Association between body composition and external load performance in official football matches

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Structure of thesis

Thesis sections

Part I: Theoretical background and methods

Part I includes introduction, theoretical framework, method, and methodological discussion. Firstly, I present an introduction to the subject matter. Secondly, I discuss body composition in different sports and its evolution before I go onto the main focus of the thesis, body composition in football. Further, I investigate the association between field tests, body composition and match performance. Thirdly, I go through the methods used in this thesis and then discuss their strengths and limitations.

Due to the word-limitation of the master thesis, results, discussion, and conclusion of the present experimental study are only included in part II.

Part I: Paper

Part II presents a research paper regarding the present experimental study and is written according to the standards of the journal. International Journal of Sports Physiology and Performance (IJSPP).

Tables and figures should be presented after the article, according to the guidelines of the International Journal of Sports Physiology and Performance, and only the location of the table should be indicated in the article. I, on the other hand, have chosen to include tables in the article to make it easier to read for the reader.

Part III: Appendix

Appendix 1: Pre- and post – test

Appendix 2: Workout explanation and workout program

Appendix 3: NSD

Appendix 4: FEK

Appendix 5: Declaration of consent

Acknowledgements

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Abbreviations

In alphabetical order

ACCs	Accelerations
BF	Body fat (kg)
BF%	Body fat percentage
BM	Body mass (kg)
BMI	Body mass index
COD	Change of directions
DECs	Decelerations
DXA	Dual-energy X-ray absorptiometry
FM	Fat mass (kg)
GPS	Global position system
HIEs	High intensity events
HSR	High-speed running distance
IMU	Inertial measurement unit
LBM	Lean body mass (kg)
Legs F%	Legs fat free mass
Legs FFM	Legs fat mass
Legs FM	Legs fat percentage
Legs LM	Legs lean mass
LSR	Low-speed running distance
MSR	Moderate-speed running distance
PL per meter	PlayerLoad^{TM} per meter
PL per min	PlayerLoad^{TM} per minute
SSR	Sprint-speed running distance
TD	Total distance
Total FFM	Total fat free mass
Total FM	Total fat mass
Total LM	Total lean mass
Total PL	Total PlayerLoad^{TM}
VO_2 max	Maximal oxygen uptake

Abstract

Objective: The objective of this study was to investigate the association between body composition and external load performance in official football matches in professional football players. **Method**: 12 professional male footballers participated in this study. Body composition was measured with two Dual-energy X-ray absorptiometry (DXA) scans where the mean of the two scans were used in the correlation analysis. From the Dual-energy X-ray absorptiometry scans were lean-, fat-and fat free mass variables extracted for the whole body and regionally in the legs. In the period between the two scans were seven official matches played. The external load variables from the matches were extracted using a tracking unit with Global Positioning System and an Inertial measurement unit. The external load variables include total distance and distance at different velocities, max velocity, high intensity events as well as an accumulated workload measure, PlayerLoad^{TM}. **Results**: Bayesian correlation analysis showed there was moderate evidence and Kendall's Tau-b correlation showed moderate to large correlation between total body fat percentage and sprint-speed running distance (BF10 = 4.15; τb = -0.52), between leg fat mass and sprint-speed running distance (BF10 = 3.17; τb = -0.49), and between leg fat percentage and PlayerLoad^{TM} per minute (BF10 = 3.31; τb = -0.49). **Conclusion**: The data indicate that lower levels of fat mass and body fat percentage are factors that affect external load performance in football. The results of this study provide practitioners with information about the association between body composition and external load performance in official matches for professional football players.

Keywords

Body fat, DXA, GPS, PlayerLoad^{TM}, professional football players, soccer

Sammendrag

Hensikt: Hensikten med denne studien var å undersøke sammenhengen mellom kroppssammensetning og fysisks prestasjon i offisielle fotballkamper hos profesjonelle fotballspillere. **Metode**: 12 profesjonelle mannlige fotballspillere deltok i denne studien. Kroppssammensetning ble målt med to «Dual-energy X-ray absorptiometri»-undersøkelser hvor gjennomsnittet av de to ble brukt i korrelasjonsanalysen. Fra «Dual-energy X-ray absorptiometri» skanningene ble mager-, fett- og fettfri masse variabler ekstrahert for hele kroppen og regionalt i bena. I perioden mellom de to skanningene ble det spilt syv offisielle kamper. Fysisk prestasjonsevne fra kampene ble ekstrahert ved hjelp av en sporingsenhet med «Global Positioning System» og en treghetsmåleenhet. Fysisk prestasjonsevne variable inkluderer total distanse og distanse ved forskjellige hastigheter, makshastighet, høyintensitetshendelser samt et akkumulert belastningsmål, PlayerLoad^{TM}. **Resultater**: Bayesiansk korrelasjonsanalyse viste at det var moderat bevis og Kendalls Tau-b korrelasjon viste moderat til stor korrelasjon mellom total kroppsfettprosent og sprint-hastighet løpedistanse (BF10 = 4.15; $\boldsymbol{\tau}$b = -0.52), mellom beinfettmasse og sprint-hastighet løping avstand (BF10 = 3.17; $\boldsymbol{\tau}$b = -0.49), og mellom beinfettprosent og PlayerLoad^{TM} per minutt (BF10 = 3.31; $\boldsymbol{\tau}$b = -0.49). **Konklusjon**: Dataene indikerer at lavere nivåer av fettmasse og fettprosent er faktorer som påvirker fysisk prestasjonsevne i fotball. Resultatene av denne studien gir utøvere og trenere informasjon om sammenhengen mellom kroppssammensetning og fysisk prestasjonsevne i offisielle kamper for profesjonelle fotballspillere.

Nøkkelord

Fettprosent, DXA, GPS, PlayerLoad^{TM}, profesjonelle fotballspillere, fotball

Part I

Theoretical backgrounds and methods

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Contents

1.0 Introduction

Body composition is shown to have a major impact on performance in various sports (Reilly & Korkusuz, 2009; Maughan, 2009; Fleck, 1983). In football has body composition changed over the last years, possibly because of the increase in work-rate in terms of actions, intensity, duration, and frequency (Barnes et al., 2014). Professional players have also become faster over the last decades (Haugen et al., 2013; Gonaus et al., 2019). Some evidence indicate that goalkeepers, lateral midfielders, and attackers have grown in stature, while central midfielders have shrunk in stature from 2008 to 2018 (Vega et al., 2020). Others have found that elite players in 2002 to 2005 were generally lighter at the same height compared to players active in the 2012 to 2015 period (Gonaus et al., 2019). The changes in match demands seem to inconsistently influence body fat percentage (BF%) changes. Briefly, BF% is the total fat mass (FM) divided by total body mass (BM), multiplied by 100. There are studies from the 1970's and 1990's reporting the same level of BF% as current day players (Raven et al., 1976; Mangine et al., 1990; Hoshikawa et al., 2005; Aziz et al., 2005a; Aziz et al., 2005b; Rico-Sanz, 1998: Papaevangelou, 2012; Withers et al., 2004; Ostojić, 2000; Silvestre et al., 2006). The same BF% in previous professional players and current day players may indicate that this is not a factor that is affected by changes in match demands. However, the older studies used inferior measurement methods that could estimate vastly different levels of BF% in the exact same test population (Lohman et al., 1984; Pollock & Jackson, 1984). More recent evidence suggests that BF% of certain positions has decreased over the last years (Vega et al., 2020). The change in body composition can also be seen in referees where it has been a decrease in body mass index (BMI) and BF% from 2001 to 2012 (Casajús & Gonzalez-Aguero., 2015).

