authors and deemed valuable to the report based on consensus agreement or disagreement with the identified direction of the paper. The down-selected articles provide an extensive view of the existing literature related to the issue of reaction times for football players.

Table 1
Keyword search.

Keyword/s Searched	Resource	Total # Results	Relevant Results
Capacity of Working Memory	ScienceDirect	96,281	2
Coach Play Calling	EBSCO	13	2
Cognitive Fatigue	ScienceDirect	71,281	16
Cognitive Fatigue	EBSCO	4334	21
Cognitive Fatigue and Noise	EBSCO	49	1
Cognitive Skill	ScienceDirect	52,585	3
Cognitive and Fatigue and Sports	EBSCO	305	9
Cognitive and Sports	EBSCO	6943	2
Defense and Reaction Time	EBSCO	241	4
Defensive Line and Reaction Time	EBSCO	19	0
Defensive Line and Reaction Time and Type of Blocking	EBSCO	1	0
Football and Signals	EBSCO	93	
Football Play Calling System	EBSCO	3	0
Olympic And Reaction time	EBSCO	9	1
Play Call Signals Football	EBSCO	0	0
Play Calling College Football	EBSCO	8	0
Play Calling Signal	EBSCO	480	1
Reaction Time	EBSCO	4845	9
Reaction Time and Football	EBSCO	80	6
Reaction Time and Age	EBSCO	156,961	10
Reaction Time and Expectancy	EBSCO	3150	7
Reaction Time and Expectancy and Football	EBSCO	2	0
Reaction Time and Expectancy and Sports	EBSCO	3	0
Reaction Time and Experience	EBSCO	56,180	6
Reaction Time and Football	EBSCO	1001	1
Reaction Time and Modalities	EBSCO	11,217	0
Reaction Time and Modalities and Sport	EBSCO	226	2
Reaction Time and Play Calling	EBSCO	5	0
Reaction Time and Practice	EBSCO	5393	1
Reaction Time and Sports	EBSCO	1059	
Reaction Time and Uncertainty	EBSCO	10,508	5
Reaction Time and Uncertainty and Football	EBSCO	16	0
Reaction Time and Uncertainty and Sports	EBSCO	161	2
Reaction Time and Uncertainty and Sports	EBSCO	25	0
Reaction Time in Sports	EBSCO	40,461	0
Reading Football Play Calls	EBSCO	1	0
Sideline Football Signal	EBSCO	370	1
Signal Detection Football	EBSCO	97	0
Signals Football	EBSCO	782	3
Sport Play Call Acknowledgement	EBSCO	16	0

3. Results

This research focuses on defensive football players because of their need to react to specific cues on the field. An offensive player has a detailed set of instructions based on the play being called. While the defense may also call a play or be assigned a formation based on coaching instruction from the sideline, their reaction to specific cues of the offensive football players determines whether they are successful. Additionally, once the play begins execution, the offensive player may make athletic moves to confuse or distract the defensive player. For example, a wide receiver, running back, or quarter back may demonstrate a move in one direction while executing a football move in the opposite direction with the intent of causing the defensive player to hesitate thereby slowing their reaction time. In this scenario, the defensive player must stay in a reactionary role in order to bring an end the offensive play. To phrase another way, the defensive players are almost always in a reactionary state while the offensive players have a known plan of execution and therefore drive the responses of the defense. Because the offensive players largely determine the reactions caused by the defense, the defensive football players are the focus for this study. Defensive players need to minimize their reaction time as much as possible to increase their probability of successfully "winning" a play.

There are multiple positions on the defense side of the ball in the sport of football. There are three primary defensive groups: (1) defensive linemen, (2) linebackers, and (3) defensive backs. Given National Football League (NFL) Combine workout and testing regimens identified by Sierer et al. (2008), these three groups align with the sport-specific defined groupings of (1) bigs (or lineman; defensive lineman), (2) big skill (linebackers and defensive ends), and (3) skill (cornerbacks and safeties). The players associated with these three groupings have similar physical statures (height and mass) and abilities (strength, speed, and six specific performance test outcomes) beyond the expectations of their football position (Sierer et al., 2008; Vitale et al., 2016). The MSU football team also denotes these three groups and constructs most workout and training events around the different physical builds and capabilities of the three groups. Specifically, MSU—like many other NCAA Division 1 athletic programs—has gamified performance outcomes (Luczak et al., 2019) in the same way as the NFL Combine in order to elicit game-level competition for the primary physical performance measures such as (1) the 40-yard dash, (2) 225-lb bench press competition, (3) vertical jump (Burch et al., 2019), (4) broad jump, (5) pro-agility shuttle test, and (6) three-cone drill (Sierer et al., 2008). For MSU, all members of the bigs, big skill, and skill groups are assigned within their own group population to determine top performers and awarded the elite designation of "Irondawg." The researchers for this study used an autoethnographic frame for this grouping explanation as well as the following description of defensive positions. The last two authors are a former MSU football player and Irondawg designee and a member of the MSU coaching staff respectively.

