The relationship between nutrition knowledge and performance measures in British collegiate American football athletes.

By

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Table of Contents

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Abstract

The purpose of this thesis was to ascertain whether or not a significant relationship exists between nutrition knowledge and athletic performance among British collegiate American football athletes. In order to quantify an athlete's nutrition knowledge and overall performance ability, a nutrition knowledge questionnaire was developed and a new performance assessment tool (Euclid) was evaluated. The nutrition knowledge questionnaire was developed using validation and reliability procedures. From the initial thirty-four questions, nine were removed due to a lack of significance shown when testing for construct validity, and a further two were also removed following the results of tests for internal consistency. The remaining twenty-three questions formed the valid and reliable questionnaire that was utilised to quantify an athlete's nutrition knowledge. Next, the Euclid model was evaluated as a way of quantifying overall athletic performance in American football in comparison with previously used methods in this area of research. The greatest support for the model's applicability came from the observed significant relationships between Euclid scores and competitive experience among offensive and defensive starters (n = 6, r = 0.922, p = 0.026; n = 4, r = 0.999, p = 0.022). While significance was not consistently observed between the Euclid performance scores and other control methods, the results warranted further examination of the model. When the nutrition knowledge questionnaire and the Euclid model were used with a British collegiate American football population, results were found to suggest the existence of a relationship between some of the variables. The offensive athletes demonstrated a significant relationship between nutrition knowledge and performance scores (n = 16; r = -0.610, p = 0.012). However, as significance was not observed for the whole group, or for the defensive athletes, further research will be required to discover the true impact of nutrition knowledge on athletic performance in American football.

Chapter 1 – Literature Review

1. Introduction

The perception that nutrition could influence athletic performance was first established during the era of the ancient Olympic games (Simopoulos, 1989). However, scientific research in the area has only emerged within the last few decades (Grandjean, 1997). In 1991, the Medical Commission of the International Olympic Committee (IOC) sponsored a meeting to develop a consensus statement summarising the research to date, relating to nutrition and its impact on athletic performance (Burke, 2003). Then, in 2003, the Medical Commission of the IOC formed a Nutrition Working Group of leading nutrition experts, who have met on two further occasions, to monitor the advancement of knowledge and consequently update their consensus statements (Maughan & Shirreffs, 2011). Furthermore, after the meetings in 2003 and 2010, the Nutrition Working Group developed a booklet entitled "Nutrition for Athletes", which has been circulated to athletes competing in Olympic, Paralympic, and Commonwealth games (Maughan & Shirreffs, 2011). With these resources available to download from the internet, the accessibility of nutrition information has never been greater. Despite this, numerous research studies have continued to find nutrition misconceptions to be common amongst collegiate athlete populations (Dunn, Turner & Denny, 2007; Jacobson, Sobonya & Ransone, 2001; Jacobson & Aldana, 1992; Rosenbloom, Jonnalagadda & Skinner, 2002).

Wardle, Parmenter and Waller (2000) stated that nutrition knowledge had a significant association with healthy eating and they found that nutritionally knowledgeable individuals were up to 25 times more likely to meet fruit, vegetable and fat intake recommendations, compared to unknowledgeable individuals. Therefore, poor nutrition knowledge has the potential to impact an athlete's dietary habits, and perhaps overall performance. In the sport of American football, the British Universities American Football League (BUAFL) and the National Collegiate Athletic Association's (NCAA) Division I, currently represent the highest level of collegiate competition in Great Britain and the United States of America, respectively. Previous research has scrutinised the issues surrounding the considerable body mass of NCAA football athletes, with the desirable body mass varying considerably by position (Jonnalagadda, Rosenbloom & Skinner, 2001). Whilst a higher body mass may be required for better performances in certain positions, it may not be conducive to the athlete's overall health, as commonly observed BMI's of over 25 kg/m^2 (Matthews & Wagner, 2008) classify individually as being clinically obese (Expert Panel on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults, 1998) and are considered unhealthy for the non-athlete.

To date, research has failed to study the direct relationship between nutrition knowledge and performance, in any sport, let alone in a collegiate American football setting. Teams are always looking for new ways to gain a competitive edge over their opponents, especially because the American Dietetic Association, the Dieticians of Canada and the American College of Sports Medicine (2009) state that optimal nutrition can lead to improved physical activity, athletic performance and recovery from exercise. However, it has been frequently reported that athletes have poor nutrition knowledge (Heaney, O'Connor, Michael, Gifford & Naughton, 2011). If a relationship is proven to exist between nutrition knowledge and performance, nutritional education interventions could consequently be designed to further facilitate higher performance in athletes.

The following literature review explores the theory behind the relationship between nutrition knowledge and performance measures among collegiate American football athletes. It will outline the multiple healthy eating barriers that student athletes are likely to face, as well as the challenges that face researchers and sport nutritionists when it comes to quantifying nutrition knowledge. It will also provide an overview for the sport of American football, factors that could affect performance, and an in-depth look at performance analysis tools: how performance is currently assessed as well as a proposition for a new assessment metric. Finally the review will summarise how nutrition is stated to influence performance.

1.2. Nutrition and life changes

Individuals that participate in American football at the collegiate level are often required to contend with the demands of being a self-sufficient student away from home for the first time, as well as the associated demands of being an athlete. In the NCAA, if the student-athletes fail to meet certain academic standards, they forfeit their eligibility to participate in intercollegiate athletics (NCAA, 2011). The transition away from home to university has been known to be an exceptionally stressful time for new college students, where they have to contend with adaptations to the new surroundings, expectations that others may have of them, and their own personal experience of starting a transition into adulthood (Dyson & Renk, 2006). Such immediate responsibility and pressure can be overwhelming for some individuals, which may result in them overlooking other aspects of their life, such as proper nutrition (Papadaki, Hondros, Scott & Kapsokefalou, 2007).

1.2.1. Nutrition and the student athlete

The environmental transition that occurs when leaving home to attend university can often lead to changes in both dietary patterns and physical activity levels of individuals (Butler, Black, Blue & Gretebeck, 2004). Consequently, a weight gain phenomenon, known as the "freshman 15", was notarised and made popular by the media as early as 1989 (Brown, 2008); whereby body mass is said to increase by 15 lbs in a student's first year at university. Research has failed to corroborate the notion of a 15 lb (6.8 kg) average increase; however, a review study into the trend observed more realistic increases to be around 6.5lbs (3kg) (Crombie, Ilich, Dutton, Panton & Abood, 2009). In the review study, Crombie et al. (2009) focused on the findings of 17 previous articles examining the weight changes of college freshmen. However, flaws of the review included the fact that four of the studies only observed weight changes during the first semester, as opposed to the entire freshman year. Another flaw of the review study was that 8 of the 17 papers only examined female freshmen. However, overall it is agreed that, male collegiate freshmen are prone to weight gains.

One of the fundamental theories suggested to explain freshman weight gains was the period of adaptation students undergo when transitioning from living at home with their parents to living at university. Papadaki et al. (2007) found that, compared to freshmen that lived at home, freshmen living in university residence developed numerous undesirable dietary habits, such as the decreased fruit, vegetable, legume and fish intakes. As students still living with their family did not exhibit any major dietary changes, it was theorised that differences were as a result of the newly independent students having to assume responsibility for food shopping and food preparation. Encompassed within these newfound responsibilities, Yeh et al. (2010) identified ‘competitive food’ and ‘time’ constructs that had significant inverse correlations with fruit and vegetable consumption among college freshmen. It was observed that craving snack foods and fast foods was the biggest obstacle to fruit and vegetable consumption, followed by the convenience of purchasing premade fast food. The findings of Yeh et al. (2010) confirmed the earlier findings of Silliman, Rodas-Fortier and Neyman (2004); whereby, the perceived barriers to following healthy lifestyles were examined among 471 collegiate students. Silliman et al. (2004) reported that 40% of collegiate students claimed ‘a lack of time’ was the reason for them not maintaining a healthy diet, whilst 22% blamed ‘a lack of money’. The same study also affirmed how significantly ($p < 0.05$) more male students simply “don’t care” about the healthiness of their diet. Notably, students must contend with a multitude of barriers in order to establish and maintain a healthy diet. Students that choose to become collegiate athletes not only have to confront barriers associated with transitioning away from home, but also those that accompany an athletic lifestyle such as their demanding training schedules and increased caloric demands.

Over the past 30 years, a trend has seen body mass and body fat percentages of collegiate football athletes increase (Matthews & Wagner, 2008), under the notion that bigger is better. Matthews and Wagner (2008) reported that 81% of a college football population was classified as overweight, with 35% of those being obese. Clear position stratification was observed, with offensive linemen reportedly having had an average body fat percentage of 27.6 ± 1.3, compared to wide receivers and defensive backs that showed averages of 15.0 ± 1.6 and 13.2 ± 1.5, respectively. The only previous study to have observed BUAFL athletes, found a similar trend, but to a much lesser extent, with average body mass being significantly ($p<0.001$) lower by 19.2 kg (18%) compared to NCAA division I football athletes (Clemo, Kass & Jacobson, 2012). Although increased size may be advantageous for certain American football positions, increased BMI values have been strongly associated with increased cardiovascular disease (CVD) risk factors (Tucker et al., 2009). Numerous techniques exist to determine the nutritional status of athletes. As a result, interventions aimed at improving dietary habits and healthy living, could be developed. One technique that has frequently been used amongst populations of collegiate athletes is nutrition knowledge questionnaires (Heaney et al., 2011).

1.2.2. Nutrition knowledge evaluation

Four main studies have investigated the nutrition knowledge of collegiate athletes. Clemo et al. (2012) and Jonnalagadda et al. (2001) exclusively observed American football athletes, whereas Jacobson and Aldana (1992) and Rosenbloom et al. (2002) both used larger and more diverse sample populations. The nutrition knowledge questionnaire of each study required athletes to agree or disagree with various statements. Clemo et al. (2012), Jonnalagadda et al. (2001) and Rosenbloom et al. (2002) each allowed a third possible response of "don't know" in case the athlete was unsure, whereas Jacobson and Aldana (1992) did not. Similar results from each study (Table 1.1) raised concerns about what athletes knew regarding; protein as an energy source, the necessity of protein supplements, and whether vitamins or minerals were a source of energy.

Table 1.1. Study comparisons for NCAA athlete nutrition knowledge

	Jacobson & Aldana (1992)	Jonnalagadda et al. (2001)	Rosenbloom et al. (2002)	Clemo et al. (2012)
Statement	Percentage of athletes who agreed			
Protein is the main energy source	N/A	61%	47%	72%
Protein supplements are necessary	82%	52%	35%	77%
Vitamins and minerals are a source of energy	83%	65%	67%	80%, 51%*

* = two separate scores for vitamins and minerals respectively

The correct response to each statement of table 1.1 was to disagree, however, with the exception of only one; all percentages shown indicated the majority of NCAA athletes responded incorrectly. Conversely, Clemo et al. (2012) observed significantly ($p < 0.001$) different scores amongst BUAFL athletes regarding the same questions. The percentage of BUAFL athletes who agreed to the first two questions were 26% and 52% respectively. When asked about vitamins and minerals as an energy source, in separate questions, agreement rates of BUAFL athletes were reported as 4% and 13% respectively. All four studies independently discovered the prevalence of nutritional misconceptions amongst collegiate athletes. In a comprehensive study to evaluate the level of nutrition knowledge among athletes, Heaney et al. (2011) systematically reviewed 29 studies. Each study was peer-reviewed, implemented on athletes, and used standardised instruments to assess overall sport nutrition knowledge. However, Heaney et al. (2011) reported that not all of the 29 studies utilised valid and/or reliable questionnaires. Kline (1993) outlined four psychometric measures that, if adhered to, would constitute a questionnaire as being valid and reliable (Table 1.2).

Table 1.2. Definitions of psychometric measures for validity and reliability

Psychometric Measure		Definition
Validity		
	Content	Questionnaire developed with expert opinion.
	Construct	Questionnaire administered to two or more groups with different training, significantly different scores obtained.
Reliability		
	Test-retest	Correlation of scores from a group who are administered the same test twice (stability of test over time).
	Internal consistency	Measures the extent to which scale items are highly inter-correlated.

(Kline, 1993)

Despite the lack of validity and reliability among the questionnaires, Heaney et al. (2011) concluded that athletes' knowledge was equal to or better than non-athletes. Although previous studies have claimed that nutrition knowledge could be pivotal in altering food behaviours (Wardle, Parmenter & Waller, 2000; Worsley, 2002), the broad review by Heaney et al. (2011) concluded that the influence nutrition knowledge had on an athlete's diet was equivocal. The disconcerting level of nutrition knowledge, exhibited by collegiate American football athletes, was backed up by research into the source of nutrition information. The first study to document the nutritional sources of information of athletes' (*n*=430) concluded that magazines were the most popular choice, followed by athletic trainers (Jacobson & Gemmell, 1991). A decade later, Jacobson, Sobonya and Ransone (2001) reported strength and conditioning coaches had become the most common source of information for athletes (*n*=205), followed by athletic trainers. Conversely, the athletes (*n*=203) used by Froiland, Koszewski, Hingst and Kopecky (2004) reported family members and fellow athletes were the most popular sources of information, ahead of coaches. Finally, the most recent study by Clemo et al. (2012) concluded that whilst coaches were the most sought after source of nutritional information among NCAA Division I football athletes, BUAFL athletes most commonly sought information from the Internet and friends. Numerous sources of information were listed in each study; however, not once was a highly nutritionally educated source listed as the top source of information, suggesting that athletes may be receiving inaccurate nutritional information, consequently having a negative impact on their dietary habits.

1.3. Performance

Since the Ancient Olympic Games, combined athletic events were thought to be the ultimate measure of an athlete's versatility (Trkal, 2003). In the modern era, combinations of performance tests have frequently been used to assess the athletic capabilities of individuals in various sports. However, to date, no standardised method exists to quantify a measure of overall athleticism in American football. The following review summarises the previous literature in regards to performance analysis of American football athletes, and goes on to propose new methods to quantify an American football athlete's overall performance capabilities.

1.3.1. Physical demands of American football

Within the sport of American football, the physical characteristics of each position differ greatly, due to the unique position-specific requirements. For example, to be successful as a lineman, the individual is required to have a high inertia to help form a blockade against opposing players trying to get past them. On the other hand, to be a successful ball carrier the individual is required to be as agile as possible to avoid being tackled. Fifteen positions (excluding special teams) comprise a team's offensive and defensive line-ups. Figure 1.1 depicts a common offensive and defensive formation.

By analysing the position-specific responsibilities, as well as the physical attributes deemed important for each position, Robbins and Goodale (2012) clustered positions together that shared similarities, to form eight clear positions. Three of the positions are defensive, whereas the remaining ones are offensive. The first defensive position is the defensive backs (DB), which comprise the cornerbacks, free safety and strong safety. DBs are the last line of defence that provide coverage of the wide receivers (WR) and defend against running plays. The second defensive position is the defensive linemen (DL), which is comprised of defensive ends and defensive tackles. The responsibilities of the DL are to contain the ball carriers on running plays and to put pressure on the quarterback (QB) on passing plays. Finally, the linebackers (LB) are made up of the inside and outside linebackers. The role of the LBs are to assist in pass coverage, put pressure on the QB on passing plays, and to defend against running plays to the inside and the outside.

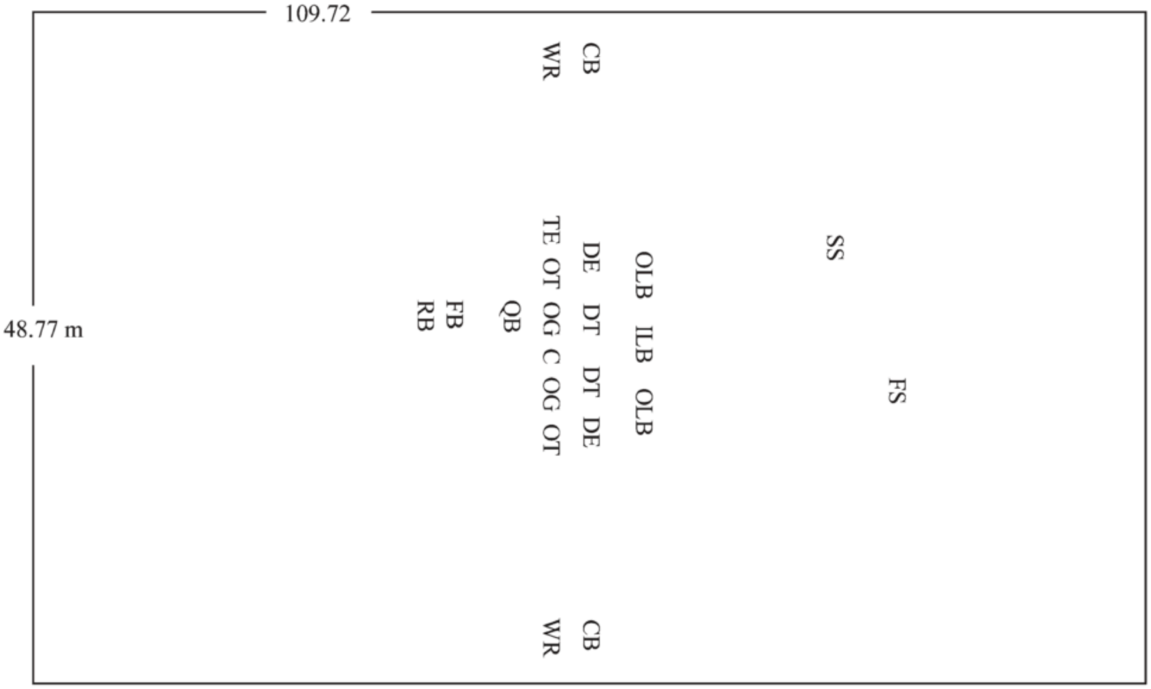

Figure 1.1. Common offensive and defensive formations in American football (figure is not to scale). C = centre; CB = cornerback; DE = defensive end; DT = defensive tackle; FS = free safety; FB = fullback; ILB = inside linebacker; OG = offensive guard; OT = offensive tackle; OLB = outside linebacker; QB = quarterback; RB = running back; SS = strong safety; TE = tight end; WR = wide receiver. (Robbins & Goodale, 2012)

The first position on a team's offense is the offensive linemen (OL). The OL contains the offensive guards, offensive tackles and the centre. The primary responsibility of the OL is to protect the QB on passing plays and to block for the ball carriers on running plays. The QB is the leader of the offense, in charge of calling which plays to run. The QB begins every play by receiving the ball from the centre and either passing the ball to a receiver in a passing play, or handing the ball to a ball carrier for a running play. The running back (RB) position is comprised of the primary RBs as well as the fullback. The main responsibility of RBs is to run with the ball as well as occasionally receiving passes and protecting the QB on passing plays. The tight end (TE) position is a hybrid position between the OL and WRs. Therefore, somewhat uniquely, TEs require the high inertia similar to the OL to protect the QB, but are also occasionally required to catch the ball on passing plays. Finally, the WR has the primary responsibility of catching passes from the QB on passing plays and intermittently blocking downfield for some running plays.

From the brief explanation of each position, it is apparent that certain positions involve fewer responsibilities than others. Kaiser et al. (2008) stated that offensive and defensive linemen were taller and heavier than other positions, due to their sole requirement to block and tackle. Conversely, the demands of DB's and LB's are more diverse, required to cover large areas of the playing field with their dynamic agility and high running speed. Due to such differences, large anthropometric diversity has been observed between positions, with body fat percentage (BF%) differing significantly between positions (Matthews & Wagner, 2008).

1.3.2. Body composition and performance

It has frequently been stated that in American football, a larger mass may be advantageous to certain positions (Matthews & Wagner, 2008), as it is more difficult to move an object of large mass compared to one with a smaller mass. Over the past 50 years, there has been a noticeable change in the anthropometric profile of American football athletes. It was found that from 1959 to 2011, the body weight of the collegiate level players had increased significantly ($P < 0.017$) over time, amongst all position groups analysed (Anzell, Potteiger, Kraemer & Otieno, 2013). Furthermore, Anzell et al. (2013) also reported that the category of mixed linemen (OL, DL, TE, LB) also showed significant increases in height and body fat percentage. Two studies have examined the efficacy of how body composition related to performance test outcomes (Miller, White, Kinley, Congleton & Clark, 2002; Stuempfle, Katch & Petrie, 2003).