Although the use of Global Positioning System (GPS) to evaluate physical performance is common today and body composition is important in determining football success, the link between the two in official matches has not been thoroughly investigated (Pons et al., 2019; Casajús, 2001). Several studies have been conducted to determine the physiological characteristics of football players at various levels and indicate that different field tests can be linked to match performance (Redkva et al 2018; Castagna et al., 2010; Krustrup et al., 2003; Bradley et al., 2011; Helgerud et al., 2001; Haugen et al., 2013; Gonaus et al., 2019). However, none of these studies have looked at the demands during official matches using GPS and an Inertial measurement unit (IMU). Reason being that before 2015 the approach of using a GPS to evaluate physical performance only allowed in training sessions and friendly matches (Mallo et al., 2015; Pons et al., 2019). Different field tests can be linked to match performance (Redkva et al., 2018; Castagna et al., 2010; Krustrup et al., 2003; Bradley et al., 2011; Apor, 1988; Wisloeff et al., 1998; Helgerud et al., 2001), and body composition can be linked to field tests (Salinero et al., 2016; Alvero-Cruz et al., 2019; Campa et al., 2019; Perroni et al., 2014; Baldari et al., 2009; Abe et al., 2020; Sporis et al., 2010), but there hasn't been much research on a direct link between body composition and match performance. There is one study indicating that players with lower fat mass cover greater total distance (TD), high-speed running distance (HSR), and sprint-speed running distance (SPR) during official matches (Radzimiński et al., 2019). When directly comparing body composition to match performance in official matches on professional players this is, to the best of my knowledge, the only study published to date, indicating a clear need for this research.

1.1 Research question

The following research questions was investigated:

- Is there any association between body composition and external load performance in professional football players?

2.0 Theoretical framework

A number of physical and psychological variables play a role in performance. Physical factors of importance include, but are not limited to, strength, power, speed, acceleration (ACCs), VO_2 max and ventilatory thresholds (Murr et al., 2017; Dellal et al., 2010; Impellizzeri et al., 2005; Tumilty, 1993; Bangsbo, 1994; Little & Williams, 2003; Sleivert & Rowlands, 1996; Sleivert & Wenger, 1993; Laurenson et al., 1993; Coyle et al., 1988; Manchado et al., 2013; Lockie et al., 2011). Psychological factors and skills of importance include, but are not limited to, relaxation, imagery, self-talk, life event stress, somatic trait anxiety, mistrust, ineffective coping, self-efficacy, and goal commitment (Thelwell et al., 2006; Jones et al., 2008; Johnson & Ivarsson, 2011; Lowther et al., 2002; Van Yperen, 2009). In addition, body composition appear to be essential for optimizing sport performance in many sports (Maughan, 2009: Reilly, 1996; Saint Onge et al., 2008; Norton & Olds, 2001; Olds, 2001; Reilly & Korkusuz, 2009; Fleck, 1983; Meyer et al., 2013; Vega et al., 2020; Dunbar & Power, 1995; Milsom et al., 2015; Papaevangelou, 2012; Sutton et al., 2009; Calbet et al., 2001; Wittich et al., 2001; Anwar & Noohu, 2016; Radzimiński et al., 2019; Sleivert & Rowlands, 1996; Laurenson et al., 1993; Manchado et al., 2013).

2.1 Body composition in sports

Body composition has been shown to have a substantial impact on performance, and an athlete's body composition must be tailored to the demands and needs of the sport (Reilly & Korkusuz, 2009). Athletes that participate in sports where their BM is supported, such as canoeing and kayaking, as well as swimming, tend to have a higher BF%. While athletes that compete in sports where a weight class is required and in anaerobic- and aerobic races have lower BF% (Fleck, 1983). A reason for this is because increased BF lowers VO_2 max (ml/kg/min). Higher BF levels increase the denominator and thereby lowers the value, and VO_2 max is shown to increase performance in various sports (Salinero et al., 2016; Alvero-Cruz et al., 2019; Helgerud et al., 2001; Sleivert & Rowlands, 1996; Sleivert & Wenger, 1993; Coyle et al., 1988).

FM and BF% are factors that likely can influence performance in many sports. According to Olds et al., (1995), a 1 kg increase in FM can increases 40-minute time-trial time by 0.2% in cycling (about 7 s). In a middle-distance runner, a 1.6% increase in FM would increase 1500 m time by 3–4 seconds and the vertical jump of a 70 kg athlete with an 80 cm vertical jump would be reduced by 1.5 cm if he gained 1 kg of BF (Maughan, 2009). This could be the difference between winning and losing.

Fat free mass (FFM) and lean body mass (LBM) also influence performance. Briefly, FFM consists of bone, muscle, vital organs, and extracellular fluid. LBM differs from FFM in that it includes lipid from cellular membranes, but this makes up a small percentage of total BM [≤ 3 % in men and ≤ 5 % in women (Janmahasatian et al., 2005: Yu et al., 2013)]. Fleck (1983) found that athletes in sports such as basketball and volleyball, where size is a distinct advantage, have a greater LBM. LBM has also been shown to greatly predict performance in weightlifting (Siahkouhian et al., 2016). The higher LBM in these sports partially can be explained by the fact that lower body LBM is strongly correlated with rate of force development (Kavvoura et al., 2018). Rate of force development is a measure of explosive strength which is important for performance in several power-demanding sports, such as sprints and jumps (Kavvoura et al., 2018). This is supported by the fact that FFM has been positively correlated with counter movement jump and standing long jump (Perroni et al., 2014; Baldari et al., 2009). Furthermore, muscle mass, which is one of the main determinants of LBM, has been moderately correlated to both absolute VO_2 max and strength which are factors that can influence performance (Marriott & Grumstrup-Scott, 1990; Garthe et al., 2011).

Athletes in various sports have a wide range of body compositions, but there can also be positional or role differences in body composition within the same sports depending on work requirements for different positions. This is true in sports such as American football (Bosch, 2019; Dengel, 2014), baseball (Czeck, 2019) and track and field (Dengel, 2020; Hirsch, 2016), but might not be true for ice hockey, possibly because similar physical demands of each position (Chiarlitti, 2018).

2.2 Evolution in body composition in sports

Anthropometric factors alter over time in response to changes in the athletic and external environment. In the last century, the average height and BM of international male athletes has changed. In 1925, athletes in 15 of the 21 sports studied in Maughan (2009) were within a height range of 170–180 cm and a BM of 60–80 kg. By the year 2000, athletes in only eight sports were within these height and BM ranges. In 1925 the difference in height and BM of a volleyball player and an elite thrower was measured at only 1 cm and 1 kg. While their heights are still comparable in 2000, the average volleyballer is more than 32 kg lighter. The BM difference between high jumpers and shot putters in 1925 was only 4 kg. In the year 2000, the difference was approximately 60 kg. The increase in anthropometric measures can also be seen in the National Football League lineman increased their height and BM from a mean 180.9 cm and 89.8 kg to 193.2 cm and 137.2 kg from the 1920s to the 1990s (Norton & Olds, 2001), in Major League Baseball they, from 1869 to 1983, gained an average of 7.6 cm in height and 12.2 kg in BM (Saint Onge et al., 2008), and in rugby the rates of increase in BM and height was 2.6 kg and 1.0 cm per decade from 1905 to 1999 (Olds, 2001). In sports such as running (distances over 800m), diving, horse racing, cycling, high jump, and gymnastics there have been a decrease in height and/or BM since the 1970s (Norton & Olds, 2001). In summary, these changes do illustrate a trend toward increasingly comparable physiques within a sport, but less comparable physiques across different sports. This indicates that an athlete’s body composition has been a factor that over the last century has been altered to create advantages over others.