Defensive linemen consist of defensive tackles (bigs) and defensive ends (big skill). Defensive linemen position themselves on the line of scrimmage and their primary objective is to rush the passer and to tackle the ball carrier on a running play. They often react to the offensive lineman or the offensive blocker lined up in front of them. Others may react to the ball movement behind the line of scrimmage. The linebackers (big skill) align themselves behind the defensive line, and often consist of the middle linebacker and outside linebackers. The linebackers assist with stopping the run, blitzing the quarterback, and coverage of the tight end or running backs on an offensive passing play. The linebacker defensive range generally covers a larger area than the defensive line; however, they are usually further off the line of scrimmage and can, therefore, view a larger portion of the field while also having more time to react and adjust to what they observe of the offense. The secondary, also known as defensive backs (skill), consist of cornerbacks and safeties. They primarily defend against passing plays and provide the last line of defense in protection from the offense's objective. The secondary (and linebackers and defensive ends to a degree) are often placed into a defensive coverage scheme designated as "man," "zone," or a creative combination of the two. Man defense requires secondary personal to be responsible for a single individual on the offensive. When the offensive play begins execution, the secondary player in man coverage must stay engaged with the receiver and defend passes directed to that individual. Secondary players in a zone coverage must "protect" a designated area of the playing field and engage with any receiver who enters their zone. Both coverage outcomes require reaction time on the part of all defensive players to "read" the offensive in order to react to their movements as strategically as possible. Configurations and quantities of each group can shift based on the desired formations of coverages which best support the desired outcome based on several factors including down, distance to goal, and opposition tendencies.

3.1. *Defensive player position on the field*

Each group of defensive players are required to react differently when the offensive play begins at the snap of the ball.

3.1.1. *Linemen*

Defensive linemen not only have to react to the snap of the ball, but also to the offensive linemen across the line of scrimmage. The post snap actions of the offensive line will inform the defensive line of what offensive play was called. If the offensive line starts to back up, the defensive linemen will—in most circumstances—know the play is a passing play, and that the offensive line is backing up into pass protection. If the offensive line starts to go forward to block, this action informs the defensive linemen them that a running play was called. Practicing response time off a snap shows to have some benefits. Christina et al. contends, that using training methods such as video of actual events provided at the same viewing angle can improve the accuracy or skill of a player to respond during the actual event (Christina et al., 2016).

Wrestlers and defensive lineman share a common form of engagement in their respective sports. Gierczuk et al. completed a study of reaction time of wrestlers between simulated matches (Gierczuk et al., 2017). The study showed that in the first round the wrestlers had a simple reaction time of 220 ms, and after the third match their reaction time degraded to 280 ms. This research substantiates the practice of rotating players in and out between plays to keep them fresh physically and mentally—a practice commonly executed by defensive coordinators and coaches on football teams.

More important for the defensive lineman versus the defensive backs is the reaction time to a stimulus that they are predicting will happen, or which play is being called. Larish and Frekany studied the reaction time of responding to a known stimulus and a predetermined action, the time to a known stimulus and a choice action, and finally the reaction time to a predetermined action and having to respond with an unexpected response (Larish and Frekany, 1985). Table 2 compares the results of the study to a football scenario. In this example, if the coaching staff called for a rush defense and the offensive play they are trying to defend is actually a passing play, the players reaction time degrades by 25 percent. Therefore, when the coaching staff is unsure of what the offense will do it is better to allow players to be ready for anything.

3.1.2. *Linebackers and defensive back*

Linebackers and the defensive backs have a greater amount of time to respond to the play, as they line up behind the linemen. Typically, the middle linebacker is the leader of the defense. As a leader, they are responsible for receiving the calls from the sidelines, disseminating the information, and aligning the other defensive players. This added responsibility requires them to process additional information before the snap, which could slow reaction time. As such, their response is comparable lineman in that they must determine if the play is a run or pass.

The secondary's reaction time can be critical at both the start and end of the play. For a cornerback and safety, it is very important for them to know when to turn their head during a pass play to ensure they are not called for a pass-interference penalty. Kenward and Nilsson studied the reaction differences between a thrown ball and a ball fired out of a cannon (Kenward and Nilsson, 2011). They proved that balls thrown were 6.6 times more likely to be intercepted, due to the body cues given by the thrower (Kenward and Nilsson, 2011). Also, in their experiment, the cannon-fired ball became more and more expected once the interceptor learned to listen for the "hiss" of the cannon (Kenward and Nilsson, 2011). To translate this to cornerback and safety actions, these athletes can train their decision making to first always keep an eye on the quarterback to see the cues of throwing the ball, and then if that is

Table 2
Study results applied to football example (Larish and Frekany, 1985).

Experiment	Parameters	Defensive Coach …	Reaction time
1 (Baseline)	Uncertain	Signs "be ready for anything"	368 ms
2	Reprogramming response trial	Calls a running play, but it is a passing play	462 ms
1 & 2 (Average)	Certain	Guesses offensive play correctly	284 ms

not possible, to learn off the cues of the receiver prior to catching the ball (i.e. eye and hand movements).

There are similarities to the reaction time of defensive backs and tennis players due to how the stimulus can be generated by both the opposing player and a ball. Salonikidis and Zafeiridis proved that certain exercise routines improved reaction time (Salonikidis and Zafeiridis, 2008). The study focused on four exercise groups: plyometric, tennis-drill, combined, and a control group of no exercise (Salonikidis and Zafeiridis, 2008). The results showed an improvement of all four groups, with the following results: plyometric had a 59 ms improvement, tennis-drills had a 34 ms improvement, combined had a 64 ms improvement, and control had a 13 ms improvement (Salonikidis and Zafeiridis, 2008). This study shows the significant reaction time improvement shown by the tennis players and therefore could predict a similar improvement if implemented in football.