In the first study, Miller et al. (2002) observed 216 NCAA Division I collegiate players, over a period of five years, to observe the relationship between body composition and performance test outcomes. Relationships were identified between two body composition measures (body weight and BF%) and six physical tests (power clean, bench press, squat, vertical jump, 36.6 m dash and the 18.3 m shuttle). Change in BF% was the only measure to show a negative impact on performance measures. Miller et al. (2002) reported that increases in BF% were negatively associated with the power clean and vertical jump measures across all position groups. Furthermore, the BF% increases of linemen were also negatively correlated with performance in the 36.6 m dash and the 18.3 m shuttle. However, body weight was seen to have a positive relationship across all position groups, in the weight lifted in the power clean and bench press. It was concluded that BF% changes were valid predictors of performance change, whereas body weight was not. A weakness of the study was the use of a skinfold assessment to determine BF%. It has previously been noted that skinfold assessments are highly prone to variance across those individuals performing the measurements (Vasudev et al., 2004). However, the use of gold standard methods, such as computed tomography (CT) scans (Ribiero-Filho et al., 2003) or Dual Energy X-ray Absorptiometry (DEXA) scans (Kirwan, 2008), have been known to be costly and time consuming.

In the second study, Stuempfle et al. (2003) contradicted Miller et al. (2002) by stating that neither body mass nor percent body fat could be used to predict performance with any degree of confidence. In comparison to the first study, Stuempfle et al. (2003) recruited athletes from the lower level NCAA Division III to participate in the study. Four of the tests conducted were the same as those used by Miller et al. (2002) (bench press, vertical jump, 36.6 m dash and the 18.3 m shuttle). Two additional tests were employed by Stuempfle et al. (2003); the 9.1 m dash and a sit and reach trial. The method of determining BF% was done through hydrodensitometry, a more reliable method of assessment compared to that of skinfold measurements (American Dietetic Association et al., 2009). Results revealed, the highest correlation was between BF% and performance in the 36.6 m dash (r = 0.70), which was only a moderately positive correlation. In conclusion, Stuempfle et al. (2003) stated that overall; BF% was not closely correlated to the results gained from the six tests. It remains difficult to establish the extent to which body composition affects performance, based on contradictory findings in the previously discussed studies. Two prominent factors need to be considered in more depth before a clear conclusion can be made on the topic: the standard of athlete being assessed, and the process by which American football performance is defined.

Due to incomparable levels of funding, Division III athletic departments are less able to competitively recruit the tallest and strongest athletes. During the 2010-2011 school year, the top-50 spending universities had an average athlete recruitment budget of over $1.2m, with the average recruitment budget of male athletes being over $865,000 (Jessop, 2012a). It was reported that the University of Tennessee, who had the highest total recruitment expenditure of all Division I universities (Jessop, 2012a) of close to $2.3m, spent an average recruitment expenditure of more than $7000 per male athlete (Jessop, 2012b). With such competitive recruitment at the top level, the use of smaller and lighter Division III athletes may be insufficient to determine the true impact of body composition on performance.

Finally, a definitive battery of tests has yet to be defined which would assess all of the fundamental requirements needed for success as an American football athlete. Defining such a battery is an essential prerequisite to developing a method able to quantify an athlete's overall football playing ability (FPA). Previous research, such as the aforementioned, have commonly derived testing batteries from the basic set used at the National Football League's (NFL) official annual scouting event; the NFL Scouting Combine. In order for future relationships to be determined between performance and external factors, a definitive testing protocol and method of analysis are required.

1.3.3. NFL Scouting Combine

Every year in the USA, the top collegiate American football athletes are invited to attend the NFL Scouting Combine. This acts as a platform on which the prospective players can demonstrate their athletic ability to scouts from each of the 32 NFL teams. Six measures form the basis of the performance test battery that each athlete undertakes (Table 1.3). Each test has been selected due to the sport-specific nature of how they relate to the requirements of the athletes when on the field. In addition, anthropometric measurements and position specific drills are also conducted. Workouts from the event are widely considered to be one of the main factors in determining whether a prospective player will be chosen to enter the professional league during the subsequent NFL Draft. Although the majority of prospects would have previously demonstrated their athletic ability during a collegiate career, the NFL Scouting Combine subjects each athlete to a set of standardised conditions, thus eliminating any bias that may have been gained from weak competitive schedules. Three key studies (McGee & Burkett, 2003; Robbins, 2010; Sierer, Battaglini, Mihalik, Shields & Tomasini, 2008) looked at the importance of the NFL Scouting Combine and the implications that successful performances may have for the athletes.

The different methodologies were critically evaluated in order to highlight strengths that may be applicable to future research.

Table 1.3. Basic performance test battery used in the NFL Scouting Combine (Robbins, 2011)

Name of test	Brief description	Measures
18.3 m shuttle	Sprint 4.6 m to the left, turn and run 9.1 m the opposite direction and finally turn again to sprint 4.6 m back to the start	Change-of-direction ability
36.6 m dash	Sprint as fast as possible in a straight line over 36.6 m	Acceleration and maximum speed
Vertical jump	Maximal vertical jump effort from a two-footed standing position with the use of countermovement allowed	Vertical jump ability
Broad jump	Maximal horizontal jump from a two-footed standing position with the use of countermovement allowed	Horizontal jump ability
Three-cone drill	Sprint as quickly as possible around three cones in the shape of an “L”, 4.6 m apart, in a predetermined route	Change-of-direction ability
102.1 kg bench press	Repeatedly bench-press 102.1 kg as many times as possible until exhaustion.	Upper body strength

Sierer et al. (2008) summarised the importance of successful performance in the NFL Scouting Combine by comparing the test results of subsequently drafted and undrafted athletes. It was determined that many significant differences existed between the two populations. Results from all six performance tests of the 2004 and 2005 Scouting Combines were used in the investigation. Positions were collated into three groups that shared similar requirements; skill players (WR, DB, RB), big skill players (LB, TE) and linemen (DL, OL). Half of all comparisons resulted in significant differences being reported in favour of the drafted athletes. Statistically significant differences in the 36.6 m dash and 3-cone drill were found in all three position groups. The drafted skill players outperformed the undrafted skill players significantly in the vertical jump and pro-agility assessments. The final significant difference was observed between the drafted and undrafted linemen during the 102.1 kg bench press performances. The difference found was expected, considering the varied fitness characteristics required by each of the position groups. For example, the drafted skill players displayed dominance in all the tests that required high speed and agility. On any given play, and at multiple times during a game, the skill positions may be required to run at an all-out pace. The results from the study indicated the validity of using the six basic combine tests to identify the top American collegiate football athletes.

The two main studies that looked to identify the relationship between the NFL Scouting Combine and the NFL Draft both utilised the 6 standard tests, as well as two additional measures. McGee and Burkett (2003) and Robbins (2010) both included time splits during the 36.6 m dash test, recorded at 9.1 m and 18.3 m because it has previously been noted that collegiate American football athletes reached maximum acceleration by 9.1 m, and that maximum velocity was achieved by 18.3m (Brechue, Mahew & Piper, 2010).

The first study to determine the relationship between combine performances and draft order used multiple linear regressions (McGee and Burkett, 2003). In this study, regression statistics were computed to determine which measurements were most closely related to the draft round for each position. From each position-specific regression equation, it was concluded that draft status could only accurately be predicted for the DB's, RB's and WR's (r^2 = 1.00), perhaps due to the fact that that they each rely on speed and agility assessments, which most of the tests measured. McGee and Burkett (2003) stated there were numerous essential traits that are problematic to measure, which would limit such predictive equations, based purely on physically measurable characteristics, such as determination, toughness or the athlete's ability to work as a part of a team. Even so, it was shown that certain performance measures were able to predict draft success to some degree. A second study by Robbins (2010), aimed to normalise performance results from the Scouting Combine in order to establish a better relationship with the draft order. The data was obtained from each NFL Scouting Combine between 2005 and 2009. The intention of normalising the performance results was to account for somatotype differences that occur between positions. Two types of normalisation were used: ratio scaling and allometric scaling. Ratio scaling is said to assume that a linear relationship exists between performance and body mass, thus the performance results were simply divided by body mass. Allometric scaling, on the other hand, assumes geometric similarity, whereby human bodies would all have the same shape and thus only differ in size (Jaric, Mirkov & Markovic, 2005). Using the method of allometric scaling, body mass is raised to a power known as the scaling exponent:

$$y = x^a$$

Body mass would be represented by: x, and a the scaling exponent. Robbins (2010) summarised that allometric power exponents had previously been derived and stated to be between 0.33 and 0.64. However, previous research had criticised the notion of geometric similarity, due to higher proportions of muscle mass being reported in athletic populations (0.44) than that predicted (0.38) (Nevill, Stewart, Olds & Holder, 2004). Nevertheless, Robbins (2010) decided upon an exponent of 0.50, in an attempt to adequately normalise performance, as exponents of 0.67 were stated to be too large. Results from each of the performance tests were subject to analysis in all three forms of normalisation (raw, ratio and allometric). By using Pearson's product moment correlation *r*, Robbins (2010) determined the correlations between the normalised results and the respective athlete's position-specific draft order. Out of the 360 correlations that were performed, only 78 were significant (raw = 29, ratio-scaled = 22, allometric scaled = 27). Therefore, the method of ratio-scaling performance results yielded no benefits, over that of the raw data, in terms of predicting draft order. Furthermore, the method of allometric scaling provided stronger correlations with draft order in the 3-cone test. However, a major limitation of the study, was the reduced accuracy observed by using a pre-determined suggested allometric exponent, instead of enduring the admittedly laborious task of determining the precise exponent required for such a population. Despite limitations, Robbins (2010) concluded that normalisation of performance data offered little advantage in terms of predicting draft order.

One issue in comparing these two studies lies in the different ways in which performance measures were examined against draft order. McGee & Burkett (2003) combined test results before correlation whereas Robbins (2010) correlated separate tests. The fact that the latter study found little significant correlation is no surprise, as players need a range of athletic abilities to succeed in American football. Determination of an appropriate means to bring together NFL Scouting Combine results might provide a useful measure of an athlete's overall performance capability. However, the scientific community still has to agree on a suitable form of such a metric.

1.3.4. Football playing ability

Several studies had previously attempted to determine measures of overall success among American football athletes (Black & Roundy, 1994; Sawyer, Ostarello, Suess & Dempsey, 2002; Schmidt, 1999). Sawyer et al. (2002) defined football playing ability (FPA) as a construct comprised of various unrelated cognitive competencies and motor skills that are not easily identified or quantitatively measured. With the ability to quantify FPA, researchers may be able to identify factors that could significantly impact on an athlete's overall performance. No study to date has yet put forward a definitive method for assessing FPA. However, two methods have previously been used in the literature.

The first method proposed was the use of playing status. Black and Roundy (1994) stratified NCAA Division I American football athletes into 16 different positions, as opposed to the more usual eight, and compared the starters (first team players for at least half of the games) of each position to the nonstarters. Comparisons were made for five measurements; body weight, maximum bench press, maximum squat, vertical jump, and the 36.6 m dash, thus providing a total of 80 statistical comparisons. Thirty-seven statistically significant differences were observed sporadically between the starters and nonstarters of each position. The only positions where starters were consistently significantly better were the starting outside LB and cornerback with significance in 4 out of the 5 measurements and the starting WR's and offensive guards, who were superior in 3 out of the five measurements. A limitation was that Black and Roundy (1994) greatly reduced the sample sizes by stratifying the positions. Had the study observed a more concise set of positions by collating similar positions together, more accurate comparisons could have been made. Schmidt (1999) on the other hand, failed to differentiate between different positions at all, and only assessed starters vs. nonstarters among nine factors. Starters were found to be higher on average across all factors, with only the seated medicine ball put, bench press and hip sled observed to be statistically significantly different ($p<0.05$). Only three out of the five factors used by Black and Roundy (1994) have been used in the NFL Scouting Combine, compared only one of the nine factors examined by Schmidt (1999). In general, the evidence was inconclusive regarding the combine tests' efficacy in indicating an athlete's overall success, but the positive trends suggest the use of starter vs. nonstarter may provide an indication of football playing ability.

The second method put forward to determine FPA was via coach rankings. Sawyer et al. (2002) used team coaches to rank the defensive players (n = 19) based on their personal opinion of each athletes' FPA. The highest rank was a value of one and the lowest had a rank of 19. Coaches then used the same protocol for the offensive players (n = 21). As there were multiple offensive and defensive coaches per team, the ranks from each coach were then averaged to gain an FPA score for each athlete. Seven performance measures were compared against the FPA rank, with only three being the same as tests used in the annual NFL Scouting Combine. Sawyer et al. (2002) concluded that 22% of all comparisons made were significantly related to FPA, whilst being significantly correlated with vertical jump in all groups. However, similarly to the limitations of Black and Roundy (1994) and Schmidt (1999), Sawyer et al. (2002) also used unconventional groups by categorising the offense together, defence together, linemen, receivers with defensive backs, and running backs with tight ends and linebackers. Conventionally, research has categorised players into the seven clear positions described above, based on the unique demands of each.

Despite the two aforementioned methods (playing status and coach rankings), a method has yet to be formulated which derives an FPA score from performance tests such as those used in the NFL Scouting Combine. Two methods, which are currently untested in an American football setting, have the potential to offer a new solution. The first process involves a scoring system, similar to that used by the International Amateur Athletic Federation (IAAF) in a decathlon setting. The second option would be by way of a performance ranking system.

1.3.4.1. Point scoring system

Sixteen years after the revival of the Olympic Games in 1896, combined events were reintroduced in the form of a decathlon at the 1912 Summer Olympics. According to Trkal (2003), before scoring tables were introduced, combined events were assessed on the athlete’s position in each of the events; the winner was declared the person with the lowest sum of positions. However, flaws were quickly detected, and as a consequence, the IAAF opted instead to derive scoring tables where performance results would receive a point score based on the difficulty of the achievement (Purdy, 1974). Reed (1971) remarked that the most gruelling human activity was not competing in the decathlon, but rather it was compiling the tables used for scoring it. The first documented scoring tables are said to have been prepared in 1884, based on a linear scale (Trkal, 2003). With a linear scoring method, points are awarded with an even distribution from the lowest score, right up to the peak (Figure 1.2). In 1912, the Olympic Games Organising Committee adopted a linear model whereby the previously established Olympic records were awarded 1000 points and lower performances would gain a score relative to the difference.

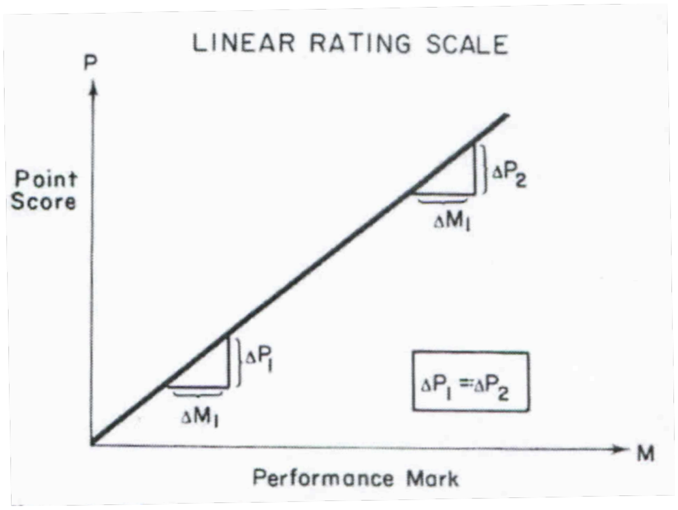

Figure 1.2. Linear rating scale for a scoring table (Purdy, 1974)

By 1934, the original scoring model was replaced by a progressive model (Figure 1.3). An aim of the progressive model was to account for the fact that performance improvements would become harder to achieve as the athlete comes closer to the upper limits of performance capabilities (Trkal, 2003). Purdy (1974) stated that the table was based on the formula $P = f(e^{M})$ where P is the point score, M is the performance mark, and e is the base of natural logarithms.

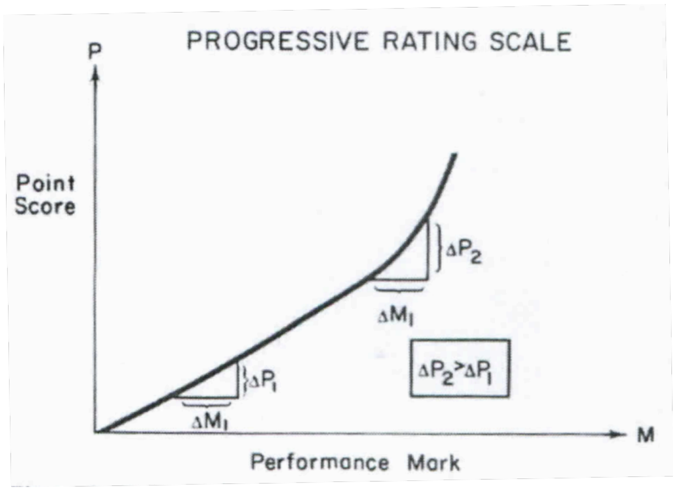

Figure 1.3. Progressive rating scale for a scoring table (Purdy, 1974)

Following various rule changes, development of technical equipment, and the overall athletic performance improvements, new scoring models were adopted in 1952 and again in 1962. Trkal (2003) reported that by the late 1970s, the general consensus was that the scoring system being used was "becoming increasingly unfair for evaluations and comparisons of disciplines". As the leader of the working group assigned to find the solution, Trkal (2003) described that one of the main aims of the new tables was to enable accurate point score comparisons between disciplines. Certain revolutionary changes, such as the evolution of a new high jump technique, and new materials being used to manufacture vaulting poles, were said to eradicate any equivalence between disciplines that previous models were able to provide (Trkal, 2003). As an example, Trkal (2003) explained that an unexceptional pole vault of 5.10 m equated as 1075 using an old model, whereas the new model that was developed would assign a score of 1075 points to a 9.99 s result in the 100 m. The IAAF adopted the most current scoring system in 1985, which comprised of independent scoring equations for track events, jumps, and throws. All equations were designed to be slightly progressive in nature. The IAAF (2001) outlined that for given athletic performances, point scores (P) are derived using the following equations;

Track events $\mathrm{P} = a(b - \mathrm{T})^{c}$ [Where T is time in seconds]
Jumping events $\mathrm{P} = a(\mathrm{M} - b)^{c}$ [Where M is measurement in centimetres]
Throwing events $\mathrm{P} = a(\mathrm{D} - b)^{c}$ [Where D is distance in metres]

The variables a, b and c are constant parameters whose values are outlined in Table 1.4.

Table 1.4. Parameters for the decathlon scoring system (IAAF, 2001)

	a	b	c
100 m	25.4347	10.00	1.81
400 m	1.53775	82.00	1.81
1500 m	0.03768	480.00	1.85
110 m Hurdles	5.74352	28.50	1.92
High Jump	0.8465	75.00	1.42
Pole Vault	0.2797	100.00	1.35
Long Jump	0.14354	220.00	1.40
Shot Put	51.39	1.50	1.05
Discus	12.91	4.00	1.10
Javelin	10.14	7.00	1.08

One of the main practical applications of such a scoring system was that individuals at the grass-roots level of the sport, and not just the world-class athletes, could use the tables. By using the simple formulas, any individual could theoretically undertake any of the events, either as a competition against athletes or by themselves during practice, and still be able to obtain a score. However, a drawback of the decathlon scoring system, is its specificity to just the events used in the decathlon. The algorithms used to determine the parameters a, b and c have not been made public, thus discouraging further scoring tables being developed for other sports or events such as the NFL Scouting Combine.

Despite multiple attempts over the past century to develop accurate scoring tables, even the most up to date system remains imperfect. Trkal (2003) stated that the latest system was designed in such a way that an athlete specialising in one discipline would not acquire sufficient points to overcome lower scores of a weaker discipline. However, two studies had claimed that scoring bias still existed within the model. Woolf, Ansley and Bidgood (2007), stated that athletes who excel in the sprint/track events could gain an advantage, whereas Cox and Dunn (2002) suggested that athletes could gain an advantage by doing well in the field events. Regardless of the weaknesses, it seems that although such a system would be valuable with the NFL Scouting Combine performance tests, without access to the parameter algorithms, it would be very time consuming to develop a similar system without such flaws.

1.3.4.2. Performance ranking system

The second potential method of assessing overall performance would be through a ranking system. The multi-objective analysis model 'Euclid' (Tavana, 2002) was identified as a method that could combine the results of multiple performance tests to form an overall score. It was stated by Zeleny (1982, cited in Tavana, 2008), that the highest achievable scores would form the "ideal" state, and that a Euclidean measure could be used to determine a distance away from it. Therefore, once all the athletes in a group have undertaken the same set of tests, each individual could be ranked according to their Euclidean closeness to the ideal.