2.3 Evolution in body composition in football

In football the demands of the games changed over the years. This can be shown in Barnes et al., (2014) where they examined the English Premier League over a 7- year period from 2006/2007 – 2012/2013. In 2006/2007, the TD covered during a match was 2% lower than in 2012/2013. In the same period the was TD, sprint-speed running (SSR), number of sprints and actions done with high intensity increased by 30%, 35%, 85% and 50%, respectively. Even though the average SSR was slightly lower in 2012/2013 than in 2006/2007, the proportion of explosive sprints increased (mean: 34% vs. 47%). The development in the match demands can also be seen in the significant increase in passing rate, game speed and player density [players around the ball (Wallace & Norton, 2014)].

Not only have the demands of the games changed, but also the physical performance in tests outside the football arena. Professional players from 2006–2010 had 1–2% faster 20 m sprint and peak velocity than players from 1995–1999 and 2000–2005. Gonaus et al., (2019) also found that current elite Austrian youth players from 2012-2015 (15-18 years) ran faster (5x10 m shuttle run) and performed better in hurdles agility run than youth elites 10 years prior. This indicates that, in modern football, sprinting velocity is an important skill.

Tønnessen et al., (2013) investigated VO_2 max in professional football players from 1989 to 2012 and found no improvements. The players during the 2006-2012 period even had lower VO_2 max than the players tested from 2000-2006. This could be because of an optimal range, shown by consistent observation of mean VO_2 max values exceeding 60 ml/kg/min in elite teams and values significantly lower than those seen in other elite athletes in endurance sports, where VO_2 max values exceeding 80 ml/kg/min have been seen. This could support the claim that a VO_2 max of around ≥60 ml/kg/min is a threshold for accomplishing the intermittent work pattern of football, and after accomplishing this, teams prioritize other physical qualities. (Reilly et al., 1990; Reilly et al., 2000; Reilly, 1996).

Haugen et al., (2013) investigated vertical jump in professional football players from three different periods: 1995–1999, 2000–2005 and 2006–2010. They did not find a significant difference between any of the periods. The absence of a higher vertical jump over the years could be due to there not being a significant correlation between vertical jump performance and selected football match variables (Rampinini et al., 2007a), this is however contradicting to Arnason et al., (2004) who found a significant relationship between team average vertical jump height and team success (league standings).

These changes in match demands and performance in mentioned physical tests seem to have an unclear effect on the body composition. Vega et al., (2020) investigated anthropometric measures of Spanish elite reserves during the 2008 to 2018 period. They found that goalkeepers, lateral midfielders, and attackers have all grown 4 cm in stature, while central midfielders have shrunk 5 cm in stature. This is somewhat contradicting to Gonaus et al., (2019) who found that elite Austrian youth football players (U-16 and U-17) are generally lighter (1,1-1,7 kg) at the same height, resulting in a lower BMI, in the 2002-2015 period. This is supported in Casajús & Gonzalez-Aguero (2015) where they found that the BMI of Spanish referees at highest levels in Spain decreased from 23.7 to 22.4 kg/m^2 from 2001 to 2012.

In terms of BF%, are there studies from the 1970's and 90s reporting a mean 9.5% in professional players using the skinfold caliper method, which is comparable to current day players (Raven et al., 1976; Mangine et al., 1990). Briefly, both studies did however report a BF% range of 2.4-13.3% and 4.2-20.7%, respectively. This large variation as well as extremely low BF% levels could indicate weaknesses in the measurement method used. It is known that variations in type of caliper used, test personnel and different prediction equations could estimate vastly different levels of BF% in the exact same test population, indicating the weaknesses of this method (Lohman et al., 1984; Pollock & Jackson, 1984). Vega et al., (2020) did however find that the BF% of defenders, but no other position, decreased in the 2008-2018 period. The change in BF% is supported by Casajús & Gonzalez-Aguero (2015) where they studied changes in body composition of 470 referees of the 1st and 2nd from 2001 to 2012. They found a decreased in BF% from 13.7 to 11.7%.

Studies on the evolution of football indicate that the TD, SSR, number of sprints and actions done with high intensity as well as passing rate, game speed and player density has increased. Performance has also improved in 20 m sprint, peak velocity and 5x10 m shuttle run, while performance in VO_2 max and vertical jump may not have. These changes may result in some players having lower BF%.

2.4 Body composition in football

2.4.1 Height and body mass

Height and BM are factors that can differ among professional football players. There are data suggesting that the average professional football player is 173-182 cm and weigh 69.7-79.5kg (Aziz et al., 2005b; Iga et al., 2014 Papaevangelou, 2012; Reilly, 1975; Faina, 1988; White et al., 1988; Gardasevic & Bjelica, 2020; Redkva et al., 2018; Radzimiński, 2020; Rampinini et al., 2007b; Pons et al., 2019; Matković et al., 2003; Silvestre et al., 2006; Suarez-Arrones et al., 2019). Several of the studies are presented with great variation within the studied population, further indicating the variation in height and BM among professional football players. There are, however, findings that suggest significant differences in BM, when comparing professionals/elite with lower league/U-teams (Papaevangelou, 2012; Dunbar and

Power, 1995; Tiryak et al., 1995), indicating that this could be a factor for making it at the highest level. It should be mentioned that for positions where winning duels in the air, such as for goalkeepers, center backs, and the forwards, height will come as a benefit. As a result, a player's stature may influence their choice of positional or tactical duties (Reilly et. Al, 1990).

2.4.2 Body fat

Professional football players have a relatively low percentage body fat with many studies reporting a mean 8-12 BF% range (Hoshikawa et al., 2005; Aziz et al., 2005a; Aziz et al., 2005b; Rico-Sanz, 1998: Papaevangelou, 2012; Withers et al., 2004; Ostojić, 2000; Silvestre et al., 2006). This is much lower than the average male between the ages of 18 and 22 who has a mean 15 BF% according to Mangine, Noyes, Mullen, & Barber (1990) and 16.5% for males in their mid-twenties according to Reilly (1996). Low BF% could therefore be seen as an important component for optimal performance in football because excess BF functions as a dead weight in sports where BM must be frequently raised against gravity during running and jumping (Reilly, 1996). This is supported by Aziz et al., (2005a) where they found a decrease in BF% and sprint time from the pre-season to the middle of the competitive season. For the time between pre-season and middle of the competitive season, correlation analysis revealed a significant relationship between body fat and 5 m ($r=0.35$, $P<0.05$) and 20 m ($r=0.43$, $P<0.01$) sprint times. This could be because BF has a strong negative association with performance in activities where the body must be moved through space, either vertically or horizontally (Can et al., 2004). This is also supported in Silvestre et al., (2006), Reilly et al., (2000), Anwar & Noohu (2016) and Sporis et al., (2009) who found strong positive correlation with BF and speed (5-30 m sprint) and a negative correlation between BF and VO_2max ($r = -0.4$ to -0.72). Leaner football players also perform better in repeated sprints and vertical jumps (Reilly et al., 2000 & Sporis et al., 2009; Esco et al., 2018; Anwar & Noohu, 2016). All these factors could collectively explain the relationship between the team average BF% and the final league standing in the two highest divisions in Iceland (Arnason et al., 2004).