3.1.3. Defensive player position lessons learned

In totality, whether looking specifically at a position or at the entire defensive team, all of the research on reaction time findings prove there is not one tried-and-true formula for success. However, improvement can be achieved through one or a combination of the previously outlined findings. Specifically, positioning the defensive players into a “ready for anything” defensive scheme is an optimal solution when faced with significant offensive play calling uncertainty. Ultimately, reliance must be placed and focused on the individual athlete and promoting the attributes they bring to the team.

3.2. Cognitive fatigue

Cognitive or mental fatigue is “a psychobiological state operationally defined as an acute increase in subjective ratings of fatigue and/or an acute decline in cognitive performance” (Smith et al., 2015). This state can impact anyone, no matter the effort or desire of that person to avoid mental fatigue. Therefore, this section will assess sources of cognitive fatigue, the potential impacts, and the preventative tasks that are available to ensure the highest level of performance for football student-athletes. The goal for the MSU coaching staff is to have complete awareness of what the players are experiencing in order to create opportunities both on and off the field that protect student-athletes from injury. Only when we understand the actual disability to endurance caused by mental fatigue, will a determination be made on how to overcome it (Martin et al., 2016).

3.2.1. Cognitive

Cognitive fatigue can happen from cognitive use or—that is to say—the use of the mind to think and respond (Ackerman et al., 2010). Studies have shown extended time under cognitive load can lead to fatigue (Sievertsen et al., 2016; Thorndike, 1900). This can impact student-athletes during the classroom portion of football activities, impacting their ability to learn new information. Inserting cognitive breaks and light physical activity, such as a short jog, can help to increase retention (Kamijo and Abe, 2019). These studies, however, focused primarily on cognitive-based tasks only and did not pair them with any physical activities.

When considering how cognitive fatigue impacts physical performance, there is research supporting both the lack of and the link to reduced efficacy. While some research does indicate that there is no link between cognitive fatigue and physical performance, it is limited and does not consider the intermittence of decision making on team sports (Clark et al., 2019; Filipas et al., 2018; Schücker and MacMahon, 2016; Wang et al., 2016). Therefore, the following link between cognitive fatigue and physical performance should be considered correct for the application of this research.

The impacts of cognitive fatigue can be seen across a wide range of sports including running, cycling, and soccer (MacMahon et al., 2014; Smith et al., 2015; Mitchell R. Smith et al., 2018; Zeuwts et al., 2016). This body of research considers the ability of athletes to maintain task-related decision making and application of physical output under the strain of cognitive load. In all cases, both cognitive and physical performance suffered. This is seen through mistakes in decision making, inability to maintain speed, and reaction times.

In addition to these factors, research points to the athlete’s desire to conserve resources for survival; which ultimately indicates a player that is mentally fatigued may modulate their low-level intensity in order to sustain their performance when high-level efforts are required. (M. R. Smith et al., 2015). This conservation may not lead to any one big play achieved by the opposing offense, but it does lend to a gradual gain.

The best way to combat this fatigue is to insert cognitive breaks between sets of activity (MacMahon et al., 2014). Changing from mentally demanding to a less mentally demanding, low response state helps to conserve mental resources for decision making and potentially recharge a student-athlete’s mental and emotional state. Additional training through long duration, mentally demanding tasks increases the endurance of the cognitive ability and the strength to move past some levels of cognitive fatigue (Martin et al., 2016).

3.2.2. Physical

Cognitive fatigue can occur in athletes through physical and biological factors. Some research has indicated there is a potential for biological and individual psychology to impact the potential susceptibility of an individual to cognitive fatigue (Martin et al., 2016). This report in this review will not focus on this aspect, however, due to the limited research and the limited ability for coaches to recruit student-athletes based on only these factors. Research on physical fatigue indicates that it can lead to cognitive fatigue and reduced performance (Xu et al., 2018). While the impacts of this type of fatigue will result in a lack of physical ability before impacting the student-athlete’s cognitive ability, the best way to combat fatigue is of course through physical conditioning. This is noted by Vitale et al. (2018) who show that habitual physical exercise late in the evening is likely not a contributor to the potential for lack of performance.

3.2.3. Sleepiness

Sleepiness and fatigue are closely related and present similar cognitive impairment symptoms (Neu et al., 2011). Existing literature on the effects of sleep on reaction time varies between impactful and no effect. This is likely due to the currently limited understanding of sleep duration or the lack of sleep duration effects in general. Significantly slower reaction times have been exhibited by collegiate student athletes when exposed to a lack of sleep for an entire night (Taheri and Arabameri, 2012). In industry, Smith-Coggins et al. corroborate this with their study of workers on day and night shifts, where their conclusions show that day shift workers received more sleep than their counterparts and that their reaction and mood ratings scores were significantly higher (Smith-Coggins et al., 1997). When investigating the effect of sleep variation in elite athletes over multiple days, there was no effect on reaction time found (Knufinke et al., 2018).

Sleepiness drives people to enlist coping mechanisms, the foremost of which is avoidance or to avoid the source of the fatigue (Neu et al., 2011). When student-athletes start with an elevated level of sleepiness, they will seek to reduce additional sources of fatigue which come from using cognitive facilities during a game. This can be curbed through the study of individual sleep patterns and implementation of adjustments to ensure a higher quality of rest.