When applying the Euclid model to athletic performance, the performance tests would be divided into two categories, dependent on whether the desirable outcome was a high value such as jump height, or a low value such as sprint time. The two categories would henceforth be referred to as maximal tests and minimal tests, respectively. Essentially, the Euclid model is comprised of two stages; normalisation and determination of the Euclidean distance. In order to further clarify the processes, terminology of the equation variables, derived from Tavana and O'Connor (2010), are as follows:

n	Number of potential athletes
m	Number of maximal tests
l	Number of minimal tests
x_{ij}	Score of maximal test j for athlete i
y_{ij}	Score of minimal test j for athlete i
$\bar{x}_{ij}$	Normalised score of maximal test j for athlete i
$\bar{y}_{ij}$	Normalised score of minimal test j for athlete i
$\dot{x}_j$	Lowest score achieved for maximal test j
$\ddot{x}_j$	Highest score achieved for maximal test j
$\dot{y}_j$	Lowest score achieved for minimal test j
$\ddot{y}_j$	Highest score achieved for minimal test j
$\bar{\bar{x}}_i$	Average normalised score of all maximal tests for athlete i
$\bar{\bar{y}}_i$	Average normalised score of all minimal tests for athlete i
D_i	Euclidean distance from the ideal state for athlete i

The model first normalises each performance test result; for maximal tests, this is done by the following process:

$$\dot{x}_j = \text{Min}(x_{ij};\ i = 1, \dots, n;\ j = 1, \dots, m)$$

$$\ddot{x}_j = \text{Max}(x_{ij};\ i = 1, \dots, n;\ j = 1, \dots, m)$$

The normalised maximal test score ($\bar{x}_{ij}$) is:

$$\bar{x}_{ij} = \frac{x_{ij} - \dot{x}_j}{\ddot{x}_j - \dot{x}_j}$$

The same normalisation process is utilised for the minimal tests:

$$\dot{y}_j = \text{Min}(y_{ij};\ i = 1, \dots, n;\ j = 1, \dots, l)$$

$$\ddot{y}_j = \text{Max}(y_{ij};\ i = 1, \dots, n;\ j = 1, \dots, l)$$

The normalised minimal test score ($\bar{y}_{ij}$) is:

$$\bar{y}_{ij} = \frac{y_{ij} - \dot{y}_j}{\ddot{y}_j - \dot{y}_j}$$

Once the results from all maximal and minimal performance tests have been determined, the average of both the normalised maximal tests ($\bar{\bar{x}}_i$) and the normalised minimal tests ($\bar{\bar{y}}_i$) are determined:

$$\bar{\bar{x}}_i = \frac{\sum_{j=1}^{m} \bar{x}_{ij}}{m} \; (i = 1, \dots, n; \; j = 1, \dots, m)$$

$$\bar{\bar{y}}_i = \frac{\sum_{j=1}^{l} \bar{y}_{ij}}{l} \; (i = 1, \dots, n; \; j = 1, \dots, l)$$

Finally, once the average normalised scores have been calculated, the distance of each value from the ideal state ($\bar{\bar{x}}_i = 1; \; \bar{\bar{y}}_i = 0$) can be determined:

$$D_i = \sqrt{(\bar{\bar{x}}_i - 1)^2 + (\bar{\bar{y}}_i - 0)^2}$$

The average normalised scores ($\bar{\bar{x}}_i, \bar{\bar{y}}_i$) can be depicted as a singular point on a two-dimensional graph (Figure 1.4). Due to the normalisation process, the points would be limited to appear within the boundaries of a single unit square. The Euclidean distance for an athlete's results from ideal (1,0) is therefore a measure of length, of the 'closeness' of that athlete to a best possible overall score. The athlete's Euclidean distances could consequently be ranked in order of size, with the smallest distance being assigned the top rank.

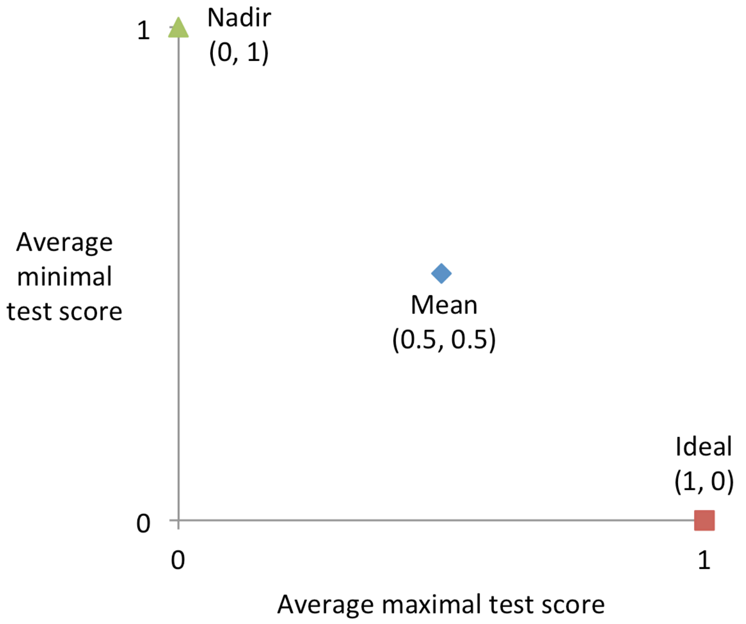

Figure 1.4. Euclidean distance output boundaries $(\bar{\bar{x}}_i, \bar{\bar{y}}_i)$.

In general, Euclid is a straightforward model that can be used on a set of performance test results to rank American football players in terms of their overall athletic ability. When comparing the Euclid model to the previously discussed point scoring method, two main factors would require future consideration. Firstly, in direct contrast to the progressive nature of the decathlon scoring system, Euclid fails to take into consideration the fact that performance increases are harder to achieve when the individual approaches the physical limits. Finally, as Euclid has yet to be utilised in an athletic scoring capacity, future research should look to determine whether or not an athlete would benefit overall if they were to specialise in a particular discipline.

Both the decathlon scoring system and the Euclid model have the potential to allow for the overall assessment of athletic ability in American football competitors. However, although the decathlon scoring method may provide for a longer-term solution of comparing performances across disciplines and between athletes, as the development of such a system would be an extremely long process, the Euclid model appears to be a more appropriate candidate for research to focus on in the immediate future.

However, both methods are limited as they fail to take into account cognitive factors such as the determination of a player's general intelligence, their personality, or their aptitude for tactical thinking. Ever since the 1970s, the Wonderlic Cognitive Ability Test has been included in the NFL Scouting Combine test battery. It is a timed, 12-minute, 50-question test (Kuzmits & Adams, 2008) to assess such cognitive traits as critical thinking, comprehension, learning ability, and decision-making (Wonderlic Inc., 2014). Wonderlic Inc. (2014) state that due to a confidentiality agreement, the results of the their test at the Scouting Combine are only shared with the NFL. Furthermore, the NFL Commissioner Roger Goodell stated that "scores on the Wonderlic test, and the like, are strictly confidential for club use only and are not to be disseminated publicly under any circumstances" (NFL, 2012). Therefore, any potential database containing the Wonderlic test scores would be founded upon unofficial reports and may be unreliable. When Kuzmits and Adams (2008) obtained Wonderlic scores from such a database, a relationship was not found to exist in relation to future NFL success of the athletes. Although the Wonderlic test has been observed to be a good predictor of general intelligence (Furnham & Chamorro-Premuzic, 2006), without rigorous independent scientific testing to confirm the applicability of such cognitive tests in a collegiate football setting, their inclusion in any overall scoring method could cast a shadow of doubt onto the results.

1.4. Nutrition for Performance

As a collegiate athlete, the student's diet not only has implications for overall healthy living and CVD factor prevention, but has been known to play a major role in three aspects of a strength-and-power athletes training schedule; fuelling, recovery, and the promotion of training adaptations (Slater & Philips, 2011). Due to the substantial sources of funding surrounding NCAA football (Langelett, 2003), collegiate athletic programs are more frequently hiring full-time sports nutritionists to help address the aforementioned aspects with their athletes to ultimately 'fuel a competitive edge' (Shattuck, 2001).

One of the challenges facing American football athletes is their ability to be sufficiently fuelled throughout their daily schedules. Estimated caloric requirements for Division I football athletes have been known to range from 4000 to 5300 kilocalories (kcal) per day (Cole et al., 2005; Kirwan, 2008). With such considerable intake requirements, dietary inadequacies have unsurprisingly been commonly observed (Cole et al., 2005; Jonnalagadda et al., 2001). When the diets of 30 Division I football athletes were examined, the average intake of 3288 kcal/day was significantly (p<0.05) less than recommended (Cole et al., 2005). However, self-reported dietary records were used as the method to analyse intake values. Moshfegh et al. (2008) found that on average, when using self-reported dietary recalls, energy intake levels were underreported by as much as 11% compared to the more accurate doubly labelled water evaluation techniques. When Jonnalagadda et al. (2001) had observed the dietary habits of Division I American football freshmen, a high incidence of eating out (4.8 times/week ± 4.1) was reported, suggesting diets were high in fat and cholesterol. It was found that 24% of the freshman population has raised cholesterol levels (Jonnalagadda et al., 2001), defined as ≥ 5.0 mmol/L (Department of Health, 2004). Therefore, not only have these athletes been frequently observed under-consuming, but also the quality of food that is consumed may not be conducive to good health.

The second implication of an athlete's diet was in terms of the recovery process during and after exercise. Competitive performances in American football consist of periods of high-intensity exercise, followed by periods of incomplete rest. The type of high-intensity exercise was stated to be fuelled through anaerobic energy sources, whilst the energy for repeated efforts and recovery came from aerobic pathways (Duthie, Pyne & Hooper, 2003). Saltin and Essen (1971) stated that after short exercise bursts (10 seconds) at maximal intensity, recovery of less than 20 seconds would not be sufficient for significant replenishment of creatine phosphate stores. Iosia and Bishop (2008) concluded that the typical exercise-to-rest ratios (E:R), in Division I football, ranged from an average of 1:7 seconds (excluding extended rest circumstances), to the shortest of 1:3 seconds, with the average play lasting 5.2 ± 1.6 seconds. Even though fatigue has been known to be induced via numerous mechanisms (Slater & Philips, 2011), it had been suggested that creatine phosphate store depletion may lead to the initial metabolic fatigue, whilst later fatigue could be caused by impaired energy production from glycogenolysis (MacDougall et al., 1999). Therefore, as the exhaustion of energy stores is hypothesized to be pivotal in the process of rapid recovery, dietary goals have been recommended to focus on the replacement of muscle glycogen (American Dietetic Association et al., 2009).

The final consideration for an athlete's diet was said to be for the facilitation of training adaptations to improve performance. For example, heavy resistance training accompanied by creatine consumption has been known to increase body mass, fat-free mass, and muscular strength (Kreider, 2003). One of the mechanisms by which creatine could assist with the aforementioned training adaptations was stated to be through the stimulation of muscular phosphocreatine re-synthesis (Maughan et al., 2011).

Phosphocreatine acts as a high-energy phosphate store for use when energy demands were high, thus enabling the individual to perform at elevated intensities. Further dietary stratagems had even been hypothesised around the theory of influencing gene expression. Although specific outlines had not been determined, Spriet and Gibala (2004) summarised that dietary changes could potentially manipulate an increase in mRNA content of genes responsible for oxidation of free fatty acids. Therefore, when faced with diminished carbohydrate stores, the athlete would utilise free fatty acids more effectively.

Sports nutritionists have numerous schemes at their disposal to improve an athlete's performance. However, ultimately it is the athlete that is required to make the decisions about what and when they eat. Sports nutritionists are recommended to tailor nutrition and hydration plans specific to each athlete and also to make them aware of why the plan was constructed in such a way. By educating athletes on fundamental nutrition concepts, they may become more inclined to want to adhere to such programmes and to make healthier dietary choices (Abood, Black & Birnbaum, 2004).

1.4.1. Fundamental sport nutrition

In order to make correct dietary choices, a certain level of sports nutrition knowledge is required; however, due to a poor understanding of fundamental nutrition concepts, athletes and non-athletes alike are often found to be confused when making sensible dietary choices (Rosenbloom, 2006). Before devising a nutrition education intervention for an athletic population, it is important to understand where the lack of knowledge is and what the potential impact would be. When developing a questionnaire to identify such areas, the majority of fundamental sport nutrition concepts can be covered in five succinct sections; macronutrients, micronutrients, hydration, recovery, and supplements.

When enquiring about macronutrient knowledge, the main area of focus revolves around sources of energy and the perception of the Glycaemic Index (GI). It has previously been noted that due to a widespread fixation on low-carbohydrate, high protein diets, many athletes "fear" carbohydrates as something fattening (Rosenbloom, 2006) when, in actual fact, complete fatty acid metabolism relies upon glycolytic substrates being produced (McArdle, Katch & Katch, 2008). Such misunderstandings may have led to athletes believing that protein was the main source of energy for muscular contractions (Condon, Dube & Herbold, 2007; Rosenbloom, Jonnalagadda & Skinner, 2002), or even influenced them to try to eliminate carbohydrates from their diets. Furthermore, the failure to understand the fundamentals of carbohydrates could lead to an athlete's lack of awareness towards the GI of foods. It had been suggested that low-GI meals pre-exercise could lead to a more stable blood glucose concentration during exercise, compared to a high-GI meal (Williams & Serratosa, 2006). However, due to large methodological variations throughout the research, the effects of different GI meals pre-exercise have proved inconclusive (American Dietetic Association et al., 2009).

The American Dietetic Association et al. (2009) went on to state that if individuals were to go as far as to eliminate a food group from their diet, they would be putting themselves at a high risk of becoming deficient in micronutrients. Two of the most common observations relating to athletes and micronutrients are: a belief that vitamins and minerals are a source of energy (Jonnalagadda et al., 2001; Rosenbloom et al., 2002; Rash et al., 2008) and that consumption of multivitamins seems to be a common practice, whether it be in an attempt to enhance performance or purely for health reasons (Froiland et al., 2004; Short & Short, 1983; Worme et al., 1990). It has been concluded that if an athlete's regular diet was well balanced and micronutrient-dense, micronutrient supplementation would not improve performance (American Dietetic Association et al., 2009). Lack of awareness of such principles would therefore lead athletes to not only waste money, but to potentially increase stress levels if they fail to see their expected outcomes. The use of micronutrient supplementation was only observed to enhance performance if the individuals were in a deficient state to begin with (American Dietetic Association et al., 2009). In high contact sports such as American football, awareness of calcium and vitamin D deficiency should be of particular importance due to the severe implications of low bone mineral density or stress fractures could have on the longevity of such an athlete's career.

The third area to be reviewed by a nutrition knowledge questionnaire would be the topic of hydration. The negative impact of dehydration (>2% body weight) on aerobic performance has been consistently observed throughout the research and consequently acknowledged as fact among organisational consensus statements (Burke, 2003) and position stands (American Dietetic Association et al., 2009; Sawka et al., 2007). During pre-season training for collegiate American football athletes, sweat losses had been observed to be in excess of 9 L per day (Godek, Godek & Bartolozzi, 2005). Sawka et al. (2007) summarised that once an athlete enters a dehydrated state, physiological strain and perceived effort increased in order for them to perform the same exercise tasks. For these reasons, it would seem logical that if athletes were aware of the appropriate times to start pre-hydrating, how they can detect the onset of a dehydrated state, and the consequences of becoming dehydrated, the severity and occurrence of dehydration could be limited.

The concept of recovery nutrition encompasses principles from both macronutrient and hydration knowledge. The position stand of the American Dietetic Association et al. (2009) stated that the dietary goals of athletes post exercise should focus on fluid, electrolyte and energy replenishment to promote rapid recovery rates. Exact timing and composition of post-exercise nutrition would greatly depend on the intensity of the exercise, and also when the timing of subsequent exercise sessions would occur (American Dietetic Association et al., 2009). To promote rapid energy store repletion, Burke, Colier and Hargreaves (1993) established that following a glycogen-depleting exercise trial, a high-GI meal would result in higher muscle glycogen levels 24 hours post-exercise compared to a low-GI meal. Following such advice could make the difference in enabling an athlete to gain the most from training sessions or competitions in the days following highly intensive exercise. For more immediate recovery techniques, athletes may focus on methods to return to a normally hydrated state and the efficacy of using electrolyte drinks for retaining fluids. By observing urine colour, volume, and body weight, Sawka et al. (2007) stated that hydration status could be accurately tracked. However, during rehydration, the consumption of copious amounts of hypotonic fluids could mislead the individual to identify frequent urination as a sign that a state of euhydration had been reached, when in actual fact, they may remain dehydrated (Sawka et al., 2007). Therefore, it is of importance to assess the awareness of rehydration techniques with electrolytes such as sodium that should be replaced to ensure the return to euhydration and to help retain fluids (Sawka et al., 2007).

The final topic for assessment would be supplementation. The manufacturing of nutrition supplements had reportedly grown into a $17 billion-per-year industry during 2005, with 235 products claiming to increase muscle growth and strength alone (Pearce, 2005). However, the American Dietetic Association et al. (2009) concluded that only five ergogenic aids (creatine, caffeine, sports drinks/gels/bars, sodium bicarbonate, and protein and amino acid supplements) had sufficient scientific research to prove they performed as claimed. The increasing popularisation of nutritional supplements was exemplified in a study by Tscholl, Junge and Dvorak (2008), where supplement consumption for every athlete participating in the 2002 and 2006 Fédération Internationale de Football Association (FIFA) World Cups was documented. It was observed that in the 2002 FIFA World Cup, an average of 0.73 supplements were taken per player per match, which significantly rose to an average of 1.3 during the 2006 FIFA

World Cup (Tscholl, Junge & Dvorak, 2008). In a collegiate American football setting, Jonnalagadda et al. (2001) reported that 42% of freshmen were consuming supplements, with the most popular being creatine, vitamins, and protein drinks. Despite creatine having been accepted as one of the five supplements that perform as claimed, it is imperative athletes are aware that it's only effective during short bursts of high intensity exercise, as opposed to endurance based activities (American Dietetic Association et al., 2009). If an athlete were to rely on creatine supplementation for energy during endurance, they could run the risk of depleting their energy stores midway, seriously compromising their performance capabilities during the event. In terms of protein supplementation, on the other hand, the American Dietetic Association et al. (2009) stated that when the energy derived from their normal diet is sufficient for gaining lean body mass, protein and amino acid supplements would provide no more or no less benefit. Thus enforcing the message that supplements do not compensate for poor food choices or inadequate diets and that specific nutrition strategies should be primarily be adopted before the consideration of supplement usage (International Olympic Committee, 2011). As protein supplements have frequently been considered by American football athletes to be necessary for muscular growth (Jacobson & Aldana, 1992; Jonnalagadda et al., 2001), it is important to discover how aware athletes are of such concepts and whether they are knowledgeable in regards to other ergogenic aids, such as caffeine and sodium bicarbonate.

In conclusion, current recommendations state that individually tailored nutrition and hydration plans should be devised for each athlete (Holway & Spriet, 2011); as the nutritional demands may vary considerably between the different positions. However, the ultimate responsibility for consumption falls upon the athlete. By assessing the knowledge of athletes on each of the five nutrition areas, any misconceptions that exist can be specifically targeted during nutrition education interventions in an attempt to influence their compliance to adhere to performance enhancing dietary trends.

1.5. Summary

Throughout the above review, the background literature pertaining to both nutrition knowledge and performance assessments, among a collegiate American football population, has been explored. Research has highlighted the multiple healthy eating barriers that are associated with the transition of collegiate students moving away from home, to college. For many students, it is likely to be the first time they are required to be self-sufficient. Such pressures and rapid change of lifestyle were often seen to lead toward the adoption of undesirable nutrition practices. When combined with the additional lifestyle challenges of being a collegiate student, the poor dietary choices being made could potentially impact their sporting performances, manifesting in a number of ways. Although collegiate athletic departments in America may be hiring sports nutritionists more frequently, to aid athletes in making the right dietary choices, the final decision on what is consumed remains with the athletes themselves. Poor nutrition knowledge has previously been associated with negative dietary trends. Therefore, a key role of sports nutritionists would be to help educate the athletes regarding the composition of a beneficial diet for performance. Such education would look to ensure the autonomy of athletes to purchase healthy foods under their own esteem, and to fully embrace beneficial dietary habits. The standard of nutrition knowledge among British American football athletes has yet to be fully assessed. The link between nutrition knowledge and performance has also not been researched. The above review has outlined the most important and relevant research in relation to these topics in order to construct the following project.

1.5.1. Aims, objectives, research question and hypotheses

The proposed research project aims to assess nutrition knowledge and performance variables of American football athletes, and evaluate whether or not a relationship exists between the two. The following aims, objectives, research questions and hypotheses were developed for the project;

Aims;

1. To develop a fundamental nutrition knowledge questionnaire that is valid and reliable;
2. To determine the applicability of the Euclid model as a potential performance assessment tool;
3. To ascertain whether or not a relationship exists between nutrition knowledge and select performance variables in collegiate American football athletes.