BF% is also something that can vary based on the level of football players. In Dunbar & Power (1995) they found that senior players from a premier league club had lower mean BF% than junior players from the same club and players from a division three club, and in Milsom et al., (2015) they found that first team players from a premier league had lower BF% than U21 and U18. This is contradicting to Tiryak et al., (1995) and Tereso et al., (2021) who also conducted similar comparisons with a team of players from the first, second and third division in Turkish football league and elite, sub-elite, and non-elite players, respectively. They found no difference between any of the divisions in terms of BF%.

2.4.3 Muscle- and lean body mass

When investigating muscle mass and LBM in football players there is limited data published. There does, however, seem to be a difference in LBM when comparing professionals/elite with lower league/U-teams, with the professionals/elite having significantly greater LBM (Papaevangelou, 2012 & Milsom et al., 2015). This difference in LBM may have led professional players to have a significantly higher jumping ability compared to U-21 and U-17 (Papaevangelou, 2012). LBM-differences can also be seen between professional players and control groups, which is to be expected (Sutton et al., 2009; Calbet et al., 2001; Wittich et al., 2001). When investigating muscle mass, it has been shown to have a significant positive correlation with vertical jump performance and a significant negative correlation with 30 m sprint time ($r = 0.72$ and $r = –0.35$, respectively. Anwar & Noohu, 2016). Given the high forces required for sprinting, a link between muscle mass and sprint time would be expected, as muscle mass is the primary determinant of force-power generation. As a result, increased muscle mass may be linked to a faster sprint time (Fitts et al., 1991 & Anwar & Noohu, 2016).

2.4.4 Positional differences

As we have seen in other sports can there be positional differences in terms of body composition. When assessing field tests for football players Dunbar & Treasure (2005) showed no significant performance differences in 10- and 20-m sprint, vertical jump, agility, or aerobic and anaerobic endurance between the three groups of outfield players. Outfield players have much greater aerobic endurance than goalkeepers, which is to be expected. Brocherie et al., (2005) supports the absence of differences in sprint time between all player groups but did find that goalkeepers jumped significantly higher than defensive, midfield and forward players, both in single jump and multiple jump procedures. Concerning outfield positions, did defensive players have greater jump performance than midfields and forwards.

When assessing positional differences in terms of body composition, are goalkeepers the heaviest and tallest of all the groups, and midfield players significantly lighter and shorter then both the defensive- and forwards players (Brocherie et al., 2005; Bell & Rhodes, 1975). The notion of goalkeepers being heavier and having a higher BF% than outfield player is supported in several studies (Matković, 2003; Bell & Rhodes, 1975; Carling & Orhant, 2010).

Carling & Orhant (2010) divided the player positioning into six distinct positions to specify the positions further. They found lower levels of BF% in central midfielders and defender's vs wings, and in central midfielders and central defenders vs forwards. They also found higher levels of BF% in forwards vs. all outfield positions, in central midfielders vs. wings and full backs, and in central defenders vs. full backs and wings. The lower levels of BF% in midfielders are supported by Owen et al., (2018) where in all five data collection points during the season, midfielders were found to be leaner than forwards and defenders. This is contradicting to Wittich et al., (2001) that showed midfielders having a greater BF% (mean: 13.6%) than backs or forwards (mean: 11.1% and 11.0%, respectively). However, it is important to remember when high variability within teams and leagues occurs, mean values are of limited value for comparison, and a coach may adjust his team's configuration and style of play to accommodate people who lack the physical traits of traditional positional duties (Reilly et al., 1990).

2.4.5 Summary

There are various body composition variables that influence football performance or player role. Firstly, it seems that height is not a roadblock to success in football, but it may influence the position chosen or playing style, while BM could be a factor for making it at the highest level. Secondly, studies indicate that professional football have lower BF% than the normal population, probably because lower BF levels help with central movements in football which confirms its role as a factor in determining football performance. Also, footballers from lower divisions and youth teams may have higher BF% then professionals, which can indicate that this is a factor for making it at the highest level. Thirdly, it seems that professionals/elite have significantly greater LBM compared to lower league/U-teams and control groups.

When investigating positional differences in football there does not appear to be any difference in sprint time. However, it seems that goalkeepers jump higher than all outfield players. Concerning the outfield positions, defensive players jump higher than midfields and forwards. Goalkeepers are the heaviest and tallest of all the groups, and midfield players seem to be the lightest and shortest. Goalkeepers also have a higher BF% than outfield player.

2.5 Association of field tests and body composition on match performance

2.5.1 Field tests and match performance

Numerous studies have been conducted to determine physiological characteristics of players at various levels. Limited studies, however, have investigated the findings of field tests to variables linked to physical demands during the game (Redkva et al 2018). Prior to 2015, using a GPS to evaluate physical performance was only allowed in training sessions and friendly matches (Mallo et al., 2015). This was changed in 2015 when FIFA modified their rules to enable the use of electronic performance and tracking systems in official matches. Therefore, in recent years, the use of GPS to evaluate physical performance has grown at an exponential rate (Pons et al., 2019). One of the tests linking field tests and match performance is the Yo-Yo test (for test procedures see Wood, 2018). Briefly, there are three different versions of the Yo-Yo test with two levels each; in the Yo-Yo Endurance Tests, participants run continuously between markers 20 meters apart, whereas in the Yo-Yo Intermittent Test, participants have a short active recovery break, of either 5- or 10- seconds (different versions) , after each 40 m run (2x20 m). Performance in the Yo-Yo endurance (level 1 and 2) and Yo-Yo intermittent recovery test is significantly related to factors such as number of high-intensity actions and sprints, HSR, SSR and TD in matches using both GPS and time–motion analysis (r = 0.58-0.88. Redkva et al., 2018; Castagna et al., 2010; Krustrup et al., 2003; Bradley et al., 2011). This is also true for the 20-m Multistage Fitness Test where performance is significantly related to high intensity actions, HSR, SSR and TD (r = 0.62-0.75. Castagna et al., 2010). When investigating VO_2 max, Helgerud et al., (2001) found that as maximal oxygen uptake increased (from a mean 58.1 to 64.3 mL/kg/min) TD covered during a match, number of sprints and number of involvements with the ball increased by 20%, 100% and 24%, respectively. An explanation of this could be due to a significant relationship between VO_2 max and heart rate recovery (r=0.56, Brown et al., 2007). This could also be why better teams (in terms of league rankings) have a higher VO_2 max (Apor, 1988 & Wisloeff et al., 1998). This is however somewhat contradicting to Metaxas (2021) who found no correlation between $\dot{V}O_2$ max and match running performance at any velocity. They did however only investigate 14 players from the second division league in Greece who covered 8 690 m ± 980 m per game which is lower than reported in other studies and therefore could be the reason for not finding a significant correlation (Ekblom, 1986: Bradley et al 2010; Bangsbo, 1994; Bangsbo et al., 1991; Sporis et al., 2017; Dellal et al., 2012; Altmann et al., 2021; Mallo et al., 2015). 10- and 30-meter sprints is also something that has been seen to have significant correlations with explosive match-play actions [ACCs, decelerations (DECs), and sprint frequency; r = -0.80 to -0.61. Gonçalves et al., 2021]. In addition, in-game high-intensity ACCs and DECs were strongly predicted by squat jump, countermovement jump, and COD ability (r = -0.78 to -0.50 & r = 0.69 to 0.75, respectively. Gonçalves et al., 2021).