3.2.4. Task switching

Task switching required by the defensive player is illustrated in Table 3, which was developed through interviews with MSU quality control coaches. Table 3 demonstrates a sample progression that a student-athlete must move through mentally between plays; Table 3 also highlights the cognitive loads and processes that are incurred during a game scenario. While benefiting from a repeating pattern instead of

Table 3
Mental Processing Map for student-athletes during a live football game event.

Cognitive Load	Question/Process
Observe	What is the down and distance?
Memory	What is the strategy for this situation?
Observe	What personnel do we have on the field?
Decision	Am I supposed to be on the field?
Memory	Is personnel correct for the situation?
Observe	Can a substitution be made?
Decision	If yes, should a substitution be made?
Observe	Receive signal.
Memory	Convert signal into coverage/blitz and action plan.
Observe	Do the other players understand the coverage and action plan?
Memory/ Observation	Experience informed actions based on offensive position/ formation and/or sideline check for important reminder.
Decision	Act based in memory/observation or hold to planned play?
Movement	Play the down.

switching between unknown cognitive tasks, the repetition alone can induce fatigue (Yan et al., 2018). Yan identifies out that this constant switching can lead to less than optimal decision making (Yan et al., 2018). This creates the potential to misread the play calls and cues between game play. While the number of times that a player must switch between tasks cannot be controlled, additional experience with this mental cycle and the previously mentioned mental breaks should decrease the impact of this component on student-athletes.

3.2.5. Environments

Work environment also has a significant impact on the cognitive fatigue of individuals. Stadiums, where players perform their work, are complex and highly challenging environments. The high levels of audible noise that student-athletes experience on defense, generally while at their home stadiums, creates a cognitively challenging environment. In contrast, when away from the home stadium, the volume is often not an issue for the defense. (Football crowds tend to keep sound volumes at low levels for the home team offense but may significantly increase volumes for the away team's offense in the hope of disrupting or distracting their play calling; thus volume for the home defense increases) This noisy environment for football defensive players can lead to high levels of fatigue, associated with having to block noise levels, and the potential for low contrast in visual signals from the sideline (Zeydabadi et al., 2019). These factors lead to failures in signal detection and, as such, a potential failure to stop an opposing offensive play. Training in similarly noisy environments will allow coaches to observe the individual differences of players, as well as address signal issues. The simulated environment also allows players to become accustomed to the distractions of both the visual noise (signal) and the sound noise (auditory) pollution.

3.2.6. Emotions

Emotions, while useful in some situations, can also play a part in cognitive fatigue. As an example, fear can be used as motivation or can become a limiter of potential achievement. Fatigue related to emotions comes in from large shifts in the emotional state of athletes (Stanger et al., 2017). While this is generally a low source of fatigue for the football student-athlete, developing emotional management techniques can benefit their ability to react on the field.

3.2.7. Other desires

Cognitive fatigue may also be experienced when student-athletes just want to do something different from what they are currently doing (Ackerman et al., 2010; Yan et al., 2018). This occurs when athletes lose interest in or lose the desire to finish the current activity. As a result, cognitive and physical performance is reduced. By creating cognitive rest breaks for student-athletes and allowing them to recharge mentally, the source of fatigue should be minimized.

3.2.8. Cognitive fatigue lessons learned

The impacts of these sources of fatigue largely come out of the student-athletes' subconscious conservation of energy; that is to say they pace themselves physically due to the cognitive fatigue that they experience (Smith et al., 2015; Thorndike, 1900). A student-athlete may also develop their own trade-off between speed of response and accuracy of the response when cognitively fatigued (Wylie et al., 2017). The result is a reduction in reaction time and decision-making ability which results in degraded on-field performance.

While each of the sources of fatigue identified also provide a specific example of how to mitigate the related cognitive fatigue, there are some general points to consider. Changing the reward for decision making performance is not going to change how a player can overcome fatigue, but a moment of effort may potentially be increased due to the student-athlete's competition reception to said award (Dodge, 1917; MacMahon et al., 2014; Wylie et al., 2017). This means that strategic plans need to be put into place to address fatigue. Development of inhibitory controls, or self-regulation of behavior, within each individual player's fatigue level will make them better players by returning performance gains in these cognitive fatigue areas. Athletes with better inhibitory control are better at differing between tasks and unrelated material in their minds and maintaining performance over longer periods of cognitive and physical tasks (Martin et al., 2016). Gaining understanding of each player's level of inhibitory control can be achieved through post activity surveys.

3.3. Age and experience

Throughout an individual's lifespan, there are notable changes in reaction time. These changes are both positive and negative and can be associated with age and experience. There is a significant amount of literature discrepancy regarding reaction times in youth and how it changes throughout puberty and beyond; however, there is a strong overlap of literature which states a significant decline in reaction time after the age of 55. As for experience regarding reaction time, there tends to be a positive correlation between the practice and the ability to respond faster to the stimulus. Effectively, time spent practicing can assist in reducing the reaction time to that stimulus, but great care must be taken to ensure over-training does not occur, resulting in a negative impact on any potential gain in speed. This section aims to review these concepts and provide further clarification as to how age and experience can positively or negatively impact reaction time.