Objectives;

- To develop a fundamental nutrition knowledge questionnaire with expert opinion;
- To subject the questionnaire to rigorous testing procedures, thus ensuring the questionnaire is valid and reliable;

- To implement the Euclid model and compare the results to previously used performance assessment tools;
- To employ the previously validated nutrition knowledge questionnaire and Euclid performance scoring model to evaluate whether or not a relationship exists between the performance values and questionnaire scores of the athletes.

Research Question;

1. Does a relationship exist between the fundamental nutrition knowledge of British American football athletes and their respective combine performance outputs?

Hypotheses;

a) There will be a significant positive relationship between fundamental nutrition knowledge and performance among British university American football athletes.

Null hypotheses;

a) There will not be a significant positive relationship between fundamental nutrition knowledge and performance among British university American football athletes.

Chapter 2 – Development of a Valid and Reliable Nutrition Knowledge Questionnaire

2. Introduction

The significant influence of nutritional intake on athletic performance has been widely recognised and acknowledged among multiple organisational position stands (American Dietetic Association, Dieticians of Canada & American College of Sports Medicine, 2009; International Olympic Committee, 2011). As such, more collegiate athletic departments have been hiring sports nutritionists to ensure their athletes are fully prepared for competition, and to reduce the chance of an athlete becoming dehydrated or energy depleted during competition (Clark, 1999; Shattuck, 2001). A common tool for sports nutritionists to improve the quality of an athlete's diet is through interventions. University is a crucial period for sports nutritionists to work with athletes, as it can often be the first time they have had sole responsibility for the content of their diet. Silliman, Rodas-Fortier and Neyman (2004) stated that the top three perceived barriers to healthy eating for collegiate students were a lack of time, a lack of money, and an uncaring attitude. By educating athletes about correct nutrition, sports nutritionists attempt to increase the athlete's willingness to adhere to better dietary habits. Multiple research studies have successfully shown that nutrition education programmes can lead to both a knowledge increase, and improvements in overall dietary habits (Abood, Black & Birnbaum, 2004; Ha & Caine-Bish, 2009; Worsley, 2002). In order to develop such programmes, individuals would typically be quizzed to determine the areas where misconceptions are most prevalent.

Multiple nutrition knowledge questionnaires have previously been used to identify misconceptions amongst athletic populations (Jacobson, Sobonya & Ransone, 2001; Rosenbloom, Jonnalagadda & Skinner, 2002; Wiita, Stombaugh & Buch, 1995). A systematic review by Heaney, O'Connor, Michael, Gifford and Naughton (2011), looking at the nutrition knowledge of athletes, revealed the poor quality of questionnaires used in previous research. Prior to 2011, 29 studies matched the criteria of assessing the nutrition knowledge of competitive (recreational or elite) athletes. Heaney et al. (2011) identified that the degree to which validation techniques had been used on the questionnaires was sporadic.

Whilst eight studies had thoroughly ensured the validity of their questionnaires, a further 10 had only partially tested the validity, and the remaining 11 failed to report any sort of validation techniques having been used at all. Failure to subject a questionnaire to rigorous validity and reliability measures compromises its integrity and so, potentially, calls into question the outcome measurements and conclusions obtained by using it.

Kline (1993) outlined 4 psychometric measures from which tests could be derived to determine the validity and reliability of a questionnaire; content validity, construct validity, test-retest reliability, and internal consistency for reliability. Content validity was the only measure that was not determined through a statistical test. Instead, it was subjectively examined during the process of development if the content of the questionnaire was conceived in accordance with the opinion of experts. Following the development, distributing the questionnaire to two or more groups of individuals with different education backgrounds and consequently observing significantly different scores between groups determine construct validity. Test-retest reliability assesses the stability of the questionnaire over time when a group of individuals are administered the same questionnaire twice. Finally, by measuring the inter-correlation of scale items, internal consistency of the questionnaire can be tested.

The aim of the present study was to develop a fundamental nutrition knowledge questionnaire, using expert opinions and to subject it to further tests to ensure its validity and reliability. By performing at least three of the aforementioned methods for determining validity and reliability, a questionnaire can be defined as having been rigorously validated (Heaney et al., 2011). As a result, scores can be reliably used as the foundation for creating effective nutrition education programmes.

2.2. Method

2.2.1. Sample selection

Following approval from the School of Life and Medical Sciences Ethics Committee at the University of Hertfordshire, course tutors from Business Studies, Geography, and Sport and Exercise Science were contacted to provide approval for the recruitment of their students. Consent was gained through the completion and return of the questionnaire.

2.2.2. Participants

To test the construct validity, participants were recruited from three unrelated university degree programmess (Business Studies, Geography, and Sport & Exercise Science) in an attempt to produce a diverse sample population in terms of their nutritional education background. A total of sixty-three final-year university students were recruited to test the construct validity and the internal consistency of the designed questionnaire.

2.2.3. Procedures

The initial design of the questionnaire was based on concepts from nutrition knowledge questionnaires that had been previously used in an American football setting (Clemo, Kass & Jacobson, 2012; Jonnalagadda et al., 2001; Rosenbloom et al., 2002). Questions were close-ended whereby respondents would either indicate their agreement towards a statement, or select a response from a multiple-choice list. Five content-specific subsections of questions were formed to categorise questions: macronutrients, micronutrients, hydration, recovery and supplements.

The content of the questionnaire was designed with the intention of testing the knowledge of American football athletes in regards to fundamental sports nutrition concepts. Sound, evidence-based questions were developed using papers from the latest IOC Consensus Conference (Holway & Spiret, 2011; Maughan, Greenhaff & Hespel, 2011; Slater & Philips, 2011) and organisational position stands (American Dietetic Association, Dietitians of Canada & American College of Sports Medicine, 2009; Sawka et al., 2007). A focus group of four subject-specific experts was formed to review the content of the questionnaire in terms of question clarity, interpretability, and accuracy of information prior. Following the recommendations of the focus group, a finalised questionnaire was created and distributed among the recruited participants. An initial question prefaced the questionnaire to determine the most advanced level to which each participant had been nutritionally educated. There were six options they could select from: university classes/seminars, college classes, self-taught, sessions with a nutritionist, high school classes, or no previous education at all. When the average correct response rates of each level of education were compared, individuals were assigned to one of two groups, depending on the significance observed, for consequent analysis purposes: nutritionally educated individuals, or nutritionally uneducated individuals.

2.2.4. Statistical analysis

To identify which standards of nutritional education produced the highest overall scores, a Mann-Whitney U analysis was performed between the mean total scores of each source of education. To verify the construct validity, an independent samples t-test was performed between the results of nutritionally educated and uneducated individuals, for each question. The alpha value for all t-tests and Mann-Whitney U analyses was set at ≤ 0.05. In addition, the reliability of the questionnaire was examined through a Kruder-Richardson (KR20) calculation to check the internal consistency of the questions of each subsection. The alpha value for the KR20 test was set at ≥ 0.7. All statistical analyses were performed with the Statistical Package for Social Sciences (SPSS, version 21, Armonk, NY). Data is expressed as mean ± standard deviation.

2.3. Results

2.3.1. Content validity

An initial questionnaire was composed of 30 questions across the five subsections, in accordance with the expert opinion from position stands and consensus statements. Following the recommendations of experts in the focus group, nineteen questions were re-worded to improve clarity and interpretability. In addition, it was recommended that four more questions be added to the micronutrient subsection so that wider areas of fundamental concepts were covered. As a consequence to the focus group, a questionnaire containing 34 questions was developed and thus termed the “first draft” (Appendix 1).

2.3.2. Construct validity

When analysing the standards to which each participant had been nutritionally educated (figure 2.1), those who had received their education from university classes/seminars (n = 18; average score = 21.8 ±

5.5) were significantly ($p<0.05$) more knowledgeable compared to the results from all other groups; college classes (n = 2; average score = 11.0 ± 5.7), self-taught (n = 6; average score = 11.0 ± 3.0), sessions with a nutritionist (n = 2; average score = 10.5 ± 6.4), high school classes (n = 23; average score = 8.8 ± 4.3), or no previous education at all (n = 12; average score = 6.9 ± 3.2). Further significance was seen when comparing results between self-taught individuals and those with no form of previous nutrition education (p = 0.012). As a consequence, to test the construct validity, participants with nutritional education from a university class/seminar were defined as being nutritionally educated (n = 18). All other participants were thus defined as being nutritionally uneducated (n = 45). When the two groups were compared, the nutritionally educated individuals scored an average of 64% ± 16% correct responses (21.8 ± 5.5), which was significantly ($p<0.001$) higher that the 25% ± 12% average score (8.8 ± 4.03) of the nutritionally uneducated individuals.

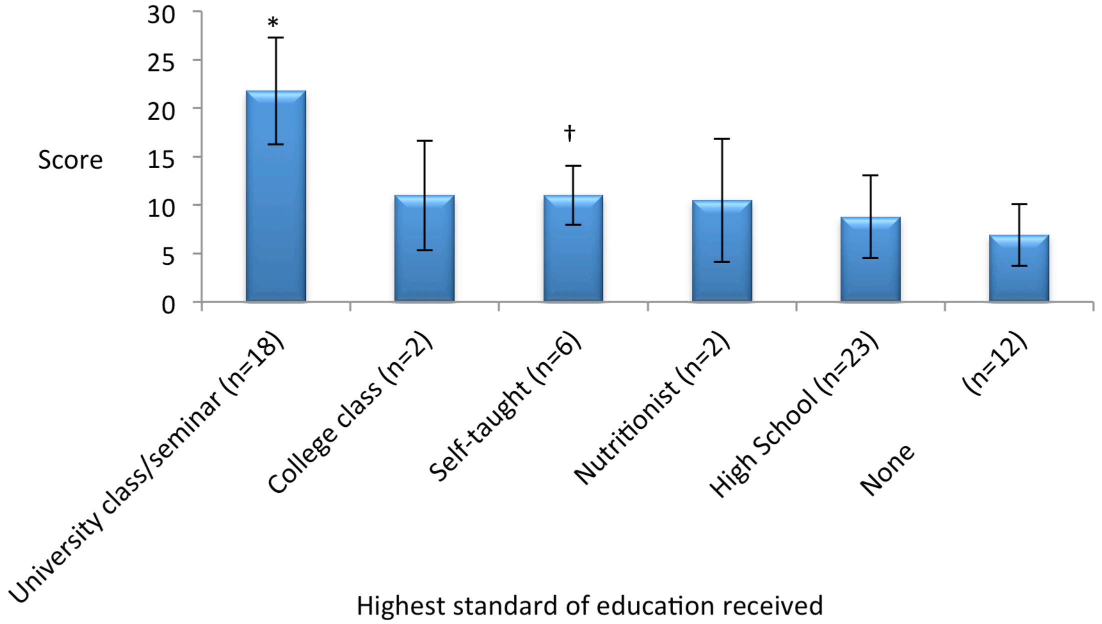

Figure 2.1. Mean questionnaire scores of participants by educational background.

* = Significantly different to the scores of all other categories ($p<0.05$); † = significantly different to the scores of individuals with no nutrition education (p = 0.012).

The mean question response rates for each group of individuals, within each subsection of the first draft of the questionnaire are presented in figures 2.2 to 2.6. In total, statistically significant differences

($p<0.05$) were observed, between the groups, on twenty-six of the thirty-four questions. All significance was observed to be in favour of the nutritionally educated individuals, except for question 14 of the hydration subsection, where the nutritionally uneducated individuals significantly ($p<0.001$) outscored the nutritionally educated individuals. As a result, nine questions (Q8c, Q8d, Q9b, Q10, Q14, Q16, Q17, Q19a, and Q24) were removed from the questionnaire due to a lack of significance in favour of the nutritionally educated group. The remaining 25 questions formed the second draft of the questionnaire.

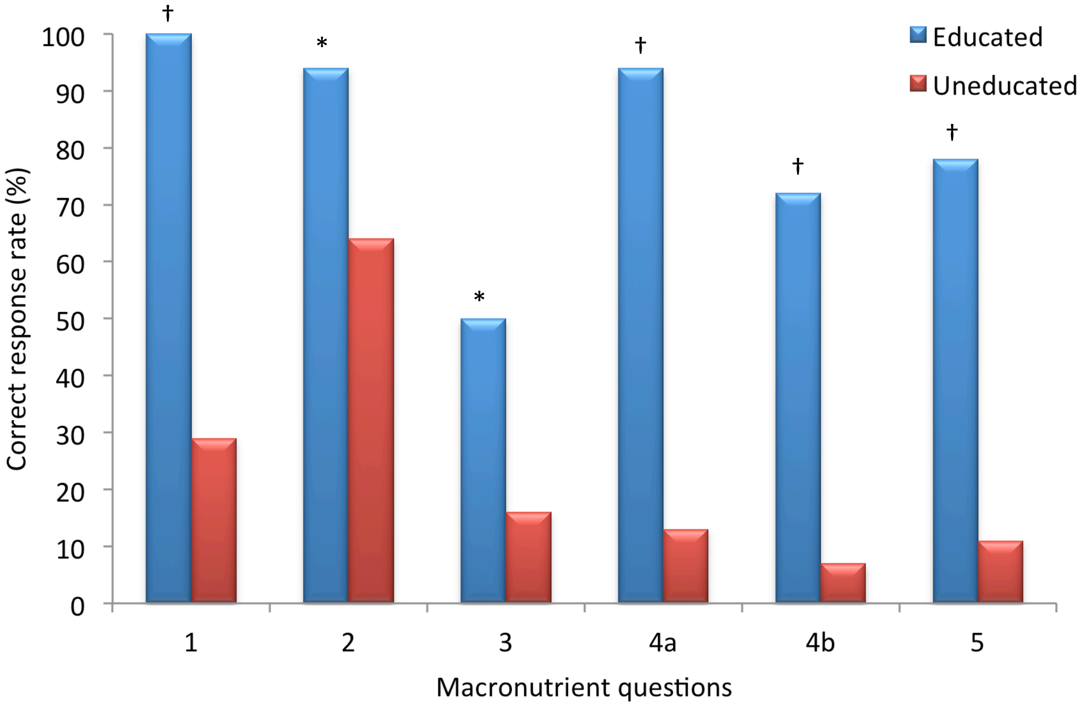

Figure 2.2. Mean macronutrient correct response rate comparing nutritionally educated (n= 18) and uneducated (n= 45) individuals. * = Significantly different to the uneducated group ($p<0.05$); † = Significantly different to the uneducated group ($p<0.001$)

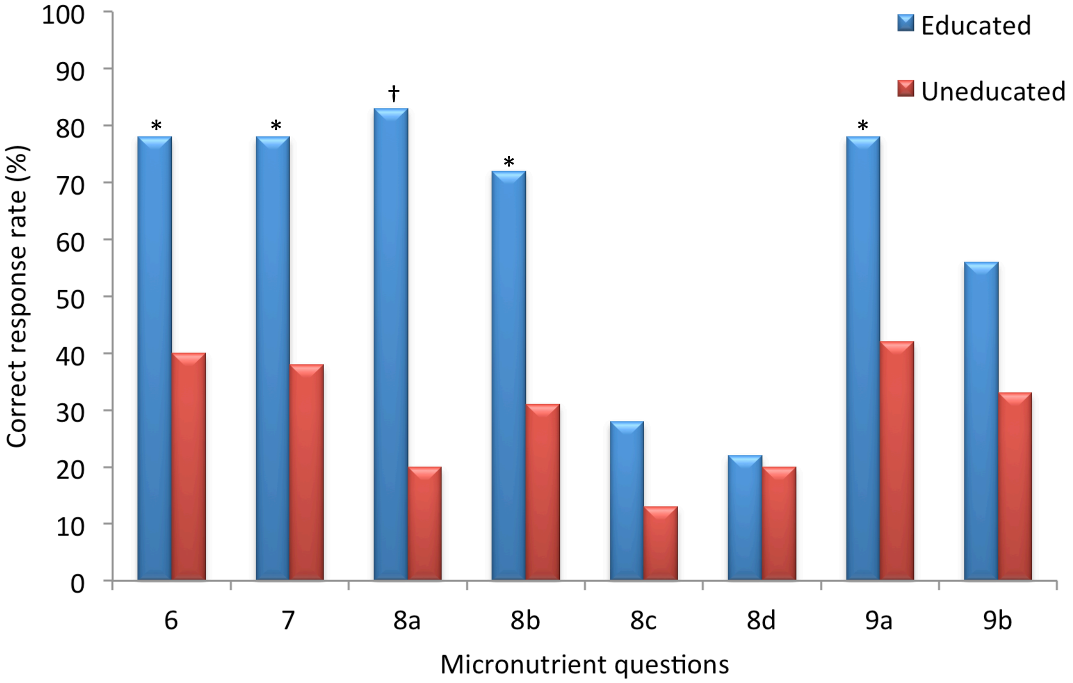

Figure 2.3. Mean micronutrient correct response rate comparing nutritionally educated (n= 18) and uneducated (n= 45) individuals. * = Significantly different to the uneducated group (*p*<0.05); † = Significantly different to the uneducated group (*p*<0.001)

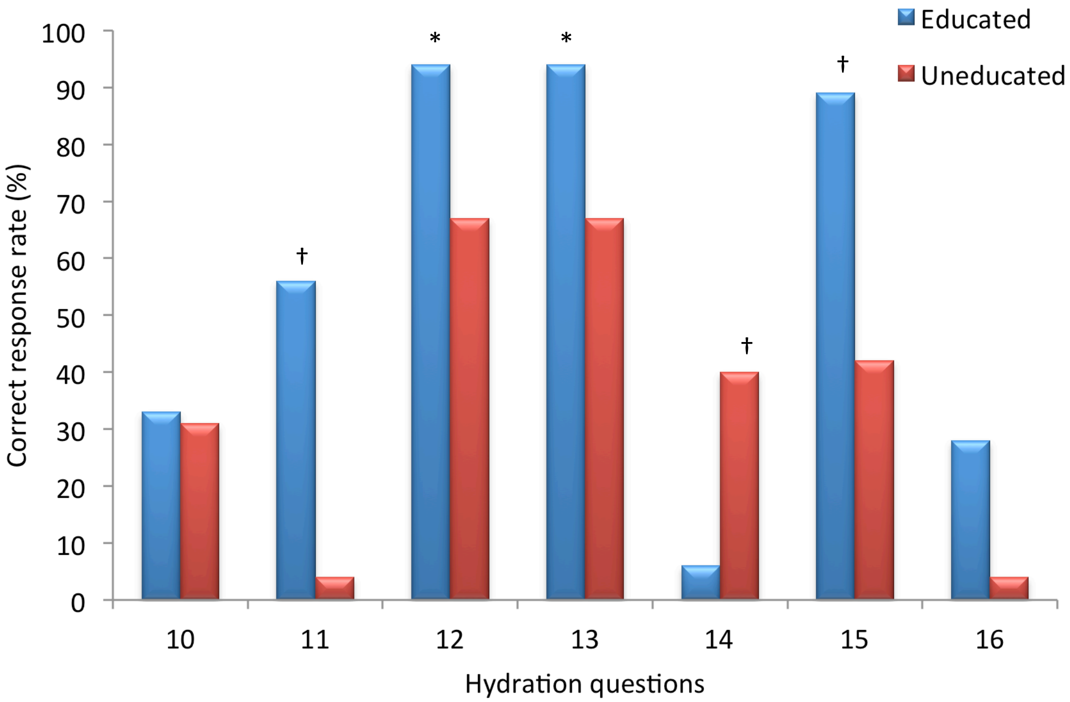

Figure 2.4. Mean hydration correct response rate comparing nutritionally educated (n= 18) and uneducated (n= 45) individuals. * = Significantly different to the uneducated group (p<0.05); † = Significantly different to the uneducated group (p<0.001)