2.5.2 Body composition and field test

Body composition is an important factor for performance in football as already shown. Generally, players with less BF% have better sprint times, jumping ability and VO_2 max (Salinero et al., 2016; Alvero-Cruz et al., 2019; Campa et al., 2019). BF% and VO_2 max have also been strongly correlated to faster times in longer running distances (27- and 42 km) and repeated sprinting ability (Salinero et al., 2016; Alvero-Cruz et al., 2019; Campa et al., 2019). Repeated sprinting ability has also been strongly related to Yo-Yo test performance, this could therefore mean that leaner football players perform better in certain match performance parameters discussed in the paragraph above (Campa et al., 2019). FFM has been positively, and BF% has been negatively correlated with jumping ability, sprint speed and VO_2 max in young football players, sprinters, and handball players (Perroni et al., 2014; Baldari et al., 2009; Abe et al., 2020; Sporis et al., 2010). Chaouachi et al., (2009), however, found no significant relationships between height, BM, and BF%, and 5-, 10-, and 30-m sprint times. Although there are studies who have explored the relationship between body composition and field tests, none of the studies used in this paragraph are not conducted on professional male football players.

2.5.3 Body composition and match performance

Although both GPS and body composition to evaluate physical performance is a regular procedure used by sports scientists and performance analyzers, the link between the two in official matches is something that is not researched in depth, at least not in professional football players. There is one study indicating that players with lower fat mass covers greater TD, HSR, and SSR (r =-0.19, r = - 0.38 and r = -0-57, respectively) during official matches in the Europa league qualifying phase (Radzimiński et al., 2019). When directly comparing body composition to match performance in official matches on professional players this is, to the best of my knowledge, the only study published to date. As previously discussed, different field tests can be linked to match performance and body composition can be linked to field tests, however a direct link between body composition and match performance has not been extensively studied. Radzimiński et al., (2020) also used the bioimpedance method to assess body composition, which can have systematic bias and/or proportional bias (see Methodological discussion: 4.3.1 DXA, p 19-20). In this thesis I decided to investigate the association between body composition, using a DXA-scan, and external load performance in official football matches in professional Norwegian football players to help fill up the current knowledge gap.

3.0 Methods

3.1 Design

This master thesis is part of a larger research project overseen by PhD-Student Per Thomas Byrkjedal, lasting from August to November 2021. During this period, a strength intervention was performed, including pre- and post-tests as well as monthly DXA scans. In addition to DXA-scans, the participants completed an Ultrasound, 30-m sprint test, Countermovement jump test and Legg press strength test in the pre- and post- test. However, none of these are relevant for the current thesis and is there not presented (For more information about the test see *Appendix 1)*. In the larger project, were the subjects randomly divided with into either objective autoregulated or self-selected training group (*Table 1*). Both groups completed one of the three premade workouts: activation before match, easy and normal. For more information about, and implementation of, the training program see *Appendix 2*. The only difference between the training groups was whether we decided the workout for the subject based on high intensity running distance (≥19,8 km/h. Hader et al., 2019) completed in training and matches the last three days or if the subjects chose for themselves, based on feeling of factors such as ability to perform, fatigue, sleep etc.

The study design that was used in the present study was a cross sectional study. The study lasted for five weeks and included the mean data from two (n=2) DXA scans and seven (n=7) official matches. The DXA scans were performed on the 31st of August and the 4th of October 2021 and the seven matches were played within this period. In the matches, the players were equipped with a GPS and IMU unit (S7 Vector, Catapult Sports, Melbourne, Australia). The manufacturer's software was used to extract the external load performance variables. The DXA-scan was measured on separate days to all the other tests as seen in *Figure 1*.

3.2 Subjects

A local professional football club was invited to participate. There were 26 professional male footballers who initially gave their written informed consent to participate in the present study, which, among other things, means that participation in the study was voluntary and that the subjects could withdraw from the study whenever they wanted, without having to state any reason for this. For the larger project ten (n=10) excluded and we were left with sixteen (n=16) who completed the larger project *(table 1).* To be included in the analysis my thesis the participants need to complete both the DXA scans, play ≥ 3 matches with ≥ 60 minutes and be a part of the first team. For this study, we excluded seven (n=7) due to not having both the DXA scans, six (n=6) for not having played ≥ 3 matches with ≥ 60 minutes in the 31.08 to

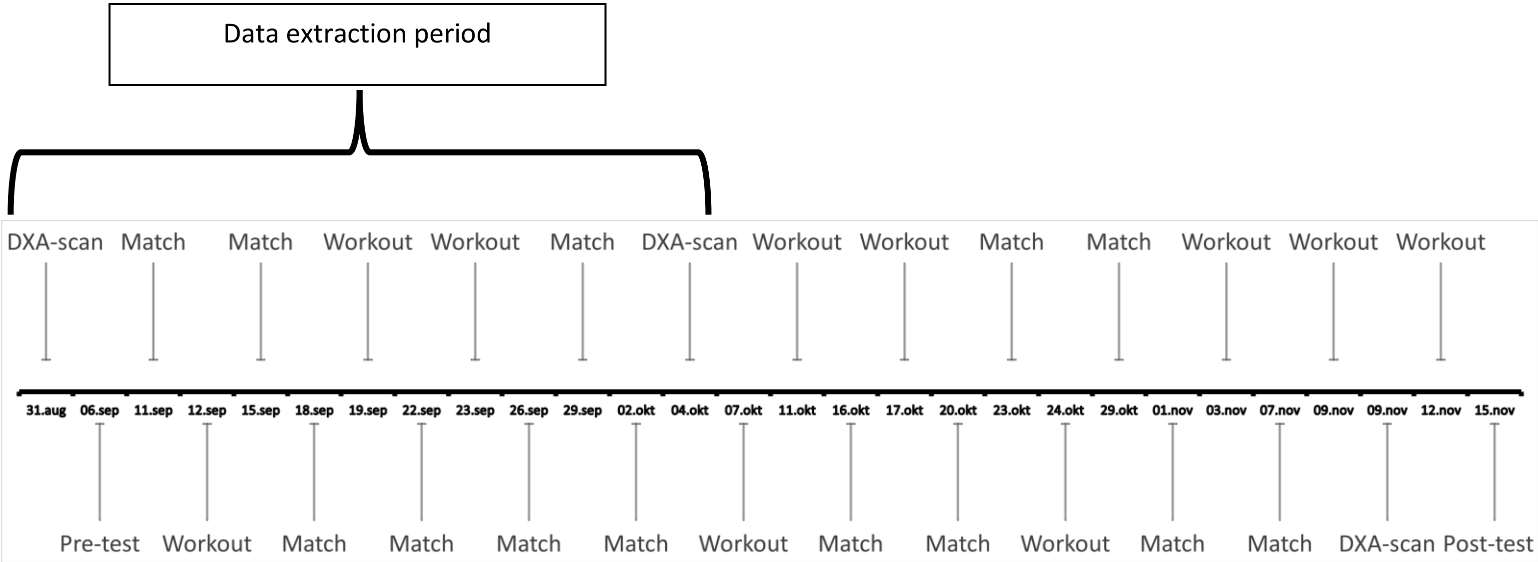
4.10 period and one (n=1) for not being a first team player. Thus 12 players (24.8 ± 3.4 years, 184.2 ± 4.6 cm and 78.3 ± 4.3 kg) were included in the analysis.