3.3.1. Age

When studying youths under the age of 18, Brychta et al. determined reaction time was significantly faster, as compared to all other age categories, for children up to their fifteenth year. Around the time of the childrens' fifteenth birthday, a slow deterioration became apparent (Brychta et al., 2013). Obetko et al. continued a study of these findings and determined the reaction time to be much slower for youths between the age of 10 and 15 (Obetko et al., 2019). Another study by Atan et al. stated 15-year-old athletes had the worst reaction times among all older youths between the ages of 15 and 18 (Atan and Akyol, 2014). In these studies, there are similarities, but the overall findings with youth reaction times lacks continuity.

Beyond the youth age category, when reviewing literature regarding the younger through advanced adult age categories of 19 and above, reaction time calculations remain unclear, but there is more continuity in the overall beliefs. Coskun et al. reported reaction time is at the fastest rate in an individual's twenties, which means as athletes enter their thirties, their reaction time is degrading at an unknown rate of increase (COŞKUN, Kocak, & SARITAŞ, 2014). Jaworski et al. also found an undetermined gradual deterioration of reaction times as people age (Jaworski et al., 2011). More significantly, the literature reported a distinct and rapid deterioration around the age of 55 and beyond (Jaworski et al., 2011). When reviewing the variations and differences among all age range findings, there was one commonality shared among all ages; males continually outscored females, resulting in males being labeled as faster than females with regard to reaction times (Atan and Akyol, 2014; COŞKUN et al., 2014; Jaworski et al., 2011; Voss et al., 2010).

For purposes of this review, the focus is on collegiate aged males. An inclusive range would start at age 17 and continue as high as age 23—the common ages for male student-athletes found on National Collegiate Athletic Association (NCAA) Division 1 football teams. With those parameters in place and in accordance with the literature findings previously stated, the assumption can be inferred that these student-athletes should be performing at their peak level of response for reaction times.

3.3.2. Experience

When thinking of how to improve a student-athlete's performance, the immediate response is to have them practice harder and longer and this will automatically improve their ability. In reality, if the athlete is overtraining or improperly training, there is very little improvement and possibly even a reversal in their reaction time. Rabbitt and Banerji found that overly prolonged training reduced an athlete's ability to improve their reaction time, due to the amount of errors that occur (Rabbitt and Banerji, 1989). The errors are significant to the reaction time because improper decision making outweighs the potentially improved reaction time.

For this response time characteristic, the key to success is in finding the proper level of practice that allows the student-athlete to gain the experience of the situation. According to Voss et al., this can be accomplished effectively through fitness and cognitive skill training in realistic scenarios (Voss et al., 2010). Presenting athletes with a range of potential outcomes, through a combination of reviewing the opponent's strategies and implementing the potential outcomes to memory from which the student-athletes can draw reference, better prepares them to have faster and more accurate decision making when placed in the live, competitive environment (Voss et al., 2010).

3.3.3. Age and experience lessons learned

By focusing on the proper amount of training necessary to maintain or even slightly improve the student-athlete's reaction time and acknowledging that these NCAA Division 1 football players are in a peak age range, coaches could take full advantage of what each athlete offers. Once the appropriate training level is determined, preferably in the off-season, coaches need only to update the defensive players' knowledge for the upcoming opponent.

3.4. Uncertainty and expectancy

Athletes have proven to have significantly lower reaction times to stimuli than their non-athlete counterpart (Ghuntla et al., 2012). In football specifically, it has been shown that skilled positions on defense (secondary), show a significantly faster visual reaction time than their non-skilled (linemen and linebackers) (Kalberer et al., 2017). This reaction time component during decision making is an important aspect to the success of the defense in stopping the offense from scoring, as a quicker and correct reaction to the offensive play leads to a defensive stop. When looking at reaction time, it is important to analyze the impacts of the uncertainty and expectancy, as well as, the effects this could have on the athlete's reaction time.

3.4.1. Uncertainty

In a sporting event, athletes make preparatory movements and decisions with the main goal of decreasing the uncertainty of the upcoming action (Gutiérrez-Dávila et al., 2013). Preparatory movements—that help to decrease the uncertainty of the opponent's movements—allow for faster reaction times in response to the movement (Gutiérrez-Dávila et al., 2013). When looking at the defense for a football team, the preparatory movements can be seen before every play with the defense lining up in a formation that they believe will be the most successful against the impending offensive play. The defensive play call allows the defense to understand the most likely play call that the offense will make due to defensive scheming. This scheme helps the defense reduce the uncertainty of the offensive movements and allows the defense to respond quicker to the stimuli that they receive after the ball is snapped. When preparatory movements are not made, the uncertainty of an event increases. An increase in uncertainty has been proven to be a significant influence to higher reaction times (Gutiérrez-Dávila et al., 2014). This increase in reaction time could be the difference between success for the defense or success for the offense.