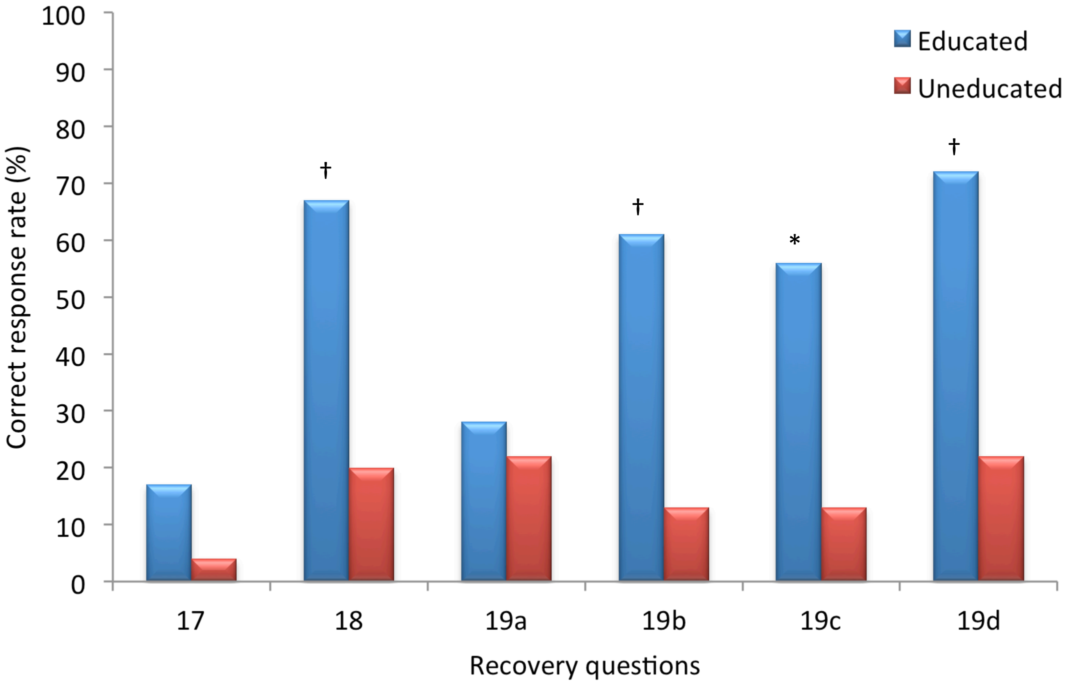

Figure 2.5. Mean recovery correct response rate comparing nutritionally educated (n= 18) and uneducated (n= 45) individuals. * = Significantly different to the uneducated group ($p<0.05$); † = Significantly different to the uneducated group ($p<0.001$)

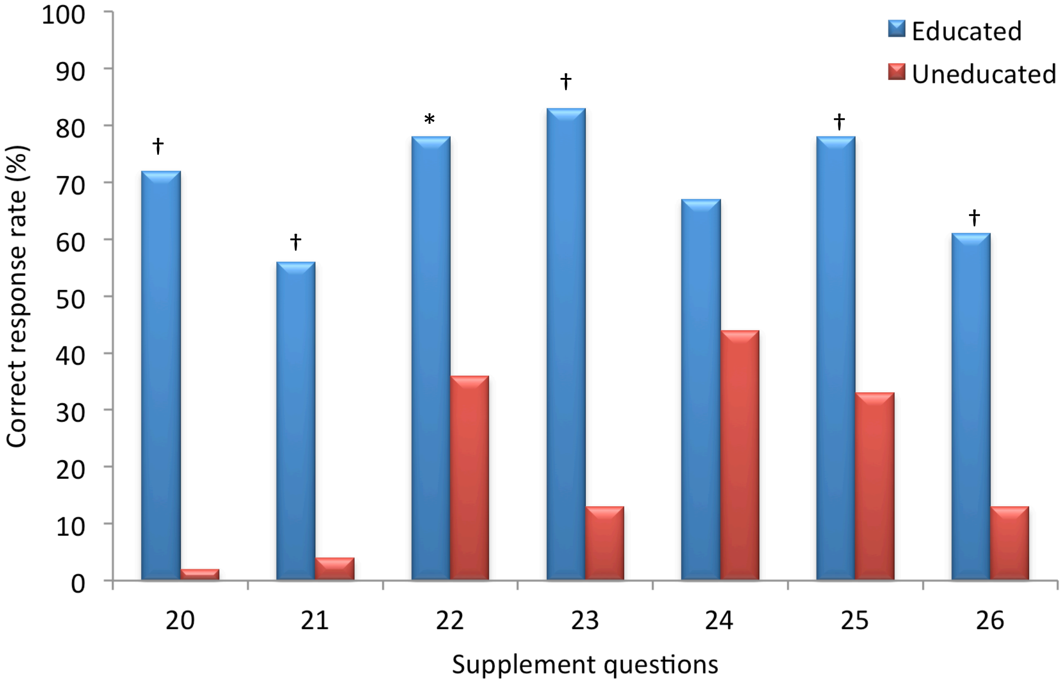

Figure 2.6. Mean supplement correct response rate comparing nutritionally educated (n= 18) and uneducated (n= 45) individuals. * = Significantly different to the uneducated group (p<0.05); † = Significantly different to the uneducated group (p<0.001)

2.3.3. Internal consistency for reliability

The KR20 test was performed on the results of questions from the first draft of the questionnaire with the original 34 questions. Education standards were not taken into consideration and the results of all subjects (n = 63) were analysed together. Once the α-value was produced for a subsection, alternative values were automatically produced to demonstrate the respective increase/decrease that would occur if a certain question were to be removed. Once all subsections had been assessed, 11 questions were identified as being able to increase their respective subsection α-values if removed. Of the 11 questions, nine were the same as those marked for removal following the construct validity t-test results. Thus highlighting a further two questions (Q2 and Q3) which were required to be removed. As a result, the remaining 23 questions formed the "final version" of the questionnaire (Appendix 2). Figure 2.7

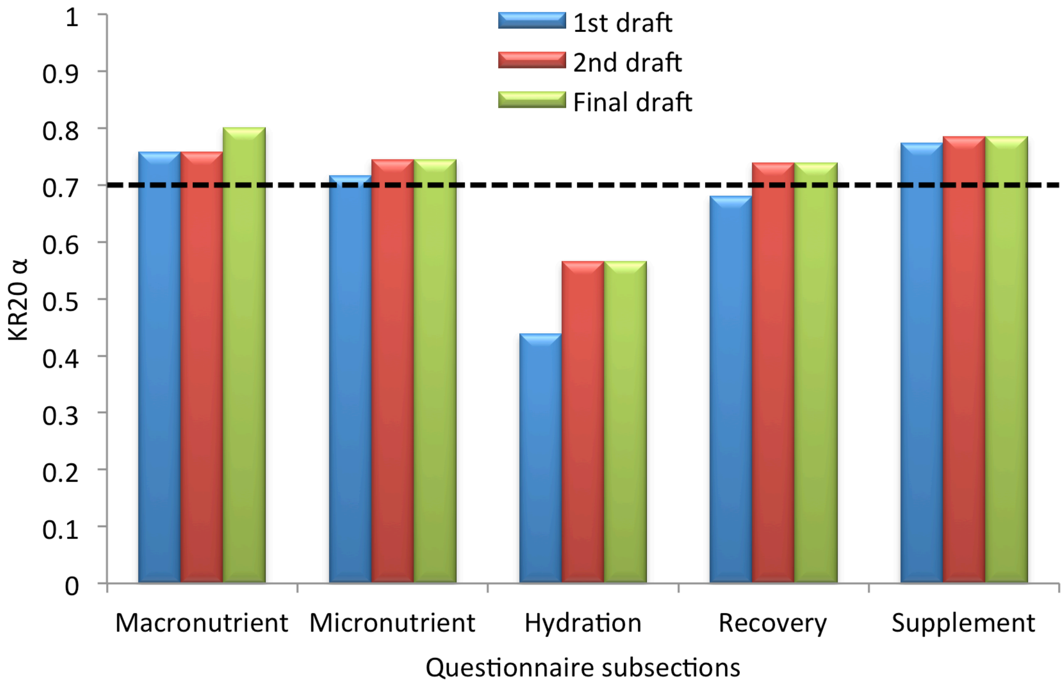

Figure 2.7. Questionnaire KR20 α scores by subsection for the 1st draft, 2nd draft, and final version of the questionnaire in relation to the significance requirement (α > 0.7).

illustrates the KR20 α-values for each subsection of the questionnaire. It also shows the α-values in terms of the first, second and the final versions of the questionnaire.

2.3.4. Final questionnaire

Once the 23-question final version of the questionnaire was determined, the results of the original questionnaire were re-examined to determine an updated average score for the nutritionally educated and nutritionally uneducated groups. Responses to the 11 invalid and/or unreliable questions were disregarded, and only the responses to the remaining 23 questions were included for analysis. The nutritionally uneducated group had an average score that remained at 25% ± 14% correct (5.8 ± 3.3), whilst the average score for the nutritionally educated group had increased to a 76% ± 19% correct response rate (17.5 ± 4.3).

2.4. Summary

The present study outlined the process of developing a nutrition knowledge questionnaire and subjecting it to a battery of validation tests. Previous research studies have frequently been seen to utilise questionnaires, which failed to show evidence of being validated beforehand (Heaney et al., 2011). Due to such oversights, the results and conclusions of said studies could potentially be called into question, as the questionnaire may not have been accurately testing what it was intended to examine. The strengths of the current study were the use of multiple tests to ensure the validity and reliability of the resultant questionnaire.

It has been stated that the content validity of a questionnaire would be ascertained if designed in accordance with the contribution of experts from the associated disciplines (Kline, 1993). The first stage of the questionnaire development involved producing questions based on sport nutrition guidelines outlined in organisational consensus statements (Holway & Spiret, 2011; Maughan et al., 2011; Slater & Philips, 2011) and position stands (American Dietetic Association et al., 2009; Sawka et al., 2007). By incorporating this process, it ensured that the correct response assigned to each question was founded on expert-led research, and so less open to doubt. The second stage of questionnaire development had a focus group of four subject-specific experts to critique the content. This produced numerous suggested revisions, which directed the questionnaire to encapsulate all the fundamental concepts of sport nutrition. Consequently, the first draft of the questionnaire was recognised as being content valid.

Once the questionnaire had been distributed among the participants, unsurprisingly those that had received nutrition education at a university level significantly outperformed those with different nutrition education backgrounds. A possible explanation for these findings, other than the in-depth and advanced standard of instruction the university-educated individuals received, is what the recruited participants received their nutrition education more recently than the majority of the nutritionally uneducated individuals. Every participant was a final year university student and, as such, even if some participants had received a high quality of sport nutrition education at college, the information would have been taught to them a minimum of 2.5 years previously, as opposed to having been taught within the preceding months. A recent review found that that approximately two-thirds to three-quarters of basic scientific knowledge would be retained a year after the education; whereas after a further year, knowledge retention decreased to just under a half (Custers, 2010). Nevertheless, at the point in time when the questionnaire was completed, it became apparent that by differentiating the participants by their sport nutrition education backgrounds, educated and uneducated individuals could be distinguished.

An unexpected result in the construct validity tests came from question 14, when the nutritionally uneducated individuals significantly outscored those deemed nutritionally educated. The question pertained to whether or not the individuals believed that in general, over-drinking was more dangerous than under-drinking. The question was included in the original questionnaire because the dangers of exercise-associated hyponatremia, i.e. over-drinking, had been observed among non-elite athletes in endurance-based events, whereby exercise can often exceed 4 hours (Almond et al., 2005). In particular, some American football athletes have been fatally affected by hyponatremia (Dimeff, 2006). It was summarised by Sawka et al. (2007) that although dehydration was more frequently observed in a sporting context, over-drinking with symptomatic hyponatremia was more dangerous. It was hypothesised that individuals with less nutrition education would be unaware of the dangers of over-drinking. However, a speculated reason to explain the questionnaire result was that an academic emphasis at the university level might have been placed on the common performance implications of dehydration, rather than the exceedingly rare fatal implications of hyper hydration. Therefore, due to an increased familiarity with dehydration, the university-educated individuals may have believed that in general, dehydration was more dangerous. As a consequence, question 14 was removed from the questionnaire, along with eight others that failed to show a significant difference in favour of the nutritionally educated. Thus the remaining questions were not only content valid, but also constructively valid.

The final statistical tests were used for reliability purposes, to assess the internal consistency of the questions of each subsection. Two types of statistical tests have previously been utilised to test internal consistency, depending on whether the questions had dichotomous or multiple answers. Kline (1993) identified these tests as the Kruder-Richhardson formula (KR20) and the Chronbach's alpha, respectively. The α-level output required for internal consistency was defined to be 0.7 for both tests. Only one out of the five subsections of the questionnaire failed to attain an α-level of 0.7 or above. The hydration subsection only achieved a level of 0.566, even after 3 questions were removed. However, numerous earlier studies had similarly reported lower α-levels for nutrition knowledge questionnaires, below that of the required 0.7 standard. For example, Turconi et al. (2003), Sapp and Jensen (1997), and

Steenhuis et al. (1996) all reported internal consistency levels of below 0.7, even as low as 0.56. Low internal consistency scores for knowledge questionnaires were rationalised by Kline (1993) who explained that such tests were most applicable to questionnaires testing an individual's opinions or beliefs rather than knowledge. DeVellis (1991) stated that α-levels as low as 0.6 could still be classified as acceptable. When considering the lower α-level requirement, the hydration subsection could be considered to have an almost sufficient score, albeit still unacceptable. Such a low score could be explained due to the sparse number of questions in the subsection. Hattie (1985) explained that a higher number of questionnaire items would consequently result in a higher Chronbach's alpha result. Nevertheless, it was deemed that the topic of hydration was too imperative to completely remove, so the valid hydration questions were accepted into the final version of the questionnaire.

Given such high internal consistency scores for 4 out of the 5 subsections of the questionnaire, the final version, which included 23 questions, was both valid and reliable. By taking into account the final average correct scores of the nutritionally educated (76%) and the nutritionally uneducated individuals (25%), possibilities arise for future practical applications. For example, various scoring bands could be defined in order to classify future respondents as being; nutritionally educated (≤75%), partially educated (25% > 75%), or uneducated (≥25%). Consequently, nutrition education programmes could be devised to accommodate different individuals depending on which band they achieved.

Chapter 3 – Discussion of a potential performance scoring system for American football athletes

3. Introduction

The concept of combining multiple athletic disciplines to form one event was first seen during the Ancient Olympic Games of 708 B.C. with the introduction of the pentathlon (Kyle, 1990). During this time, the act of writing was still in its infancy in Greece; therefore, the precise procedures used to determine the overall winner would not have been deemed important enough for historical documentation (Kyle, 1990). As a consequence, historical scholars have attempted to piece together information found among numerous ancient documents. Although the exact method has yet to be conclusively determined, the most accepted system was that only a first place finish would count, and that once an individual had won three of the disciplines, the pentathlon was over (Ebert, 1960; Kyle, 1990). Such primitive methods drastically changed around the time of the revival of the Olympic Games into the modern era, with a fixation on fairness and standardisation. In 1912, linear scoring tables were adopted for each event; however, since then, the official scoring system has been updated four more times into formulas that were progressive in nature (Trkal, 2003). Despite the updates, it is still claimed that the latest version provides a scoring bias to athletes who specialise in certain disciplines (Cox & Dunn, 2002; Woolf, Ansley & Bidgood, 2007). However, the precise algorithms for the latest scoring method have not been publicly disclosed, and thus cannot be fully scrutinised or modified for potential improvement by independent research.

The notion of combining athletic disciplines has since evolved from the original pentathlon into the current Olympic sports of heptathlon and decathlon. It has even evolved outside of a competition context and into a sophisticated tool, used by professional scouts, to assess an athlete's overall performance capabilities. Multiple professional sports leagues have adopted the practice of holding a Scouting Combine in the lead-up to their annual draft. One of the most renowned Scouting Combines is that of the National Football League (NFL). Each year, around 300 of the top college football prospects are selected to attend the event to showcase their overall athletic ability in front of scouts and coaches from the professional teams. However, unlike in the heptathlon and decathlon, an official scoring system has not been developed for the NFL Scouting Combine to identify the most successful athletes. It has been observed in the past that the desired physical characteristics of American football athletes can vary drastically, with one study demonstrating fifteen separate position-specific profiles (Robbins, 2011). Due to such differences between players, if a scoring system would be developed similar to that used in the heptathlon and decathlon, separate algorithm variables would need to be calculated for each position. Considering the extensive work over the past century to create the pentathlon, heptathlon and decathlon scoring algorithms, the current study instead looks to test the validity of an existing statistical model in assessing overall performance.

Tavana (2002) outlined a relatively simple but sophisticated model called 'Euclid', which was initially designed as a tool to aid in decision-making. Essentially, the model analysed numerically formatted factors that were either beneficial or harmful to a choice, normalised them and then combined the results to form a score. The model had not been previously applied in a sporting context, but it was noticed that the underlying mechanisms could be easily extrapolated. If used in the context of the NFL Scouting Combine, the Euclid score would become a measure of how far away an athlete was from producing the best result in each of the performance tests, compared to the other athletes in the group. Previously, the most common methods used to determine an athlete's football playing ability were coaches' rankings (Barker et al., 1993; Sawyer et al., 2002), and starter status (Barker et al., 1993; Black & Roundy, 1994; Schmidt, 1999; Stuempfle, Katch & Petrie, 2003). Both methods had varying levels of success in predicting which athletes would perform the best in various athletic trials and were therefore chosen for the present study for validation of the Euclid scores. However, despite their previous use, both methods have inherent limitations. It has been suggested that the prevalence of favouritism, whether it be due to athletic prowess or compatible personalities between coaches and certain athletes, was human nature (Fraser-Thomas, Côté & Deakin, 2008). If favouritism were to exist within a team, the increased exposure between coaches and their favourite athletes may lead to biased rankings. Furthermore, when observing starting status, not only could coach preferences influence the starters of each match, but injuries could also affect an athlete's starting designation. Regardless of an individual's athletic proficiency, if a minor injury exists, coaches may be compelled to pre-empt further aggravation by resting the athlete at the start of the game. Such factors only strengthen the need to establish a more reliable and objective method of performance analysis.

The aim of the present study was to validate use of the Euclid scoring system to identify the overall best athlete, based on the results of multiple performance tests. By undertaking an NFL-style Scouting Combine with a British university American football team, Euclid scores could be ascertained and compared to the two aforementioned methods to determine validity. As an extra validation tool, the Euclid score was also compared against the competitive experience of the athletes, as this concept has yet to be explored.

3.2. Method

3.2.1. Sample selection

Following approval from the School of Life and Medical Sciences Ethics Committee at the University of Hertfordshire, the head coach of a British university American football team was contacted to approve the recruitment of their respective team's athletes into the study. Other than to be physically fit and able, athletes were required to be male, between the ages of 18-35, to be enrolled onto a British university American football team and their primary role was not being a "special teams" player (i.e. kicker, punter etc.). Prior to participation in the study, all participants gave their signed informed consent and completed a health screen questionnaire.

3.2.2. Participants

Twenty-five British university American football athletes were recruited to take part in the study. The use of coaches' rankings and starter status as analysis methods meant that athletes could only be recruited from a single team. For example, if athletes were recruited from multiple teams, there would be no guarantee that a starter on one team would still be classified as a starter when in competition with athletes from another team. When combined with the naturally smaller team rosters in the UK compared to those in the top American leagues, the number of athletes that could be recruited from each individual position was limited. Therefore, for all comparisons, athletes were grouped together into either the offensive or defensive group in accordance to their respective playing position, as opposed to, ideally, analysing positions separately. The offensive playing positions included Offensive Linemen (n =

2), Quarterback (*n* = 1), Running Backs (*n* = 6), and the Wide Receivers (*n* = 7). The playing positions in the defensive group were Defensive Backs (*n* = 6), Defensive Linemen (*n* = 1), and Linebackers (*n* = 2). Table 3.1 outlines the physical characteristics of the athletes.

Table 3.1. Physical characteristics of population (mean ± standard deviation).

	Offense (*n* = 16)	Defence (*n* = 9)
Age (years)	19.9 ± 0.9	19.8 ± 1.6
Height (cm)	180.5 ± 6.7	180.7 ± 6.4
Body mass (kg)	85.3 ± 15.3	80.1 ± 12.3
Body Mass Index (kg/m^2)	26.2 ± 4.9	24.5 ± 2.9

3.2.3. Procedures

Performance tests, suitable for field-testing, were selected from those used at the NFL Scouting Combine to form the basis of the testing battery used in the present study. Prior to participation in the performance tests, anthropometric measurements were collected from each athlete. Body weight and height were measured following the removal of shoes and any other articles of heavy clothing, using a calibrated set of weight scales and a stadiometer.

Following the performance tests, a single overall performance score was produced for each athlete by using the multi-objective analysis model 'Euclid'. Furthermore, three additional methods of performance indication were collected for the purpose of validity testing: coaches' rankings, competitive experience, and starter status. The present study followed the outlined methodology of Barker et al. (1993) in order to collect the coaches' rankings. All the offensive position coaches (*n* = 3) were asked to rank the offensive players based on their own perception of them, regardless of their individual positions. Defensive position coaches (*n* = 3) were similarly asked to do the same for their respective players. The head coach ranked both the offensive and defensive players, separately. The player that each coach perceived to have the highest football playing ability received a rank of 1, the second highest with a rank of 2 and so on, until all offensive or defensive players had been ranked. Rankings were collated from all coaches until each athlete had an average rank within their respective squad.

In order to determine competitive experience, each athlete was asked to state their current age and the age at which they began competing in the sport of American football. The difference between the two ages provided a value of competitive experience in years. Finally, the head coach was asked to provide a list of the number of games during the season each athlete had started. Those athletes who had started ≥50% of all games were further classified as starters, whereas those that started <50% of all games were classified as non-starters.