Table 1: Descriptive data of participants for the whole project

Group	N	Age (years)	Height (cm)	Body mass (kg)
Both groups	16	23.9 ± 4.0	183.4 ± 6.0	77.0 ± 7.3
Objective	7	24.1 ± 4.3	181.4 ± 4.7	76.6 ± 6.6
Self-selected	9	23.7 ± 3.7	185 ± 6.5	77.4 ± 7.9

All values are presented as mean ± SD.

Figure 1: Timeline for the project



3.3 Testing procedures and instruments

All athletes were familiar with strength training and the test procedures. All athletes were instructed to prepare for the test days as they would for a regular competition in terms of nutrition, hydration, and sleep, and to abstain from strenuous exercise the day prior to testing. The testing protocol consisted of a DXA-scan, ultrasound, sprints, countermovement jumps and a leg press test with incremental loads. The subjects came in one by one with 30 min intervals. The testing protocol took about 1 hour to complete.

3.3.1 Dual-energy X-ray absorptiometry (DXA)

Before undergoing the DXA scan body mass and height were measured wearing only underwear. Nutritional intake, if any, and a subjective restitution measure from 1-10 was also noted. The first scan took place between 8:00 and 11:40 a.m. the 31st of August and the second scan between 8.10 and 11.30 a.m. the 4th of October. We scheduled the same time for each participant for both tests (see *table 3)*. BM was measured using a Seca weight scale, to the closest 0.1 kg (Seca 1; model 861, Seca, Germany). Height was measured without shoes using a wall-mounted centimeter scale (Seca Optimera, Seca, UK) to the closest 0.1 cm. Body composition was measured by a skilled technician using DXA (GE-Lunar Prodigy, Madison, WI, USA) at the University in Agder (Kristiansand, Agder) lab. No jewelry or other ornaments were allowed to be worn during the DXA test. The participants laid in a supine position in the scanning area, with their feet and legs in a natural position and kept straight using Styrofoam molds and straps. Similarly, the participants hands were put alongside, slightly away from the body, in a natural position with palms in a midprone position with the thumbs upwards using Styrofoam molds. The subjects were scanned from head to toe.

Table 2: DXA scan times

	Time	
Participants	31.08	4.10
IKSA-FP102	09:10	09:20
IKSA-FP104	09:30	09:10
IKSA-FP105	09:20	09:10
IKSA-FP111	11:00	10:30
IKSA-FP112	10:40	09:10
IKSA-FP113	11:20	10:50
IKSA-FP203	10:50	10:20
IKSA-FP204	08:50	08:40
IKSA-FP206	08:40	08:30
IKSA-FP215	11:30	11:00
IKSA-FP302	08:10	09:00
IKSA-FP308	11:40	11:10

3.4 Match performance measurements / football performance

The different running measures during training and matches were measured using GPS (S7 Vector, Catapult Sports, Melbourne, Australia) with a sample frequency of 10 Hz and an inertial measurement unit (IMU) consisting of an accelerometer, gyroscope, and magnetometer, all collecting data at 100Hz. Briefly, Catapult has specific algorithms that convert raw IMU data into easily understandable metrics for physical demand analysis in team sports. These variables can be classified as workload variables or event detection variables in general. Workload variables are solely based on accelerometer data, whereas event detection variables also include gyroscope data. Catapult Sports PlayerLoad^{TM} is an example of a workload variable (Luteberget, 2018). Players wore vests with a custom pouch between their shoulder blade for the unit. The size of the units is 81x43.5x15.9 mm and weighs approximately 53 grams. Each participant wore the same unit in every match to reduce inter-unit error. The equipment's validity and reliability will be further discussed in “Methodological discussion.”

3.5 Data processing

The Openfield software (Catapult Sports, version 2.5.0) was used to extract total distance, distance in speed zones, max velocity (max vel), PlayerLoad^{TM}, PlayerLoad^{TM} per min, PlayerLoad^{TM} per meter, accelerations (ACCs), decelerations (DECs), and change of directions (CODs). The sum of ACCs, DECs, and CODs is displayed as high intensity events

(HIEss). Speed zones thresholds were chosen and divided into low-speed running distance [LSR (0–14.4 km/h)], moderate-speed running distance [MSR (14.4–19.8 km/h)], high-speed running distance [HSR (19.8–25.2 km/h)], and sprint-speed running distance [SSR (> 25.2 km/h)]. PlayerLoad™, HIEss, ACCs, DECs, and CODs were applied as previously reported by Luteberget & Spencer (2017). Briefly, PlayerLoad™ is calculated by taking the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors (x, y, and z axes), divided by 100 (Boyd et al., 2011). PlayerLoad™ per min is calculated by dividing PlayerLoad™ by the duration of the activity. ACCs, DECs, and CODs is a summary of identified movements in the respective direction with an intensity > 2.5 m/s. Only time on pitch were included in the analysis. Data were extracted from the manufactures software and organized in Microsoft® Excel® for Microsoft 365 MSO (Version 2203 Build 16.0.15028.20218) 64-biters.

3.6 Statistical analysis

To examine the relationship between the DXA scans and external load variables, a Bayesian correlation analysis with non-parametric Kendall's Tau correlation coefficients was conducted in JASP version 0.16.1.0. The results were reported as Bayes factor (BF_{10}) and Kendall's Tau. The BF_{10} value was interpreted according to the recommendations of Quintana & Williams (2018). The magnitude of BF_{10} is divided into extreme ($BF_{10} \leq 0.01$), very strong (BF_{10} = 0.01-0.03), strong (BF_{10} = 0.03-0.1), moderate (BF_{10} = 0.1-0.33) and anecdotal (BF_{10} = 0.33-0.1) evidence for the null hypothesis and extreme ($BF_{10} \geq 100$), very strong (BF_{10} = 30-100), strong (BF_{10} = 10-30), moderate (BF_{10} = 3-10) and anecdotal (BF_{10} = 1-3) evidence for the alternative hypothesis. The magnitude of Kendall's Tau correlation coefficient was classified in accordance Hopkins et al., (2009): Trivial (τ = <0.1), small (τ = 0.1-0.3), moderate (τ = 0.3-0.5), large (τ = 0.5-0.7), very large (τ = 0.7-0.9) and nearly perfect (τ = >0.9). Descriptive results were calculated using Microsoft® Excel® for Microsoft 365 MSO (Version 2203 Build 16.0.15028.20218) 64-biters. Data are presented as mean ± SD.

3.7 Ethical considerations

Approval from the Norwegian Centers for Research Data [(NSD) *Appendix 3*] and the Faculty's Ethics Committee [(FEK) *Appendix 4]* was required to complete the project. All data used are anonymous, and the data are stored without name and date of birth or other recognizable information. The statement of consent implies certain guidelines in the study. All test results and all information associated with the subjects will solely be used in this study. Only authorized personnel associated with this project have access to the name list. The list of names and all data that can be associated with the subjects will be deleted after the project is completed. When the results of the project are published, it will not be possible to identify the subjects. Figures / graphs may be used to show individuals, but none of the results will make it possible to identify individual characters.