When looking to decrease the reaction time for a defensive athlete on the field it is important to give them the most information needed to respond to the offensive stimuli. When conveying the plays to the defense, it may be better to use movement calls or pictures instead of wording on a big board (Obrenović et al., 1996). The work of Obrenovic et al. demonstrated that reaction time has been shown to be shorter when displaying drawings in place of printed words (Obrenović et al., 1996). Proper relaying of the play information is an important factor as it allows the defense to understand the most likely play call that the offense will make. In most situations, the defensive players understand that there are only a certain number of play combinations that the offense can run out of a certain alignment in regard to their position or responsibilities on the field. Decreasing the number of plays that the offense is likely to run will help to decrease the uncertainty of the event for the defense. A decrease in the number of possible outcomes to an event leads to a decrease in the reaction time (Proctor and Schneider, 2018). An increase in the uncertainty of an event leads to a significantly higher reaction time to the stimulus (Bonnet et al., 2008). Uncertainty within the context of an event occurring can be further broken down into temporal and spatial uncertainty. When playing football, the offense can snap the ball on a silent count, a random color call, a clap, a high step, or any given number of possible ways. The numerous possibilities for this to occur introduces a large amount of temporal uncertainty into the defensive strategy. When an event has a large amount of temporal uncertainty the reaction time of the response can increase (Hackley et al., 2009). An increase in the amount of spatial uncertainty of an event taking place has also been shown to increase reaction time (Jarbo et al., 2018). A key to decreasing the reaction time of defensive athletes is to decrease the amount of uncertainty that the athlete experiences.

3.4.2. Expectancy

Expectancy of an event has been shown to be a significant factor impacting the reaction time of a response to a stimulus. The more that an athlete expects an event to occur, the faster that athlete will be able to react to the event that actually occurs (Perruchet et al., 2006). Over the course of a game, a defensive athlete can learn to "read" or understand the offense better and this could lead to a decrease in the reaction time to a specific play, snap of the ball, or ball movement. In opposition, the offense's goal is to trick the defense into responding to a play that is not actually being run (i.e. redirection, misdirection). Reaction time has been shown to decrease as the stimulus is learned (Barrett and Livesey, 2010) and as an audible stimulus is constantly followed by a visual stimulus (Destrebecqz et al., 2010). These two findings could be the key to why defenses are caught off-guard by changing the cadence on offense. As the game continues, the defense will learn the offense snap count and the reaction time to the stimulus will continually decrease. This decrease in reaction time is due to the expectancy of the ball being snapped. When that event is discontinued, reaction time increases (Sommer et al., 1990), thus giving the offense more time to complete their goal of moving the ball down the field. While learning the normal pattern of a stimulus will help to decrease the reaction time, it is important for the defense to remain ready for the pattern to be broken because it will cause an increase in their reaction time.

3.4.3. Uncertainty and expectancy lessons learned

Reaction time has been shown to decrease when attending focus to the area that needs response in comparison to unattended areas (Handy et al., 2001). Having the defensive player focus on their assignment for a specific play could be vital in the ability of that athlete to react to the stimulus. Thus, when a defensive-back is responsible for covering a wide receiver in man-to-man coverage, it may be beneficial for the defensive-back to focus on the wide receiver and not the ball being snapped. When looking at expectancy and how it impacts reaction time, it can easily be seen how reaction time decreases when expectancy increases and is correct. There are instances where the expectancy that impacts reaction time can be controlled voluntarily (Matt et al., 1992). This could prove important to not letting the offense catch the defense off-guard with a play call that is not expected.

3.5. Visual ability

Visual ability is another critical factor influencing player reaction time. This factor receives significant focus as NCAA Division 1 football student-athletes typically have their vision (e.g. near- and far-sightedness, astigmatism, etc.) and vision characteristics (e.g. color blindness, peripheral view, etc.) tested during preliminary physicals and screenings prior to any practice scenarios. After all, "a well-developed visual system is integral to the dynamic nature of sport performance among collegiate athletes" (Feldhacker et al., 2019). Not to oversimplify the quality of safety awareness that goes into player visual protection, but just as football student-athletes' heads get fitted for the best helmet, so too do their eyes for the best visual-based correction intervention (should it be needed). "The visual system is the most complex sensory system which is engaged in creating feedback and dominates the other sensory systems" (Mańkowska et al., 2015). Further, many high-level and elite football players have high visual ability as this it what enhances their reaction times which aided their capacity to become elite in the first place. Still, there are components of visual ability or visual ability training that have relevance in this reaction time-based literature review as more than 80% of stimulus input during sport competition is visual based (Feldhacker et al., 2019).

3.5.1. Visual acuity & anticipation ability

Visual acuity (or clarity) refers to the sharpness of one's vision regarding the ability to discern stimulus at a given distance (Poltavski and Biberdorf, 2015) and plays an important role in showing the highest possible level of stimulus reaction in both central and peripheral fields of vision as is required of athletes in elite sports (Mańkowska et al., 2015). Visual acuity is also an important element of an athlete's anticipation ability and elite athletes have been proven to perform better in movement anticipation tests (Tanaka et al., 2011) as they can predict the decision of their opponents (Mańkowska et al., 2015). Recent studies have shown that defensive players (regardless of sport) who simultaneously keep the opponent's trunk within their central vision and the opponent's feet within their peripheral view will be more likely to predict final direction of the opponent's movements (Fujii et al., 2014). Similarly, Mańkowska, et al. found that an athlete's ability to quickly assess the position and direction of an opponent significantly correlated with their reaction times.