3.2.3.1. Performance testing

During the performance test battery, five stations were set up in a circuit with one test at each station. Athletes were split up into even groups, which rotated around each station in the same order, to ensure similar testing conditions for every athlete. Members of the testing staff did not rotate around the stations. Instead, they were assigned a station and instructed to stick to the specific test guidelines for each group of athletes, to maintain identical testing procedures and instruction for each group of athletes. All athletes underwent a brief 10-minute warm-up session prior to commencing the first performance test. The following tests were carried out in the order listed:

18.3-metre shuttle run (Figure 3.1). Starting in a 3-point stance, straddling the starting line (point 1), the athlete began by sprinting to touch a line 4.6 m away in one direction (point 2). As soon as the line was touched, the athlete turned to sprint in the opposite direction to touch the second line 9.1 m away (point 3). The moment that line was touched, the athlete changed direction again to sprint back through the start/finish line 4.6 m away (point 4).

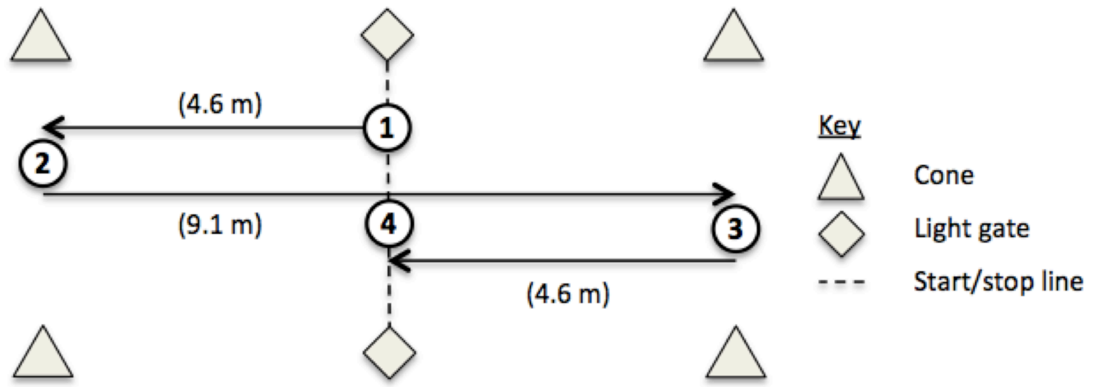

Figure 3.1. Outline of the 18.3 m shuttle run test.

Seated 3 kg medicine ball throw. Athletes were instructed to sit on the ground with their back flush against the wall, and holding a 3 kg medicine ball with two hands against their sternum. The medicine ball was then thrown as far as possible in a single outward explosive movement, with no countermovement (elbow flexion, hip extension etc.) permitted. The distance of the throw was measured from the wall to the point at where the ball first made contact with the ground.

Broad Jump. Direction was given to the athletes to perform a maximal horizontal jump with the use of countermovement and arm swing. All athletes stood with their toes on the starting line. Distance of the jump was measured from the front edge of the starting line, to the closest point at which the body made contact with the ground upon landing (usually the proximal heel strike).

Three-cone drill (Figure 3.2). Three cones positioned 4.6 m apart in the shape of an inverted "L" form the outline of the test. Starting in a 3-point stance at the first cone (point 1), athletes sprinted to touch the ground at the second cone (point 2), change direction as quickly as possibly and return and touch the start/finish line (point 3). Whilst continually moving, the athlete again turned 180° to sprint around the outside of both the second and third cone (point 4), and back again around the outside of the second cone and through the start/finish line (point 5) Athletes were not permitted to touch or move the second or third cones during the duration of the test, otherwise it resulted in the repetition of the test.

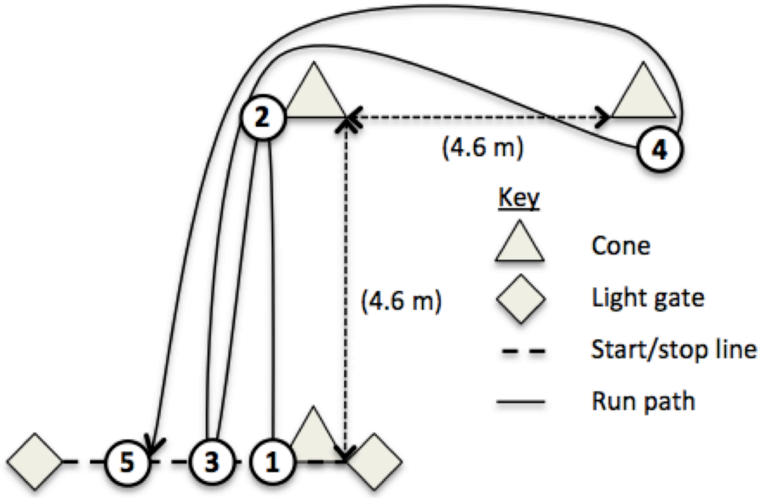

Figure 3.2. Outline for the running route of the three-cone drill.

36.6-meter dash. From a 3-point stance, without countermovement to increase the initial sprint momentum, each athlete in turn sprinted as fast as possible over a distance of 36.6 m.

The 18.3 m shuttle, the three-cone drill, and the 36.6 m dash all utilised a calibrated Brower TC (Brower Timing Systems., Draper, Utah) light gate timing system to recorded the athlete's times. The light gates were set up along the start and finish lines of each of the three aforementioned tests. Athletes performed each of the five aforementioned tests twice. A minimum rest period of two minutes was given to each athlete in-between repeated performances. The best result of the two repetitions was used during further analysis in the study. However, the 18.3-metre shuttle run was performed once when the initial sprinting direction was to their left, and once when it was to their right, the average of the two scores was calculated for later analysis.

3.2.3.2. Euclid model

For the purposes of the model, each performance test was defined as being either a minimal or maximal test depending on whether the desired outcome was a low value (the 18.3 m shuttle, the 3-cone drill and the 36.6 m dash) or a high value (the seated 3 kg medicine ball throw and the broad jump), respectively. The statistical model is comprised of two stages: the normalisation of minimal and maximal test scores and the calculation of the Euclidean distance from the ideal (being the top performer in all performance tests). The equations of the aforementioned stages are outlined below. Definitions of the symbols used in the model's equations are illustrated in table 3.2.

Table 3.2. Symbol definition for the Euclid model equations

Symbol	Definition
$\boldsymbol{n}$	Number of athletes
$\boldsymbol{m}$	Number of maximal tests
$\boldsymbol{l}$	Number of minimal tests
$\boldsymbol{x_{ij}}$	Score of maximal test j for athlete i
$\boldsymbol{y_{ij}}$	Score of minimal test j for athlete i
$\overline{\boldsymbol{x}}_{\boldsymbol{ij}}$	Normalised score of maximal test j for athlete i
$\overline{\boldsymbol{y}}_{\boldsymbol{ij}}$	Normalised score of minimal test j for athlete i
$\dot{\boldsymbol{x}}_{\boldsymbol{j}}$	Lowest score achieved for maximal test j
$\ddot{\boldsymbol{x}}_{\boldsymbol{j}}$	Highest score achieved for maximal test j
$\dot{\boldsymbol{y}}_{\boldsymbol{j}}$	Lowest score achieved for minimal test j
$\ddot{\boldsymbol{y}}_{\boldsymbol{j}}$	Highest score achieved for minimal test j
$\overline{\overline{\boldsymbol{x}}}_{\boldsymbol{i}}$	Average normalised score of all maximal tests for athlete i
$\overline{\overline{\boldsymbol{y}}}_{\boldsymbol{i}}$	Average normalised score of all minimal tests for athlete i
$\boldsymbol{D_i}$	Euclidean distance from the ideal state for athlete i

Prior to normalising the maximal and minimal performance test scores, the highest and lowest achieved scores for each test were determined. The following equations lead to the production of normalised performance tests scores.

$$\dot{x}_j = \mathrm{Min}(x_{ij};\ i = 1, \dots, n;\ j = 1, \dots, m) \qquad \dot{y}_j = \mathrm{Min}(y_{ij};\ i = 1, \dots, n;\ j = 1, \dots, l)$$

$$\ddot{x}_j = \mathrm{Max}(x_{ij};\ i = 1, \dots, n;\ j = 1, \dots, m) \qquad \ddot{y}_j = \mathrm{Max}(y_{ij};\ i = 1, \dots, n;\ j = 1, \dots, l)$$

$$\bar{x}_{ij} = \frac{x_{ij} - \dot{x}_j}{\ddot{x}_j - \dot{x}_j} \qquad \bar{y}_{ij} = \frac{y_{ij} - \dot{y}_j}{\ddot{y}_j - \dot{y}_j}$$

To produce the final overall performance score (D_i), the normalised maximal and minimal test scores ($\bar{\bar{x}}_i$ and $\bar{\bar{y}}_i$ respectively) were calculated.

$$\bar{\bar{x}}_i = \frac{\sum_{j=1}^{m} \bar{x}_{ij}}{m}\ (i = 1, \dots, n;\ j = 1, \dots, m) \qquad \bar{\bar{y}}_i = \frac{\sum_{j=1}^{l} \bar{y}_{ij}}{l}\ (i = 1, \dots, n;\ j = 1, \dots, l)$$

$$D_i = \sqrt{(\bar{\bar{x}}_i - 1)^2 + (\bar{\bar{y}}_i - 0)^2}$$

A resultant score of 0 would indicate an athlete had achieved the ideal state within the tested group of athletes by producing the best results in every test. In contrast, if an athlete were to be the worst performer in each test, they would attain the lowest possible Euclid score of 1.41.

3.2.4. Statistical analysis

The analysis was split into three sections for which to compare the Euclid method against: Euclid and starting status, Euclid and coaches' rankings, and finally Euclid and competitive experience. For each section, athlete results were assessed according to their starting status (starter or non-starter) within the offensive team and the defensive team according to their playing position. Prior to the testing, an independent samples t-test was used to determine the difference in competitive experience between starters and non-starters in order to assess validity in the present study. Throughout the first section of analysis, independent samples t-tests were used to identify the differences between starting status in respect to Euclid score, and the results of each performance test. In the second section, Pearson's product-moment correlation coefficients (r) were utilised to determine the linear relationship between the Euclid scores of athletes and their coaches' ranking and between the performance test results and the coaches' rankings. In the final section of analysis, Pearson's coefficients were used to determine the relationship between competitive experience and the Euclid scores and the relationship between competitive experience and the performance test results. All statistical tests were performed with the statistical Package for Social Sciences (SPSS, version 21, Armonk, NY). The significance level for all statistical tests was set at $p \leq 0.05$. Data is expressed as mean ± standard deviation.

3.3. Results

3.3.1. Competitive experience

The difference in competitive experience of starter and non-starter athletes within offensive positions, defensive positions, and the whole team are presented in table 3.3. The strongest level of significance was observed when comparing the competitive experience between starting status within the whole team ($p<0.001$).

Table 3.3. Comparison of competitive experience between starters and non-starters.

	Starter		Non-starter	
	n	Comp. exp. (years)	*n*	Comp. exp. (years)
Offense	6	5.40 ± 3.78	10	1.67 ± 0.82
Defence	4	4.33 ± 1.53*	5	0.60 ± 0.22
Whole team	10	5.00 ± 3.02†	15	1.18 ± 0.82

* = Significant difference compared to non-starters ($p<0.05$); † = significant difference compared to non-starters ($p<0.001$)

3.3.2. Euclid and starting status

The starting offensive athletes (n = 6) scored an average Euclid score of 0.68 ± 0.30 which was not significantly different compared to the average Euclid score of the offensive non-starter athletes 0.72 ± 0.17 ($p = 0.799$). The starting defensive athletes (n = 4) on the other hand, scored an average Euclid score significantly ($p = 0.045$) lower than the defensive non-starter athletes (0.50 ± 0.31 and 0.95 ± 0.25 respectively). Tables 3.4 and 3.5 show the difference between starters and non-starters for the offensive and defensive athletes in each performance test.

Table 3.4. Differences between average test results of the offensive starters and non-starters

Variable	Starter (n = 6)	Non-starter (n = 10)
Broad jump (cm)	240.50 ± 36.77	259.20 ± 19.07
Medicine ball throw (cm)	584.17 ± 51.42*	507.00 ± 73.53
18.3-meter shuttle run	4.81 ± 0.32	4.92 ± 0.21
Three-cone drill	7.84 ± 0.62	7.87 ± 0.26
36.6-metre dash	5.38 ± 0.49	5.30 ± 0.13

* = Significant difference compared to non-starters ($p<0.05$)

Table 3.5. Differences between average test results of the defensive starters and non-starters

Variable	Starter (n = 4)	Non-starter (n = 5)
Broad jump (cm)	269.25 ± 45.88	232.00 ± 23.80
Medicine ball throw (cm)	583.75 ± 29.26*	470.00 ± 60.31
18.3-meter shuttle run	4.71 ± 0.30	5.10 ± 0.32
Three-cone drill	7.66 ± 0.66	8.10 ± 0.39
36.6-metre dash	5.03 ± 0.23*	5.51 ± 0.34

* = Significant difference compared to non-starters ($p<0.05$)

3.3.3. *Euclid and coaches' rankings*

When the Euclid scores of the Offensive athletes (n = 16) were compared with the respective coaches' rankings, there was a no significant correlation (r = 0.130, p = 0.632). Furthermore, the relationship between the defensive athlete Euclid scores (n = 9) and their coaches' rankings also showed no correlation, (r = 0.625, p = 0.720). When the offensive and defensive rankings were correlated against the performances of each performance test, the only statistically significant result came between the defensive athletes and the results of the medicine ball throw (r = -0.724, p = 0.028).

3.3.4. Euclid and competitive experience

The Euclid scores of both offensive and defensive starter athletes demonstrated significant relationships with competitive experience, with near perfect correlations (r = 0.922, p = 0.026 and r = 0.999, p = 0.022 respectively). In contrast, the offensive and defensive non-starters showed no correlation between competitive experience and Euclid score (r = 0.340, p = 0.510 and r = 0.551, p = 0.335 respectively). Table 3.6 and 3.7 outline the relationships between competitive experience and performance test results for the starters and non-starters of the offensive and defensive athletes respectively.

Table 3.6. The relationship between performance test results and competitive experience of the offensive athletes (n = 16).

	Starter (n = 6)		Non-starter (n = 10)	
Variable	Correlation (r)	Significance (p)	Correlation (r)	Significance (p)
Broad jump (cm)	-0.867	0.057	-0.196	0.709
Medicine ball throw (cm)	0.124	0.843	-0.351	0.495
18.3-meter shuttle run	0.861	0.061	0.509	0.302
Three-cone drill	0.773	0.126	0.001	0.999
36.6-metre dash	0.955	0.011*	0.149	0.778

* = Significant relationship compared to non-starters (p<0.05)

Table 3.7. The relationship between performance test results and competitive experience of the defensive athletes (n = 9).

	Starter (n = 4)		Non-starter (n = 5)	
Variable	Correlation (r)	Significance (p)	Correlation (r)	Significance (p)
Broad jump (cm)	-0.983	0.117	-0.611	0.274
Medicine ball throw (cm)	-0.908	0.275	-0.693	0.195
18.3-meter shuttle run	0.828	0.379	0.202	0.745
Three-cone drill	0.968	0.162	0.259	0.674
36.6-metre dash	0.839	0.367	0.219	0.724

3.4. Summary

The current chapter analysed a method able to produce a single overall score from the results of multiple performance tests. The Euclid method was effectively a measure of distance an athlete was from being the top performer in each test, also known as 'the ideal state'. Therefore, the individual with the lowest Euclid score would theoretically be the best overall athlete, having consistently performed best over the most performance tests. If validated, the Euclid performance score could be an invaluable tool, not only for coaches to identify the best athletes to recruit/start, but also for individuals to track their athletic development and set more specific training programmes. Previous research had investigated the use of starting status (Barker et al., 1993; Black & Roundy, 1994; Schmidt, 1999; Stuempfle, Katch & Petrie, 2003) and coaches' rankings (Barker et al., 1993; Sawyer et al., 2002) in the context of determining success among American football athletes; however, until now competitive experience had not been explored. In an attempt to justify the use of Euclid scores in further research, the current study assessed the scores alongside the starting status, the coaches' rankings, and the competitive experience of athletes.

Numerous studies have identified the prevalence of significant differences between starters and non-starters in terms of performance test results (Barker et al., 1993; Black & Roundy, 1994; Schmidt, 1999; Stuempfle, Katch & Petrie, 2003). However, in each study there failed to be any differentiation between the offensive and defensive athletes, only analysis as a whole team. During present study, it was found that the Euclid scores for both the offensive and defensive starters were lower than their respective non-starters, however significance ($p = 0.045$) was only observed between the defensive starters (0.50 ± 0.31) and defensive non-starters (0.95 ± 0.25). In all three of the analysis areas, the most positive results were observed among the defensive athletes compared to the offensive athletes, with higher correlations being found in regards to the Euclid score and coaches' rankings, and also with the Euclid score and competitive experience. Barker et al. (1993) suggested that the starting status of athletes might have been related to an athlete's training experience. When competitive experience of starters and non-starters were compared in the present study, it was found that there was again a significant difference between the defensive starters and non-starters, but not between the offensive starters and non-starters. Thus, demonstrating that in some cases, coaches in the present study may have had more confidence starting the experienced athletes rather than the most athletically talented ones.

When the present study correlated coaches' rankings and Euclid scores, no significant relationship was found for either the offensive or the defensive athletes. Barker et al. (1993) found that coaches' rankings correlated most strongly to performance test results if athletes were on the first team roster. Therefore, the poor correlations seen in the present study, between coaches' rankings and the Euclid score could be due to the fact that the majority of the athletes were non-starters whose on-field athletic capabilities would be less exposed to the coaches. In an attempt to minimise the earlier described subjectivity of coaches' rankings, three offensive and three defensive coaches contributed towards the averaged rankings.

There was a significant difference observed between starter and non-starters in the medicine ball throw where the defensive starters significantly outperformed the defensive non-starters (p = 0.011). Furthermore, the defensive coaches' rankings displayed a very large and significant correlation with the distances thrown (r = -0.724, p = 0.028). These observations confirm similar results found by Schmidt (1999) and Sawyer et al. (2002). Schmidt (1999) found that Division III starters (offensive and defensive players combined) (n = 35) performed significantly (p<0.05) better than the non-starters (n = 43) in the seated medicine ball put and also in two other upper body power tests. When Sawyer et al. (2002), correlated offensive and defensive coaches' rankings with performance test results, only three of the eight tests showed a significant correlation. Two of the tests were related to upper body strength and power and significance was only observed for the defensive athletes, similarly to the present study where the defensive athletes displayed the strongest correlations in all tests. The reason for this occurrence would most likely be due to the greater need of defensive athletes to utilise upper body strength in competitive situations to tackle the offensive players and drag them to the ground as quickly as possible.

The final section of analysis produced the greatest support for use of the Euclid score. Both offensive and defensive starters displayed strong correlations between the Euclid scores and years of competitive experience (r = 0.922, p = 0.026; r = 0.999, p = 0.022). A possible explanation was strong correlations found between the individual performance test results and years of competitive experience. However, the Euclid scores of both the offensive and defensive non-starters failed to correlate significantly against their competitive experience (r = 0.340, p = 0.510; r = 0.551, p = 0.335). As competitive experience has yet to be researched in such a context, it is difficult to make conclusions from the results of the present study. However, it was promising to see that for the offensive starters, the strongest correlations were observed between competitive experience and the sprinting and agility tests (36.6 m sprint r = 0.955, p = 0.011; 18.3 m shuttle run r = 0.861, p = 0.061), while the strongest defensive correlations occurred during the explosive strength tests (broad jump r = -0.983, p = 0.117; medicine ball throw r = -0.908, p = 0.275) as well as the shorter sprint and agility trial (three-cone drill r = 0.968, p = 0.162). This may reflect importance of the offensive positions to burst off the line of scrimmage and sprint long distances to get behind and away from the defensive players. It also reflects that shorter sprint bursts are required for the defensive positions in combination with the requirement to utilise upper body strength for tackles.

A major limitation of using both coaches' rankings and starting status was the constraint of the ability to only recruit athletes from a single team. If multiple teams were used, there would be no guarantee that a starter on one team would still be classified a started among the extra group of athletes. A similar conflict would exist in the coaches' rankings, whereby there would be no guarantee that the top ranked player of one team would still be one of the best when combined with athletes of another team. In addition, coaches would only be familiar enough with their own athletes to be able to produce accurate rankings; thus, if multiple teams were recruited, any attempt at combining multiple sets of coaches' rankings would further compromise their validity. This restriction greatly reduced the maximum number of athletes that could potentially be recruited and this may in part reflect the popularity and structure of American football at universities in this country.