4.0 Methodological discussion

4.1 Design

In this study, a cross-sectional design was used. We recruited IK Start Football team as the population. Cross-sectional studies are conducted at a single moment in time or across a brief period. Individual characteristics, as well as information regarding the outcome, can be collected at the same time which is what we wanted in this study. Cross-sectional studies give a "snapshot" of an outcome and related factors at a specific point in time which let us explore the link between body composition and external load performance in official football matches (Levin, 2006). Another strength with this design is that it takes little time to conduct and that it is relatively inexpensive (Gratton, & Jones, 2010). This was only partially true in this study as the test equipment used for the body composition test and the collection of external load performance, is costly. This design does however come with some limitations. In cross sectional studies it is difficult to make causal inference. Another limitation is that the timeframe chosen could impact results (Levin, 2006). This is seen in multiple studies where they find seasonal changes in body composition (Milanese et al., 2015; Aziz et al., 2005a; Owen et al., 2018; Iga et al., 2014; Carling & Orhant, 2010). Also, situational and environmental factors can affect running performance in football matches. This is shown in Trewin et al., (2017) systematic review where they found that possession, team formation and match status (win, lose, draw), as well as temperature and altitude influence on the variability and differences in match-running performances from match-to-match. It is therefore possible to speculate if we would have gotten other results in a different timeframe

4.2 Study sample

The sample in a study is decisive for the result. In this study, the sample consisted of twelve professional male football players for IK Start playing in the second highest division in Norway (OBOS-league). Although it would be favorable to have even more players and have them at a higher level, I would consider that the level of the players is one of the strengths of this study. The second highest division in Norway is still a relatively high level and is, for example, better than a lower league team or a youth team. We could also have used multiple clubs in the second division to get a higher number of subjects, however we did not have time, opportunity, or resources to include more clubs at that level for this study. Furthermore, the sample used constitutes a group of people where the total population is relatively small, which in turn makes it difficult to recruit a larger sample size than this study has done. Another challenge around recruitment is that the group being studied can be considered special, as they are professional athletes. This can lead clubs and athletes themself not wanting to participate in the study as it can, for example, be disruptive to the training program they perform.

For future studies, it is possible to reflect on the advantages and disadvantages of using professional teams. It is a strength to get participants with almost equal training routine and training basis, as well as athletes who are used to performing in a high-performance environment. There can, however, be some disadvantages. This study had a high exclusion of subjects, from 26 to 12. This is much lower compared to the 23 players that participated in Radzimiński et al., (2020). Several subjects got injured, were ill, or did not play enough in the studied period etc., as can happen in any professional team during a period of the season. Concrete change to future research would be to ensure enough participants, possibly recruit from several teams in the same series system. It could also be considered in future studies to use players from lower levels than the second division, which can make implementation easier, however, at the cost of the players being “less professional.” It could also be considered to use a team or teams from the highest division in Norway, “Eliteserien.”

4.3 Testing procedures and instruments

A thorough body composition description of the participants was obtained by height and BM measurements as well as a completed DXA scan. The participants height, BM and body composition was measured at the same conditions in terms of clothing, time of day, nutritional intake and measuring instrument. Such controlled conditions around the measurements can contribute to an increased reliability.

4.3.1 DXA

Variations in the DXA scan can be divided into two categories: technical errors and biological variation. A DXA scan protocol should include standardization around these factors to ensure a high level of precision (Nana et al., 2015; Raffan et al., 2006). Technical errors can be caused by machine flaws or by a lack of standardization in subject preparation (clothing and jewelry), subject positioning (where differences in limb placement on the scanning bed cause variations in body composition) and the technician's protocols (Mazess et al., 1990; Lohman e al., 2009; Phillipov et al., 2001; Covey et al., 2008; Nana et al., 2016).

Biological variation in DXA estimates is caused by factors related to subject presentation, including changes in tissue hydration, as well as gastrointestinal tract contents [i.e., undigested dietary components (Horber et al., 1992 & Thomsen et al., 1998)]. In a DXA methodology review it was shown that only a third of the studies required subjects to be fasted, despite literature indicating that acute food and fluid intake can affect measurement reliability (Nana et al., 2015; Going et al., 1993; Horber et al., 1992; Thomsen et al., 1998). Nana et al., (2015) also found that training prior to the DXA scan produced detectable changes in estimates of body composition.

These are factors that have been seen, in other previous studies on athletes, to be different and poorly standardized (Nana et al., 2015), which is why we wanted to have a reliable and standardized protocol. To ensure equal conditions for each participant, the same DXA machine by the same test personnel was used during the testing of all the participants. The DXA machine was calibrated before each test day. Subject preparation, subject positioning, and hydration and food intake were all standardized as mentioned in the "Method" chapter of this thesis. The standardization we performed will therefore be a strength of this study.

There are other alternatives to the DXA scan. In the investigation of body composition have magnetic resonance- and spectroscopic imaging (MRI, MRSI), as well as computed tomography (CT), have been proven to be efficient (Bazzocchi et al., 2016). The great precision and repeatability in mass quantification and body composition are advantages of these procedures. DXA, on the other hand, is less costly, intrusive, and widely available, and only exposes patients to a small amount of ionizing radiation compared with these methods (Bazzocchi et al., 2016; Lee & Gallagher, 2008; McCargar, 2007). Bioimpedance analysis is another method used in body composition studies. This method (InBody$_{230}$, InBody$_{720}$, InBody$_{770}$, Tanita BC 418 MA) has been shown to have systematic bias (underestimation of BF% and FM and overestimation of FFM) and/or proportional bias for FM in women and FFM in men (McLester et al., 2020; Esco et al., 2015; Völgyi et al., 2008). Skinfold caliper is also a method used in studies where body composition is investigated. This method is known for variations in type of caliper used, test personnel and different prediction equations could estimate vastly different levels of body fat in the exact same test population, indicating the weaknesses of this method (Lohman et al., 1984; Pollock & Jackson, 1984).

4.3.2 GPS

When compared to 1 Hz and 5 Hz units, the 10 Hz (Catapult) GPS unit has a better ability to measure team sport movement demands (Johnston et al., 2014; Rampinini et al., 2015). A reason for this is as the speed of locomotion increases or the distance decreases, the measurement accuracy for 1 Hz decreases (Jennings et al., 2010; MacLeod et al., 2009). This is supported by Coutts & Duffield (2010) who found that at speeds greater than 20 km/h, GPS units sampling at 1 Hz may be unable to detect significant changes in running distances. This is also seen in 5 Hz units where Rampinini et al., (2015) discovered that as running speed increased, during multiple bouts of a 70-m straight-line intermittent shuttle course, validity worsened significantly. The 10 Hz GPS unit (MinimaxX S4, Catapult) also seem to be a superior for tracking athlete movement over the 15 Hz GPS unit [GPSport (Johnston et al., 2014)]. Further, the 10 Hz units produce valid measures for 15-35 m sprints, but validity decreases as speed increases (Rampinini et al., 2015). Johnston et al., (2014) supports this by pointing out the limitations when recording movement demands at speeds greater than 20 km/h. This could be a weakness in measuring HSR and SSR in this study. The intra-unit reliability in these short sprints does, however, seem to be good (Castellano et al., 2011). The inter-unit reliability of the Catapult vector S7 (same used in this study) is suitable and consistent for measures of distance, velocity, and average acceleration (Crang et al., 2021). Previous GPS units from Catapult (MinimaxX v4.0) has also been seen to have high inter-unit reliability when measuring 15- and 30 m sprints, with accuracy improving with increased distance (Castellano et al., 2011). The Catapult vector S7 has, however, been shown not to be inter-unit reliable and consistent for threshold-based accelerations and decelerations (Crang et al., 2021). Which is why we followed to recommendations of Scott et al., (2016) that an athlete should wear the same unit whenever data is collected, because when comparing a single player's running profile on multiple occasions, this eliminates any error caused by discrepancies in inter-unit reliability. According to the findings, 10 Hz GPS units can accurately track movements with good intra-unit and inter-unit reliability, however inter-unit may not be reliable for threshold-based accelerations and decelerations.