3.5.2. Visuomotor Choice Reaction Time & visual training

Recent studies with NCAA Division 2 football players demonstrate that student-athletes with slow Visuomotor Choice Reaction Time VCRT are at increased risk of musculoskeletal sprains and strains (Wilkerson et al., 2017). Visual training is one mechanism to improve VCRT and mitigate those soft tissue injury risks. While elite football athlete may already possess higher-than-average visual abilities, traits and characteristics can always be improved upon. An increasingly popular method within more elite-level football and basketball sports programs for both analyzing and training reaction times are VCRT paradigms (Engeroff et al., 2019). Similar in concept to the study performed by Shelly et al. (2019), football players react to a visual stimulus (such as LED lights positioned about the student-athlete) by attempting to interact with the light stimulus as quickly as possible. For a response time test (where reaction time was assessed using AMTI force plates), a FITLIGHT ™ Trainer device was used for upper body extremity interaction (Shelly et al., 2019) and for a reaction time-based training test, The Quick Board ™ device was used for both upper and lower body extremity training and assessment (Engeroff et al., 2019). Both tools are viewed as training equipment standards within the higher levels of collegiate and professional training. In the case of the Shelly et al. study, response time (a byproduct from reaction time) was reduced based on helmet (shell and facemask) blockage of peripheral view. In this case, the student-athlete was trained to have an increased response time but the effect of certain equipment types on how quickly an athlete responds was quantified thereby showing the importance of external equipment on overall reaction time (Shelly et al., 2019). For the Engeroff et al. study, VCRT training was shown to have positive effects in upper body extremity reaction time. Another device used for general visual training and reaction time testing within softball and other athletes at the collegiate level is the Dynavision ™ D2 (Feldhacker et al., 2019). During a multi-week training study using the Dynavision ™ D2, a significant decrease in reaction time was seen when student-athletes trained in both proactive and reactive training modes.

3.5.3. Visual ability lessons learned

The visual ability for defensive football players is critical given that 80% of all sports-related stimulus is visual-based (Feldhacker et al., 2019) and so assessment of their visual traits and characteristics should be performed regularly. The visual acuity or clarity characteristic is especially critical as it impacts the defensive player's anticipation ability regarding the movement and direction of the offensive player. Defensive players who are better at predicting the position of an offensive player will react faster to their movement (Mańkowska et al., 2015). A lot of emphasis is placed on defensive training such that the football player should remain focused on and aware of the offensive player's trunk. Research shows, however, that the awareness of the opponent's trunk isn't enough as the feet of the opponent must remain in the defensive player's peripheral view while the trunk simultaneously remains in the players central view in order to have significant improvements in reaction time (Fujii et al., 2014). Also, given that average reaction time for most athletes is quantifiable at 250 ms or lower (Mańkowska et al., 2015), visual training with VCRT paradigms are critical for reducing defensive player's reaction times along with their potential risk of sprains and strains (Wilkerson et al., 2017). VCRT training and assessment tools such as a FITLIGHT ™ Trainer device, The Quick Board ™ device, the Dynavision ™ D2, among others have demonstrated the ability to reduce reaction time.

4. Discussion and conclusions

The scope of this research was to determine how a defensive football player's reaction time to the physical movement of offensive players changes based on how much information was presented to them prior to the movement or athletic play; and how factors such as cognitive fatigue, age, experience, player position, information received, information presentation, expectancy, and uncertainty can impact player decision making reaction time along with possible solutions for improvement. Based on a thorough literature search, the authors have determined this is the first review on this topic.

First, the defensive football player position on the field can be divided into three positions, the defensive linemen, the linebackers, and the defensive backs. Improvement strategies for the lineman include frequent rotation from the field (Gierczuk et al., 2017), practicing by learning from videos (Christina et al., 2016), and the awareness that reaction time is quicker for known outcomes, and worsens if the reaction to movement must be adjusted prior to any action (Larish and Frekany, 1985). Linebacker and defensive back improvements can be realized by learning the cues of the quarterback while throwing (Kenward and Nilsson, 2011) and exercising in other sports besides just football (Salonikidis and Zafeiridis, 2008). Improvements that impact the defensive groups include: utilizing psychologically "close" images in picture boards, utilizing dual coding (i.e. putting words with pictures) to transfer information (Amit et al., 2009), exercise (Jain et al., 2015), sleep habits (Smith-Coggins et al., 1997), and the knowledge that reaction time is quicker during exhaling versus inhaling (Buchsbaum and Callaway, 1965).

Second, cognitive fatigue is simply defined as mental tiredness or fogginess. Several factors of cognitive fatigue for humans include: cognitive tasks, physical fatigue, task switching, work environment, sleepiness, emotions, and desire to do other things. Specifically for football players, cognitive fatigue leads to slower decision-based reaction time or the inability to recall the current play and further drives a lack of effort when performing a task. Smith et al. also suggest that when players are mentally fatigued, they start to pace their low intensity functions, saving energy for the high-intensity efforts (Smith et al., 2015). Counteractions to these fatigue sources include: sleep routines standardization, emotional stability, additional practice with signals and reactions, simulated field environment, developed cognitive rests between active periods, and exercise. The timing and variance of when exercise consistently occurs does not appear to impact performance (Vitale et al., 2018). Likewise, while a lack of sleep has shown to induce significantly lower reaction times (Taheri and Arabameri, 2012), variation in sleep over multiple days was shown to have no effect on reaction time in student-athletes (Knufinke et al., 2018). Lastly for this reaction time factor, a mental processing map for football players was used to demonstrate task switching before the snap or execution of an offensive play (Table 3).

Third, data from age and experience shows that reaction time deteriorates as people age. Rabbitt and Banerji show that overtraining can cause a negative effect due to errors, which ultimately negates any improvement in the reaction time (Rabbitt and Banerji, 1989). Additional proven success strategies include fitness and cognitive skill training through a range of potential plays and outcomes specific to the opponent. Also, the quality control coaches interviewed as part of this review recognize that, for the football teams upcoming fall training camp, they must find the appropriate level of training for each of their defensive groups and student-athletes.