In Great Britain, the British Universities & Colleges Sport (BUCS) is the national governing body for higher education sport, comprised of 170 institutions (BUCS, 2013a) with only 41.2% (n = 77) having an American football team (BUCS, 2013b). However, in the United States of America, the National Collegiate Athletic Association (NCAA) is the athletic governing body, comprised of three divisions. The most elite of the three is Division I, made up of 340 member schools whereby 71.2% (n = 242) offer an American football programme (NCAA, 2013). The NCAA (2013) went on to state that 26,325 athletes were participating in Division I American football programmes alone, equating to an average of 108.8 athletes per team. Although BUCS have not publically released similar information regarding the number of athletes participating in BUCS American football, after conversations with one head coach, British collegiate American football rosters rarely exceed a maximum of 80 athletes per team, which is at best 25.9% fewer players compared to NCAA Division I teams. Therefore, due to the comparison methods chosen for the present study, a low number of athletes were recruited, which consequently lead to low sample sizes, for example, when analysing defensive starters (n = 4) or defensive non-starters (n = 5).

A final limitation of the presented Euclid score is its exclusion of cognitive assessments. If two athletes were to demonstrate very similar physical capabilities, it is undeniable that a coach would take into consideration extra factors such as the tactical aptitude of each individual to determine the better overall athlete. Due to the confidential nature of the Wonderlic Cognitive Ability Test, which is administered to athletes at the NFL Scouting Combine, previous research has had to rely on unofficial reported scores from various news outlets. Despite having been included in the Scouting Combine's test battery since the 1970s, one study that correlated the test scores against success measures (NFL Draft order, NFL salary, games played, and yards per carry/reception or quarterback rating) found only 2 significant results out of the 30 observed (Kuzmits & Adams, 2008). Further research into Wonderlic-style tests would be needed before cognitive assessments could reliably contribute towards a Euclid performance score.

In conclusion, the results of the present study suggest further investigation is required into the use of a Euclid score to assess combine performances. When the Euclid scores were evaluated in conjunction with starter status, coaches' rankings and competitive experience, a total of three of the eight results (Euclid score of defensive starters vs. the Euclid score of defensive non-starters; competitive experience of offensive starters against Euclid scores; competitive experience of defensive starters against Euclid scores) were significant. Based on the current findings, the Euclid model would be a valid tool for coaches and scouts to implement in order to determine the most athletic individuals, following the results of an NFL Scouting Combine, i.e. the players that are most likely to be starters. As comparison between methods of starter status and coaches' rankings limited subject recruitment to one team, the Euclid model may be an effective method to enable future researchers to recruit from multiple teams and consequently investigate relationships and differences between individual playing positions. Finally, the present study has shown that the Euclid model can produce a performance score for a group of athletes without the need for complex population and test-specific algorithms. Therefore, it can be used at any level of competition, such as with grassroots athletes and could easily be adapted to incorporate a different combination of performance tests, which perhaps more accurately meet the requirements of the population.

Chapter 4 – The relationship between the nutrition knowledge and Euclid score of collegiate American football athletes

4. Introduction

There is an absence of scientific research examining British Collegiate American Football (AF) athletes, especially in regards to the relationship between nutrition and performance. The concept that an athlete's diet could influence consequent athletic performance has been well documented among international position stands (American Dietetic Association, Dietitians of Canada & American College of Sports Medicine, 2009; International Olympic Committee, 2011). American universities have even begun to acknowledge the advantage of hiring full-time sports nutritionists to help athletes gain maximum benefit from workouts and recover faster in order to gain a competitive edge (Shattuck, 2001). However, despite the potential impact, nutritional misconceptions have been frequently observed amongst athletic populations (Jacobson, Sobonya & Ransone, 2001; Rosenbloom, Jonnalagadda & Skinner, 2002; Wiita, Stombaugh & Buch, 1995). Although, to date, the standard of nutrition knowledge among British collegiate American football athletes has yet to be investigated with the use of a valid and reliable nutrition knowledge questionnaire.

Previous research into the area of nutrition knowledge and its influence on dietary behaviour has largely been somewhat contradictory. Studies by Wardle, Parmenter and Waller (2000) and Worsley (2002) asserted that nutrition knowledge could be crucial in prompting healthy dietary patterns. However, more recently Heaney et al. (2011) conducted a systematic review of nutrition knowledge research and determined that the true impact was unclear from past work. This has prompted further exploration into the area, as many of the tools used to determine nutrition knowledge often lack the rigorous reliability and validation tests prior to implementation (Heaney et al., 2011). It stands to reason, that an increased awareness of what constitutes healthy or unhealthy food could influence athletes to reassess their eating habits and potentially influence performance. Three dietary practices that may impact sporting performances are: fuelling, recovery, and training adaptations (Slater & Philips, 2011). If an athlete were unaware of basic sport nutrition principles and the importance that carefully planned out dietary plans could potentially have on performance, they may be susceptible to such adverse effects as unwanted weight gains.

One of the most frequent methods of assessing obesity in a population has been through the measurement of Body Mass Index (BMI). Nevill et al. (2006) stated that BMI unreliably represented accurate adiposity levels, which consequently meant that due to increased muscle mass, collegiate American football athletes were commonly being misclassified as overweight or obese (Ode, Pivarnik, Reeves & Knous, 2007). Matthews and Wagner (2008) agreed with the statement, finding that more than 50% of Division I football athletes had been over-classified as overweight or obese, when compared with body fat percentage measurements. A common theme of the research investigating BMI and body fat percentage in Division I football athletes, was that the OL position consistently displayed the highest mean BMI (Kaiser et al., 2008; Matthews & Wagner, 2008; Noel, VanHeest, Zaneteas & Rodgers, 2003) and the highest mean body fat percentage (Kaiser et al., 2008; Matthews & Wagner, 2008) of all the playing positions.

However, body fat percentage may not always be a practical method for use in field-testing. The leading methods for determining body fat percentage rely on either a power source being present (Bioelectrical impedance analysis, Dual-energy x-ray absorptiometry, Bod Pod), an underwater testing environment (hydrostatic weighing), or lengthy time demands (skinfold measurements). An alternative, time-efficient method that has also been shown to explain obesity related health risks was the measurement of waist circumferences (Janssen, Katzmarzyk & Ross, 2004). When Matthews and Wagner (2008) reported waist circumference measures of Division I football athletes, the OL position achieved the highest mean results compared to the other positions. Due to the abundance of research reporting the OL position as a population at risk for obesity-related diseases, it would be important to discover in the present study if nutrition knowledge strongly correlates with BMI or waist circumference measures.

Robbins (2012) stated that in America, physical testing batteries were implemented at both the collegiate and professional levels to help monitor the training adaptations of athletes. The most commonly utilised battery in American football mimicked that of the National Football League (NFL) Scouting Combine (Stodden & Galitski, 2010). The Scouting Combine is a testing camp where prospective NFL rookies go to showcase their talents to professional team scouts, by undertaking multiple field tests (McGee & Burkett, 2003; Robbins, 2012). Associations had been made between performance test outcomes and overall football playing ability (Davis et al., 2004; Ghigiarelli, 2011; Sawyer, Ostarello, Suess & Dempsey, 2002). However, as previous research had failed to quantify football playing ability into a single score, true relationships between performance and external variables are difficult to determine accurately.

The first objective of the current chapter was to implement the validated nutrition knowledge questionnaire, presented in Appendix 2, among a group of British collegiate American football athletes. The main aims of the questionnaire were: to determine the standard of nutrition knowledge among British collegiate American football athletes, understand their primary sources of nutrition information and to find out what the biggest influences were on day-to-day dietary habits. The second objective was to perform an NFL-style Scouting Combine performance assessment on British collegiate American football athletes and to utilise the Euclid scoring system to determine overall performance scores for each athlete. The final aim was to compare the nutrition knowledge scores with the Euclid scores to determine whether a relationship existed between the two variables.

4.2. Method

4.2.1. Sample selection

Following approval from the School of Life and Medical Sciences Ethics Committee at the University of Hertfordshire, the head coach of two British university American football teams were contacted to approve the recruitment of their respective team's athletes into the study. Other than to be physically fit and able to exercise, athletes were required to be male, between the ages of 18-35, to be enrolled onto a British university American football team and their primary role was not allowed to be a "special teams" player (i.e. kicker, punter etc.). Prior to participation in the study, all participants gave their signed informed consent and completed a health screen questionnaire.

4.2.2. Participants

Thirty-three British university American football athletes were recruited to take part in the study. The athletes were recruited from teams that reached the national playoffs at the end of the season. The average amount of competitive experience for the whole group of athletes was 2.74 ± 2.50 years. Table 4.1 outlines the physical characteristics of the athletes.

Table 4.1. Physical characteristics of population (mean ± standard deviation)

Position	*n*	Age (years)	Competitive exp. (years)	Height (cm)	Body mass (kg)
DB	9	19.8 ± 1.5	2.17 ± 1.89	179.66 ± 5.05	75.88 ± 8.14
DL	5	20.6 ± 1.8	2.80 ± 2.14	186.40 ± 4.83	102.36 ± 6.49
LB	3	21.6 ± 1.5	3.17 ± 2.75	179.03 ± 6.03	83.13 ± 1.89
OL	4	19.5 ± 1.2	6.75 ± 4.03	174.50 ± 8.67	102.08 ± 16.23
RB	6	19.6 ± 1.0	1.42 ± 0.92	180.88 ± 7.48	89.70 ± 10.70
WR	6	20.0 ± 0.8	2.00 ± 0.89	182.78 ± 4.98	77.87 ± 8.49

BMI = Body Mass Index; DB = Defensive Back; DL = Defensive Lineman; LB = Linebacker; OL = Offensive Lineman; RB = Running Back; WR = Wide Receiver.

4.2.3. Procedures

The procedures of the current study were broadly categorised into two areas: performance assessment and the evaluation of nutrition knowledge. Anthropometric measurements including height, body mass, Body Mass Index (BMI) and waist circumference were collected from each athlete prior to the performance tests. Body weight and height were measured following the removal of shoes and any other articles of heavy clothing, using a calibrated set of weight scales and a stadiometer. Waist circumference was measured around the narrowest part of the torso, located above the umbilicus, but below the xiphoid. As two university teams were used, two separate performance assessments were conducted.

Following the performance tests, the multi-objective analysis model 'Euclid' was used to combine the results of each athlete, which produced a single overall performance score per athlete. In the days following the performance assessment, each athlete was reminded to complete the second part of the study, which was a nutrition knowledge questionnaire administered online. A time limit of two weeks was set for the athletes to complete the questionnaire, in an attempt to record the knowledge and performance measures in close proximity.

4.2.3.1. Performance testing

During the performance assessment, five stations were set up in a circuit with one test at each station. Within the team, athletes were split up into even groups that rotated around each station in the same order, to ensure similar testing conditions for every athlete. Testing staff were assigned to a station and instructed to stick to the specific test guidelines for each group of athletes, to maintain identical testing procedures and instruction. All athletes underwent a brief 10-minute warm-up session prior to commencing the first performance test. The tests were conducted in the following order:

1. 18.3-metre shuttle run
2. Seated 3 kg medicine ball throw
3. Broad jump
4. Three-cone drill
5. 36.6-metre dash

The testing procedures were the same as those previously outlined in section 3.1.3.1 of the present thesis. The 18.3 m shuttle, the three-cone drill, and the 36.6 m dash all utilised a calibrated Brower TC (Brower Timing Systems., Draper, Utah) light gate timing system to recorded the athlete's times. The light gates were set up along the start and finish lines of each of the three aforementioned tests.

Athletes performed each of the five aforementioned tests twice. A minimum rest period of two minutes was given to each athlete in-between repeated performances. The best result of the two repetitions was used during further analysis in the study. However, the 18.3-metre shuttle run was performed once when the initial sprinting direction was to their left, and once when it was to their right, the average of the two scores was calculated for later analysis.

4.2.3.2. Euclid model

The Euclid methodology was outlined in section 3.1.3.2 of the present thesis.

4.2.3.3. *Evaluation of nutrition knowledge*

The evaluation of each athlete's nutrition knowledge was achieved with the use of the validated questionnaire (Appendix 2). This tested the knowledge of the athletes in relation to fundamental sport nutrition concepts. It encompassed twenty-three questions, divided into five nutrition subsections: micronutrients, macronutrients, hydration, recovery, and supplements. All questions were close-ended, whereby respondents either indicated their agreement towards a statement, or selected a response from a multiple-choice list. Each correct response earned one point towards the overall knowledge score.

An extra section was added to determine some background information about each athlete. The additional questions asked the level at which they had been formally educated in relation to sport nutrition, where they primarily sought their nutrition education from, who/what most influenced their day-to-day dietary habits and if they participated in consuming dietary supplements to aid performance.

4.2.4. *Statistical analysis*

Differences between playing positions for average BMI and waist circumference were determined using one-way ANOVAs. To assess the relationship between the two anthropometric measures and overall performance, Pearson's product-moment correlation coefficients (r) were performed. The same correlation coefficient tests were used to determine the relationship between nutrition knowledge and the Euclid performance scores. For analysis, athletes were grouped by playing position, as offensive or defensive players and also as a whole group. Finally, a one-way ANOVA was again used to determine if there were statistically significant differences of nutrition knowledge scores between athletes with differing day-to-day dietary influences and sources of nutrition information. All statistical analyses were performed with the Statistical Package for Social Sciences (SPSS, version 21, Armonk, NY). The significance level for all tests was set at $p \leq 0.05$. Data is expressed as mean ± standard deviation.

4.3. Results

4.3.1. Anthropometry

When BMI and waist circumferences were assessed, the OL position possessed the highest average of both variables (33.49 ± 4.82 kg/m^2, 103.88 ± 11.64 cm respectively), which were also significantly different ($p < 0.05$) compared to all other positions except for the Defensive Linemen (DL). In total, six inter-positional significances were observed for each variable. The significances observed for BMI were the same when waist circumferences were analysed. The means and standard deviations for each playing position's BMI and waist circumferences are shown in table 4.2.

Table 4.2. Average Body Mass Index (BMI) and waist circumferences by playing position (mean ± standard deviation).

Position	BMI (kg/m^2)	Waist circumference (cm)
Defensive Backs ($n = 9$)	$23.47 \pm 1.85^{a,b}$	$79.72 \pm 3.13^{a,b}$
Defensive Linemen ($n = 5$)	29.45 ± 1.28^{d}	95.86 ± 6.38^{d}
Linebackers ($n = 3$)	26.02 ± 2.40^{b}	86.10 ± 2.42^{b}
Offensive Linemen ($n = 4$)	$33.49 \pm 4.82^{c,d}$	$103.88 \pm 11.64^{c,d}$
Running Backs ($n = 6$)	27.36 ± 2.10	85.33 ± 5.74
Wide Receivers ($n = 6$)	23.38 ± 3.08	80.92 ± 4.94

Significantly ($p < 0.05$) different from: [a]Defensive linemen; [b]Offensive linemen; [c]Running Backs; [d]Wide Receivers.

4.3.2. Nutrition knowledge and BMI

When the relationship between BMI and nutrition knowledge were examined, no significant relationships were observed either as a whole team, by offensive or defensive teams, or when analysed by individual playing positions.

4.3.3. Nutrition knowledge and waist circumference

Despite showing the same mean inter-positional significances as BMI, significant relationships were observed to exist between waist circumference and nutrition knowledge scores. Waist circumference and nutrition knowledge showed a significant correlation, with higher waist circumferences associated with poorer knowledge scores (r = -0.374, p = 0.032). However, when athletes were separated by offensive or defensive positions, no significant relationships were observed (r = -0.468, p = 0.067; r = -0.192, p = 0.460 respectively). When analysed by position, only the offensive linemen exhibited a significant relationship, which was highly correlated (r = -0.975, p = 0.025). Table 4.3 outlines the relationships between waist circumference and nutrition knowledge for each playing position.

Table 4.3. Relationship between nutrition knowledge and waist circumference, by playing position.

Position	Correlation (r)	Significance (p)
Defensive Backs (*n* = 9)	-0.018	0.962
Defensive Linemen (*n* = 5)	-0.359	0.553
Linebackers (*n* = 3)	0.500	0.667
Offensive Linemen (*n* = 4)	-0.975	0.025*
Running Backs (*n* = 6)	0.629	0.181
Wide Receivers (*n* = 6)	-0.262	0.616

* = Significant relationship (p<0.05)

4.3.4. Nutrition knowledge and Euclid scores

The mean nutrition knowledge score for the whole group of athletes was identified as 9 ± 4, out of a maximum score of 23, representing an average result of 40.8%. No athletes achieved a score of 23. When analysed by offensive and defensive teams, average scores marginally changed to 9 ± 5 and 10 ± 4 respectively, which were not significantly different (p = 0.476). The mean Euclid scores for the whole group of athletes was 0.71 ± 0.26. The mean Euclid scores of the offensive and defensive athletes were (0.71 ± 0.29 and 0.71 ± 0.23 respectively). Table 4.4 details the average nutrition knowledge and Euclid performance scores divided into playing position.

Table 4.4. Average nutrition knowledge and Euclid performance scores, by playing position (mean ± standard deviation).

Position	Nutrition knowledge score	Euclid performance score
Defensive Backs (*n* = 9)	11 ± 5	0.72 ± 0.32
Defensive Linemen (*n* = 5)	9 ± 5	0.69 ± 0.32
Linebackers (*n* = 3)	10 ± 1	0.71 ± 0.21
Offensive Linemen (*n* = 4)	4 ± 3	0.95 ± 0.08
Running Backs (*n* = 6)	11 ± 5	0.53 ± 0.16
Wide Receivers (*n* = 6)	9 ± 4	0.72 ± 0.20

4.3.5. Nutrition knowledge and performance relationship

When analysed as a whole group, no significant relationship was observed between nutrition knowledge scores and the Euclid performance scores (r = -0.221, p = 0.216). When athletes were grouped by their offensive or defensive playing positions, the defensive athletes displayed no significant relationship (r = 0.112, p = 0.669), but the offensive athletes produced a statistically significant relationship between the nutrition knowledge and Euclid scores (r = -0.610, p = 0.012). Table 4.5 shows the relationship between nutrition knowledge scores and Euclid scores when athletes were grouped by playing position. Only the WR position demonstrated a significant negative relationship, between nutrition knowledge and Euclid scores.

Table 4.5. Relationship between nutrition knowledge and Euclid scores, by playing position.

Position	Correlation (r)	Significance (p)
Defensive Backs (*n* = 9)	-0.910	0.815
Defensive Linemen (*n* = 5)	0.438	0.460
Linebackers (*n* = 3)	0.898	0.291
Offensive Linemen (*n* = 4)	-0.147	0.853
Running Backs (*n* = 6)	-0.120	0.822
Wide Receivers (*n* = 6)	-0.921	0.026*

* = Significant relationship between nutrition knowledge and Euclid scores (p<0.05)

4.3.6. Dietary influences and sources of knowledge

When athletes were asked what had the greatest influence on their day-to-day dietary habits, forty-two percent (*n* = 14) stated "family members", twenty-seven percent (*n* = 9) stated "friends", nine percent (*n* = 3) stated "themselves" or "other", six percent (*n* = 2) chose the "internet", and three percent (*n* = 1) selected either their "lecturer" or "coach". When the average nutrition knowledge scores were categorised according to the reported day-to-day influences, no significant differences were found between the groups (*p* = 0.410).

Furthermore, athletes were questioned where they primarily received their nutrition information. Figure 4.1 depicts the mean nutrition knowledge scores of the athletes when grouped by their reported primary sources of information, those who primarily gained nutrition information from lecturers scored significantly higher on the questionnaire than those that sought it from family members (*p* = 0.040) or friends (*p* = 0.008).

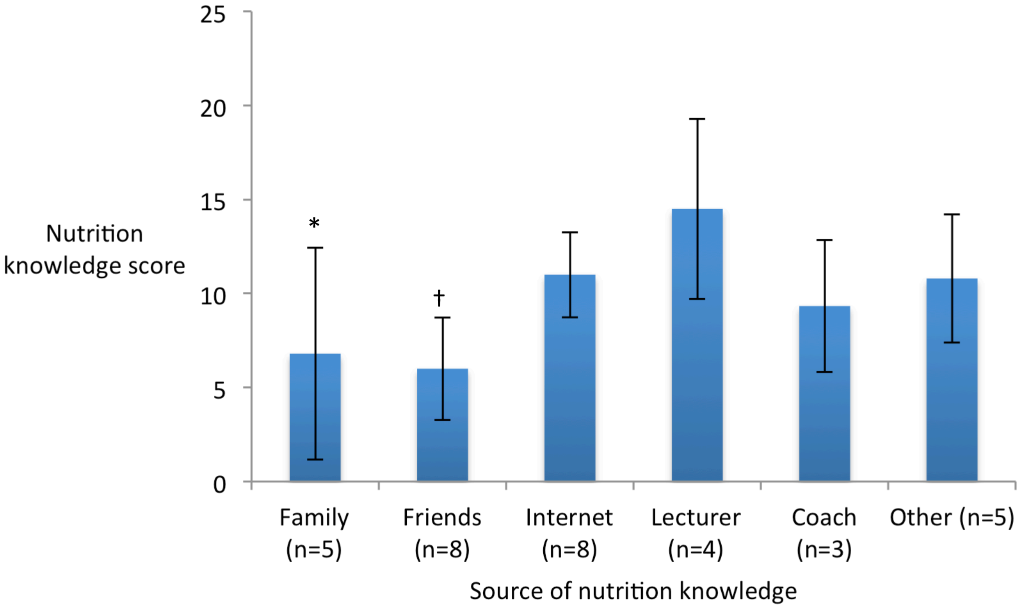

Figure 4.1. Mean nutrition knowledge scores grouped by the athlete's reported primary source of information. * = Significantly different to "lecturer" category (*p* = 0.040); † = significantly different to "lecturer" category (*p* = 0.008).