Fourth, uncertainty and expectancy research showed many findings for and applications in football. Uncertainty findings include that athletes make preparatory movements and decisions with the main goal of decreasing the uncertainty of the upcoming action (Gutiérrez-Dávila et al., 2013) and that a decrease in the number of possible outcomes to a decision making event leads to a decrease in the reaction time (Proctor and Schneider, 2018). Practical applications to improve uncertainty include solid defensive play calling to the players on the field. Expectancy research findings include that the more that an athlete expects an event to occur, the faster the athlete will be able to react to the event actually occurring (Perruchet et al., 2006) and that reaction time has been shown to decrease when attending focus to the area that needs response in comparison to unattended areas (Handy et al., 2001). Expectancy reaction time improvements include having the defensive player focus on their assignment for a specific play and learning the normal pattern of a stimulus over a course of the game.

Lastly, the visual ability for all athletes plays a critical role in most of the stimulus used to make decisions and react (Feldhacker et al., 2019) while visual acuity has a significant impact on the athletes ability to predict movements of the opponent (Mańkowska et al., 2015). For a better reaction time, research has demonstrated that central focus must be placed on the opponent's trunk with peripheral attention simultaneously given to the opponent's feet (Fujii et al., 2014). Visual training with VCRT paradigms is critical for reducing athlete reaction time and their potential risk of musculoskeletal injuries (Wilkerson et al., 2017). VCRT training and assessment tools such as a FITLIGHT ™ Trainer device, The Quick Board ™ device, and the Dynavision ™ D2 appear in several studies across multiple sports and demonstrate the ability to reduce reaction time in elite athletes.

Overall, the research does support the theory that a football player's reaction time is impacted by multiple factors both on and off the field (summaries presented in Table 4). Some of these factors are inherent to human nature, while others can be modified through selective training and customized workout regimens. While the MSU quality control coaches suspected some of these concepts, having specific guidelines for improvements in decision making training for improved reaction times allows them to focus on subtle changes that can be made during training camp and throughout the upcoming NCAA Division 1 football season. Perhaps the biggest takeaway for the defensive coaching staff was the penalty in student-athlete reaction time for calling the wrong play versus the benefit gain of correctly calling a play that properly defends the offense's formation. Successful defensive coordinators in NCAA Division 1 may often predict the offense's strategy and the decrease in reaction time is an excellent way to quantify how they are successful.

4.1. Future directions and limitations

Throughout the analysis, the authors have identified recommendations for future research from the findings of the overall literature reviewed. First, future research into different, but similar, sports and how the reaction time can be modified for individual athletes based on similar activities can have a synergy for reaction time improvements.

Table 4
Summary of results.

Reaction Time Factor	Application to Defensive Football Players
Defensive Player Positioning	• Positioning the defensive players into a "ready for anything" defensive scheme is an optimal solution when faced with significant offensive play calling uncertainty. • Allowing talented football players to utilize their natural skillset is better than improperly positioning them.
Cognitive Fatigue	• Players subconsciously conserve energy when fatigued and may develop their own tradeoff between reduced reaction time and reduced on-field performance. • Increasing rewards-based output for improved decision making will not change how players overcome fatigue but their competitive nature may increase moments of effort in response to an award. • Post activity surveys or discussions can be used to gain an understanding of each player's level of inhibitory control; improvement in self-regulation of behavior will return performance gains.
Age and Experience	• NCAA Division 1 football players are in a peak performance age range, therefore, determining appropriate training level is critical for making reaction time improvement gains.
Uncertainty and Expectancy	• Reaction time decreases for players trained to focus on their assignment (the offensive player) versus the snap of the ball or other areas of on-field stimulus cues in which the player won't be directly engaging. • Expectancy improves reaction time over the course of a game as the defensive players learn to understand and expect certain stimulus and responses from the offense. • This same expectancy rule also leads to poorer defensive reaction time when the offense recognizes that the defense expects one outcome and they change expectancy by modifying snap count or other stimulus cues.
Visual Ability	• Eighty percent of all sports are visual stimulus driven; therefore, visual ability and clarity should be assessed on a regular basis. • Defensive players should be trained to simultaneously keep the offensive players trunk in their central view and the offensive players feet in their peripheral view. • Reaction time can be decreased through the training and assessment on VCRT tools such as: FITLIGHT TM Trainer, The Quick Board TM, and Dynavision TM D2.

This can be seen in the presented relationship between a wrestler and a lineman and how they shared techniques to achieve success. Second, future investigations into which combinations of exercising would result in improved response time. Research has shown that additional exercising outside of merely just football can be beneficial. Third, methods of how expectancy can be accelerated during a game to improve response time could be studied to improve reaction time. Finally, studying strategies to reduce cognitive fatigue may yield advances to reducing reaction time based on decision making in football.

There are two specific limitations of concern for the authors regarding this review. First, there is a limited knowledge base around football literature in general, and specifically studies which include football and reaction time. Second is the heterogeneity of the review. Higgins stated that “heterogeneity is to be expected in a meta-analysis: it would be surprising if multiple studies, performed by different teams in different places with different methods, all ended up estimating the same underlying parameter” (Higgins, 2008).

Author acknowledgement

Review and Editing, Alex Calhoun.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ergon.2020.102942.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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