4.4. Summary

This study is the first to document the relationship between nutrition knowledge and overall performance capabilities of American football athletes, despite an abundance of research investigating the two variables separately. One factor that has negated such a comparison was the ability to define the overall performance capabilities of an athlete into a single figure. However, in the present study, development of the Euclid scoring system solved this issue. Previous investigations have either examined relationships between individual performance test results (Black & Roundy, 1994; Schmidt, 1999), or against subjective methods of determining athletic prowess, such as through coach rankings (Barker et al., 1993; Sawyer et al., 2002).

When nutrition knowledge scores were correlated against Euclid scores, despite no significant relationship for the group as a whole (r = -0.221, p = 0.216), significance was detected when the offensive positions were grouped (n = 16; r = -0.610, p = 0.012). The significant negative correlation observed among the offensive players represented that as nutrition knowledge scores increased Euclid scores became closer to an ideal state. Such significance could be explained by the average nutrition knowledge of each position within the offensive group. The offensive group contained both the RB and OL playing positions, that respectively scored the highest and lowest average knowledge scores among all six playing positions, for both the nutrition knowledge and Euclid performance scores. The group also comprised players in the WR position, who displayed a significant relationship between knowledge and performance (r = -0.921, p = 0.026); however reasons for the significant relationship remain unclear. One possible reason for the overall poor display of significance is the competitive standards to which the athletes of the current study participate. In Great Britain, it is common practice for collegiate American football teams to recruit athletes into their starting line-up regardless of their previous experience playing the sport prior to attending university, as was reflected by the average competitive experience of 2.7 ± 2.5 years. The present study's findings in relation to competitive experience reflected those shown in previous research. Clemo, Kass and Jacobson (2012) showed that British collegiate American football athletes had significantly less competitive experience (2.0 ± 2.3 years) compared to Division I football athletes (10.6 ± 3.3) ($p < 0.001$). In both the present study and that of Clemo, Kass and Jacobson (2012), the standard deviation of British collegiate American football athletes almost matches that of the amount of experience itself, suggesting that many athletes may be in the team despite no previous competitive experience at all.

In all previous studies observing the nutrition knowledge of American football athletes, scores had simply been reported as a whole team, rather than by position (Clemo, Kass & Jacobson, 2012; Jonnalagadda et al., 2001; Rosenbloom et al., 2002). However, there may be a need to do so in the future if certain positions, such as the OL, are determined to be specifically at risk of the dangers of poor nutrition knowledge. It has been frequently noted that the morphological profiles of American football athletes can vastly differ between playing positions (Kaiser et al., 2008; Matthews & Wagner, 2008). Previous observations, also reflected in this study are that the OL position has the highest average BMI of the team and this has been seen at both collegiate level (Kaiser et al., 2008; Matthews & Wagner, 2008) and also at the professional level (Kraemer et al., 2005; Tucker et al., 2009). The present study failed to find any significant relationships between BMI and nutrition knowledge, however the use of BMI among athletic populations has been considered controversial through previous studies (Matthews & Wanger, 2008; Ode et al., 2007). Janssen, Katzmarzyk and Ross (2004) stated that in actual fact, waist circumference was a stronger predictor of health related factors such as type 2 diabetes, cardiovascular disease, and strokes, compared to BMI. An important finding of the present study was the significant relationship observed between the waist circumference of the OL athletes and their nutrition knowledge scores (r = -0.975, p = 0.025). In order to be successful in the OL position, athletes are generally required to have a high inertia to primarily help block players on the opposing team from getting past them. The significance observed suggests that individuals in the OL position may have an unhealthy waist circumference due to their poor knowledge of nutrition. Due to the fact the other studies have not begun to report nutrition knowledge results by playing position, the current study is unable to determine whether or not other athletes competing at the OL position are equally unaware of sports nutrition concepts. When previous nutrition knowledge research on American collegiate American football athletes has been implemented, participant numbers have been consistently higher that of the present study (Clemo, Kass & Jacobson, 2012: n = 99; Rosenbloom, Jonnalagadda & Skinner, 2002: n = 111) and would be more suitable to analyse knowledge by playing position. The small number of athletes per position in the present study inhibits the validity of any conclusive statements made in relation to specific positions. However, based on the preliminary findings of OL nutrition knowledge and waist circumference, it would be recommended that athletes whose success partially depends on a high body mass are targeted with nutrition education interventions, to inform them about risks of high body weight. Future research should look to implement similar methodology used in the present study on Division I collegiate American football athletes, to ensure a high number of athletes are recruited from each playing position. Where possible, future research should also look to observe body fat percentage measurements alongside nutrition knowledge scores, as opposed to BMI or waist circumferences.

Furthermore, previous research had attributed poor nutrition knowledge of athletes to the unreliable sources from which they primarily gained nutrition information (Jacobson & Gemmell, 1991). Multiple studies have observed that American athletes reported athletic coaches and trainers as a common source of nutrition information (Burns, Schiller, Merrick & Wolf, 2004; Froiland, Koszewski, Hingst & Kopecky, 2004; Jacobson, Sobonya & Ransone, 2001). However, Jacobson and Gemmell (1991) found that most coaches actually had little or no formal sports nutrition training. A more recent study concluded that from a large sample of premier club rugby coaches (*n* = 168), the majority (83.8%) would give nutritional advice to their players, despite being inadequately prepared to do so, due to insufficient nutrition training (Zinn, Schofield & Wall, 2006). However, the findings from the present study differ from those implemented on American athletes, with only 9% (*n* = 3) of the British athletes stating coaches as their primary source of information. The top three sources instead consisted of friends (24%, *n* = 8), the Internet (24%, *n* = 8), and family members (15%, *n* = 5). The differences between cultures was expected, as it is more common for American football coaches to be employed on a full-time basis throughout the American Division I, compared to the limited part-time employment of British collegiate American football coaches. The difference in employment status may limit how much contact the British athletes have with their coaches. Thus, the coach-athlete relationship may not be as strong compared to the American athletes, although this is speculative, as previous research has failed to investigate such differences.

When sources of information were evaluated in conjunction with nutrition knowledge scores, it was found that the two most common sources (friends and family) lead to those athletes producing the lowest nutrition knowledge scores on average. The primary source of information associated with the highest average nutrition knowledge scores was lecturers (14.50 ± 4.80), which was significantly higher than family (6.80 ± 5.63; *p* = 0.040) and friends (6.00 ± 2.73; *p* = 0.008). As a consequence, athletes should be made aware of the reliability of nutrition information sources to avoid adopting incorrect strategies, which could potentially affect their performance.

In conclusion, the current study found some promising results that require further investigation to discover the true impact nutrition knowledge might have on performance. It is possible that low levels of significance discovered in the present study would be amplified if conducted at the elite level, where nutritional strategies may make a bigger difference to performance. Also, if more teams were approached for athlete recruitment, more detailed analysis could take place for each individual playing position, as the number of participants in the current study were not high enough to infer conclusions. Finally, based on the significance observed at the OL position between waist circumference and nutrition knowledge, it is crucial future nutrition knowledge results are reported by position, in order to be able to identify particular groups that may be consistently at risk for long-term health problems.

Chapter 5 – Discussion and conclusions

5.1. Research summary

The first aim of the study was to develop a fundamental nutrition knowledge questionnaire that was valid and reliable. To achieve the first aim, the first two objectives outlined in section 1.4.1 of the present thesis were completed: to develop the questionnaire with expert opinion, and to subject it to rigorous testing procedures to ensure its validity and reliability. As outlined in section 2.1.3 the content of the questionnaire was based initially on the content of institutional consensus statements and position stands, compiled by internationally recognised sport nutrition experts. In addition, the content of the questionnaire was subject to a focus group of subject specific experts to ensure it was content valid. During the subsequent testing procedures, nine questions were removed due to an absence of significance, which ensured construct validity. The final statistical tests highlighted another two questions for removal to guarantee the internal reliability of the remaining questions. Therefore, the final questionnaire formed of twenty-three questions fulfilled the aim of being valid and reliable.

The second aim of the study was to determine the applicability of the Euclid model as a potential performance assessment tool. Chapter 3 documented the implementation of the respective objective; to use the Euclid model and compare the results to previously used performance assessment tools. Moderate significance was found when observing Euclid scores against competitive experience, starting status and coaches' rankings. One of the main conclusions was that the use of starting status and coaches' rankings as comparison tools brought about small sample sizes due to the restriction of having to recruit from a single team. Nevertheless, the Euclid model proved effective in producing overall performance scores for a group of athletes without the need for complex algorithms, and so can be considered as a valid tool for use in subsequent performance analyses. Further testing with a greater sample size with elite athletes would be recommended, to fully determine the potential of the system as an ability-determining system.

The final aim of the present study was to ascertain whether a relationship existed between nutrition knowledge and selected performance variables in collegiate American football athletes. Chapter 4 combined the resultant nutrition knowledge questionnaire validated in Chapter 2, and the Euclid model discussed in Chapter 3 to complete the final objective of the present study; to evaluate the relationship that exists between nutrition knowledge and performance in collegiate American football athletes. No significant relationship was observed between nutrition knowledge and Euclid performance scores when all the athletes were observed as a whole group. However, significance was observed between nutrition knowledge and performance in the offensive athletes. Another noteworthy outcome of Chapter 4 was in regards to the relationship between nutrition knowledge and long-term health risk factors such as BMI and waist circumference. The use of BMI has been criticised as an unreliable tool for use among athletic populations such as American football and no significant relationships were observed when compared with nutrition knowledge. However, waist circumference, on the other hand, had been identified as a much more reliable prediction tool, and the present study observed a significant relationship between waist circumference and nutrition knowledge when athletes were grouped as offensive positions, and also within the Offensive Lineman (OL) position. It was summarised that although significance was observed, definitive overall conclusions could not be made to suggest nutrition knowledge has a significant impact on performance or health risk predictors such as waist circumference, due to the low number of athletes recruited from each position. However, further research is warranted to overcome the limitations of the present study and thus draw more reliable conclusions.

5.2. Future research

From the results and discussions of the present study, three recommendations have been made for future research to investigate. Firstly, to fully understand the potential of the Euclid scoring model, future research should look to implement the model with the previously published National Football League (NFL) Scouting Combine results from all preceding years. The resultant Euclid scores should consequently be correlated against the respective year's NFL Draft order to determine their potential predictive capabilities. The analysis could also serve as validation for the specific combination of performance tests that predict the best performers at each position. Furthermore, the possibility to expand the Euclid test battery with the addition of some thoroughly tested cognitive assessments should be investigated.

Secondly, future research should reinvestigate the relationship between nutrition knowledge and long-term health risk indicators. The research should aim to recruit American football athletes competing in multiple teams at the Division I level, as opposed to from the British collegiate level. Relationships should be examined between nutrition knowledge and waist circumference, as well as the addition of an examination between nutrition knowledge and body fat percentage. Nutrition knowledge scores and the relationship analyses should be reported by position to determine if specific positions, such as the OL, are at a higher risk of subsequent disorders than other positions.

The final recommendation for future research would be to re-evaluate the relationship between nutrition knowledge and performance. Again, research should aim to recruit athletes from multiple Division I teams. The combination of performance tests should be modified according to the conclusions of preliminary work and the nutrition knowledge questionnaire from the present study should be implemented again. Furthermore, an increase in athlete sample size and years of competitive experience would enable definitive conclusions to be made about the relationship between nutrition knowledge and athletic performance in American football.

5.3. Conclusions

In conclusion to the present thesis, the hypothesis that “There will be a significant positive relationship between fundamental nutrition knowledge and performance among British university American football athletes” is rejected due to such a relationship only being found significant among the offensive athletes. Therefore the null hypothesis is accepted. The process of developing tools for establishing nutrition knowledge and overall performance scores yielded the most positive results of the study though. The nutrition knowledge questionnaire was successfully deemed valid and reliable for future research to implement, and the Euclid scoring system proved a straightforward versatile model that, if future researchers desire alternate performance tests, can adjust accordingly. Additional testing among different athletic populations will be able to determine the full potential of both tools.

Word count: 24,132

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Appendix 1

<u>Macronutrients</u>

1. Protein is the main energy source used by muscles, during high intensity exercise

   ○ Agree ○ Disagree ○ Not sure

2. The elimination of carbohydrates from a diet is beneficial to athletic performance

   ○ Agree ○ Disagree ○ Not sure

3. What percentage of an athlete's total energy intake should be derived from fat?

   ○ <10%

   ○ 10% - 20%

   ○ 20% - 30%

   ○ 30% - 40%

   ○ 40% - 50%

   ○ >50%

   ○ Not sure

4. Do you know what the Glycaemic Index (GI) is?

   ○ Yes

   ○ No

   a. What is the benefit of consuming high Glycaemic Index foods?

      ○ Glucose will be absorbed gradually, for a steady release of energy

      ○ Glucose will be absorbed rapidly, for a quick release of energy

      ○ Not sure

   b. Which of the following has the highest Glycaemic Index (GI) rating?

      ○ Apple

      ○ Crisps

      ○ Honey

      ○ Pasta

      ○ Peanuts

      ○ Not sure

5. Which macronutrient contains the most energy (kcal) per gram?
   ○ Carbohydrates

   ○ Fat

   ○ Protein

   ○ Not sure

<u>Micronutrients</u>

6. Vitamins are a source of energy
   ○ Agree ○ Disagree ○ Not sure

7. Minerals are a source of energy
   ○ Agree ○ Disagree ○ Not sure

8. Which vitamin...

	Vitamin				
	Vitamin B6	Vitamin B12	Vitamin C	Vitamin D	Not sure
a. Is an antioxidant	○	○	○	○	○
b. Aids calcium absorption	○	○	○	○	○
c. Is involved in energy production	○	○	○	○	○
d. Is required for red blood cell production	○	○	○	○	○

9. Which mineral...

	Mineral				
	Calcium	Iron	Magnesium	Zinc	Not sure
a. Deficiency can lead to stress fractures	○	○	○	○	○
b. Deficiency can lead to decreased endurance	○	○	○	○	○

Hydration

10. The goal of pre-exercise hydration is to: -
    - ○ Start exercise with normal hydration levels
    - ○ Start exercise with elevated hydration levels
    - ○ Not sure

11. Pre-exercise hydration should be started at least: -
    - ○ 4 hrs before exercise
    - ○ 2 hrs before exercise
    - ○ 1 hr before exercise
    - ○ 30 mins before exercise
    - ○ Not sure

12. Meal consumption can contribute to levels of hydration

    ○ Agree ○ Disagree ○ Not sure

13. Body weight changes can reflect sweat loss during exercise

    ○ Agree ○ Disagree ○ Not sure

14. In general, overdrinking is more dangerous than underdrinking

    ○ Agree ○ Disagree ○ Not sure

15. Dehydration increases an athlete’s perceived effort of an exercise task

    ○ Agree ○ Disagree ○ Not sure

16. Caffeinated drinks can contribute to dehydration during exercise

    ○ Agree ○ Disagree ○ Not sure

Recovery

17. The timing of carbohydrate replenishment is crucial, even if the athlete is to rest one or more days between intense training sessions.

    ○ Agree ○ Disagree ○ Not sure

18. After a carbohydrate-depleting bout of exercise, which type of food will result in higher glycogen levels the next day?
    ○ High GI foods
    ○ Low GI foods
    ○ Not sure

19. The consumption of a drink containing sodium after exercise, will;

	Options		
	Agree	Disagree	Not sure
a. Increase thirst perception	○	○	○
b. Delay the return to a normally hydrated state	○	○	○
c. Reduce excessive urine production	○	○	○
d. Increase fluid retention	○	○	○

<u>Supplements</u>

20. What is the **primary** function of creatine?
    ○ Aid protein transport to the muscle
    ○ Act as an energy source
    ○ Increased blood flow to the active muscles
    ○ Not sure

21. Creatine supplementation is effective in improving endurance
    ○ Agree ○ Disagree ○ Not sure

22. Caffeine supplementation can lead to decreased perception of effort
    ○ Agree ○ Disagree ○ Not sure

23. Consumption of sodium bicarbonate can cause a delayed onset of muscular fatigue
    ○ Agree ○ Disagree ○ Not sure

24. In general, protein supplements are essential for muscular growth
    ○ Agree ○ Disagree ○ Not sure

25. In general, it is essential for athletes to consume multivitamins

○ Agree ○ Disagree ○ Not sure

26. Which dietary option is better for gaining lean body mass? (provided that the energy provided is the same for each)

○ High protein meal

○ Protein and amino acid supplementation (protein shakes etc.)

○ Equally as effective

○ Not sure

Appendix 2

Macronutrients

1. Protein is the main energy source used by muscles, during high intensity exercise

   ○ Agree ○ Disagree ○ Not sure

2. Do you know what the Glycaemic Index (GI) is?

   ○ Yes

   ○ No

   a. What is the benefit of consuming high Glycaemic Index foods?

      ○ Glucose will be absorbed gradually, for a steady release of energy

      ○ Glucose will be absorbed rapidly, for a quick release of energy

      ○ Not sure

   b. Which of the following has the highest Glycaemic Index (GI) rating?

      ○ Apple

      ○ Crisps

      ○ Honey

      ○ Pasta

      ○ Peanuts

      ○ Not sure

3. Which macronutrient contains the most energy (kcal) per gram?

   ○ Carbohydrates

   ○ Fat

   ○ Protein

   ○ Not sure

Micronutrients

4. Vitamins are a source of energy

   ○ Agree ○ Disagree ○ Not sure

5. Minerals are a source of energy
   ○ Agree ○ Disagree ○ Not sure

6. Which vitamin...

	Vitamin				
	Vitamin B6	Vitamin B12	Vitamin C	Vitamin D	Not sure
a. Is an antioxidant	○	○	○	○	○
b. Aids calcium absorption	○	○	○	○	○

7. Which mineral...

	Mineral				
	Calcium	Iron	Magnesium	Zinc	Not sure
a. Deficiency can lead to a stress fracture	○	○	○	○	○

Hydration

8. Pre-exercise hydration should be started at least: -
   ○ 4 hrs before exercise
   ○ 2 hrs before exercise
   ○ 1 hr before exercise
   ○ 30 mins before exercise
   ○ Not sure

9. Meal consumption can contribute to levels of hydration
   ○ Agree ○ Disagree ○ Not sure

10. Body weight changes can reflect sweat loss during exercise
   ○ Agree ○ Disagree ○ Not sure

11. Dehydration increases an athlete’s perceived effort of an exercise task
   ○ Agree ○ Disagree ○ Not sure

Recovery

12. After a carbohydrate-depleting bout of exercise, which type of food will result in higher glycogen levels the next day?

    ○ High GI foods

    ○ Low GI foods

    ○ Not sure

13. The consumption of a drink containing sodium after exercise, will;

	Options		
	Agree	Disagree	Not sure
a. Delay the return to a normally hydrated state	○	○	○
b. Reduce excessive urine production	○	○	○
c. Increase fluid retention	○	○	○

Supplements

14. What is the **primary** function of creatine?

    ○ Aid protein transport to the muscle

    ○ Act as an energy source

    ○ Increased blood flow to the active muscles

    ○ Not sure

15. Creatine supplementation is effective in improving endurance

    ○ Agree ○ Disagree ○ Not sure

16. Caffeine supplementation can lead to decreased perception of effort

    ○ Agree ○ Disagree ○ Not sure

17. Consumption of sodium bicarbonate can cause a delayed onset of muscular fatigue

    ○ Agree ○ Disagree ○ Not sure

18. In general, it is essential for athletes to consume multivitamins

    ○ Agree ○ Disagree ○ Not sure

19. Which dietary option is better for gaining lean body mass? (provided that the energy provided is the same for each)

    ○ High protein meal

    ○ Protein and amino acid supplementation (protein shakes etc.)

    ○ Equally as effective

    ○ Not sure