According to Barreira et al., (2016) can the built-in accelerometer in GPS devices have moderate to high reliability at various speeds, ranging from moderate intensity efforts to maximal intensity efforts, and thus can be used to monitor these types of efforts in football. This is supported in Luteberget et al., (2018) who investigated the reliability of the IMU (OptimEye S5, Catapult Sports, Melbourne, Australia) in high level handball players. They found that IMU reliable for measuring actions presented as total actions or actions ≥ 2.5 m/s. For the magnitude and direction of movement the IMU did show good reliability, however only moderate reliability as task complexity increased. Furthermore, the study found that

PlayerLoad^{TM} variables were highly reliable. This is further supported by Nicolella et al., (2018). They found that the Catapult OptimEye S5 had great intra-unit reliability, however the inter-unit reliability was found to be highly inconsistent. This indicates that players should wear the same unit whenever data is collected. Also, previous accelerometers from Catapult (MinimaxX) have shown acceptable reliability both within and between devices under controlled laboratory conditions, and between devices during field testing (Boyd et al., 2011).

The validity of various event detection factors (ACCs/DECs/COD) in football was investigated by Meylan et al., (2017). They discovered that the MinimaxX S4 correctly identified all cases of high ACCs, DECs, and COD, indicating that the event variables have a high validity (Meylan et al., 2017).

4.3.2.1 Video-based tracking systems

Shortly, I want to mention some other methods of tracking movement during matches used later in the thesis (See Part 2: Paper). Gregson et al., (2010), Barnes et al., (2014) and Bradley (2009) used a multiple-camera computerized tracking system (ProZone Sports Ltd®, Leeds, UK) which could affect the result compared to the GPS tracking system used in this study. However, prozone® is a valid motion analysis system for examining players movements on a football pitch, further validation of the tracking system can be found in Valter et al., (2006).

4.4 Statistical analysis

Bayesian correlation present the likelihood of the null or alternative hypothesis compared to the other (Miles & Banyard, 2007). Therefore one of the advantages of using Bayesian statistics, in comparison with the frequentist framework, is that it is possible to compare the degrees of belief for two competing hypotheses (Wagenmakers, 2007; Hoijtink et al., 2019). Briefly, the traditional p-value method, in the frequentist framework, is only concerned with disproving the null hypothesis; there is no way to determine whether the data favors the null hypothesis over the alternative hypothesis. Even a "large" non-significant p-value does not imply that the null hypothesis is true (Royall, 1997; Hoijtink et al., 2019). A quantity known as the Bayes factor can be used to compare the degrees of belief (Andraszewicz et al., 2015). The Bayes factor can represent the relative strength of evidence for two theories (Dienes, 2014). A Bayes factor below 1.0 indicates that there is more evidence for H0, whereas a Bayes factor above 1.0 indicates that there is more evidence for H1. None of the hypotheses are favored if the Bayes factor is 1.0 (Wagenmakers, 2007).

Kendall's Tau can be thought of as a simple function of the likelihood of seeing concordant and discordant pairs (Kerridge 1975). To put it another way, it is the difference between the probability that two variables are in the same order in the observed data versus the probability that they are in different orders. Kendall correlation and other nonparametric correlation estimators are widely used in the applied sciences (Croux & Dehon, 2010). Kendall's Tau is, however, less widely used than Spearman's rank correlation coefficient (Lapata, 2006). They are frequently robust, in the sense that they are resistant to outlying observations (Croux & Dehon, 2010). We chose to use the Kendall's tau in this study because it is better than Spearman and Pearson for small sample sizes (Bonett, & Wright, 2000). While the correlations frequently yield similar results in practice, there are times when they diverge. Kendall's Tau, for example, approaches the normal distribution faster than Spearman's r providing a benefit for small to moderate studies with 30 or less data points (Kendall, 1948; Lapata, 2006; Arndt et al., 1990). This is especially important when working with a small group of people, as we did in this study. Another issue that is related is sample size is that the Spearman rank correlation coefficient is a biased statistic (Kendall, 1948; Lapata, 2006). The smaller the sample, the more r deviates from the true population value, underestimating it most of the time. Kendall's Tau, on the other hand, does not provide a biased estimate of the true correlation. Kendall's tau also maintains a high level of control over type I error rates (Lapata, 2006; Arndt et al., 1990). Arndt et al., (1990) evaluated and compared Pearson, Spearman and Kendall's correlation coefficients using sample sizes ranging from 8 to 50. Type I error rates, power, bias, and confidence interval width were used as criteria for evaluating the correlations. They found that from a statistical standpoint, Kendall's Tau is superior. Pearson's r was the most unstable from replication to replication and produced the widest confidence intervals, despite being unbiased. The variability of Spearman's correlation was nearly identical to that of Pearson's. At small sample sizes, Spearman's r was also significantly biased for some of the scales, which is a major disadvantage when trying to estimate the size of an effect or relationship. Kendall Tau's performance was superior to both alternatives and was completely unbiased (Arndt et al., 1990).

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Part II

Paper

Association between body composition and external load performance in official football matches

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University of Agder

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Association between body composition and external load performance in official football matches

Hans-Petter Moen

Abstract

Purpose: The objective of this study was to investigate the association between body composition and external load performance in official football matches in professional football players. **Method**: There was 12 professional male footballers who participated in this study. Body composition were measured with two Dual-energy X-ray absorptiometry (DXA) scans where the mean of the two scans were used in the analysis. From the DXA scans, lean-, fat-and fat free mass variables were extracted for the whole body and regionally in the legs. In the period between the two scans seven official matches were played. The external load variables from the matches were extracted using a tracking unit with Global Positioning System (GPS) and an Inertial measurement unit (IMU). External load variables include total distance and distance at different velocities, max velocity, high intensity events and PlayerLoad™. **Results**: Bayesian correlation analysis showed there was moderate evidence and Kendall's Tau-b correlation showed moderate to large correlation between total body fat percentage and sprint-speed running distance (BF_{10} = 4.15; $\boldsymbol{\tau}_b$ = -0.52), between leg fat mass and sprint-speed running distance (BF_{10} = 3.17; $\boldsymbol{\tau}_b$ = -0.49), and between leg fat percentage and PlayerLoad™ per minute (BF_{10} = 3.31; $\boldsymbol{\tau}_b$ = -0.49). **Conclusion**: The data indicate that lower levels of fat mass and body fat percentage are factors that are related to external load performance in football. The results of this study provide practitioners with information about the association between body composition and external load performance in official matches for professional football players.

***Keywords*:** DXA, GPS, PlayerLoad™, soccer, body fat

Introduction

Although the use of GPS to evaluate physical performance is common today and body composition is important in determining football success, the link between the two in official matches has not been thoroughly investigated (Pons et al., 2019; Casajús, 2001). Several studies have been conducted to determine the physiological characteristics of football players at various levels and indicate that different field tests can be linked to match performance (Redkva et al 2018; Castagna et al., 2010; Krustrup et al., 2003; Bradley et al., 2011; Helgerud et al., 2001). Briefly, none of these articles have looked at the demands during official matches using Global Positioning System (GPS) and an Inertial measurement unit (IMU). Reason being that before 2015 the approach of using a GPS to evaluate physical performance was only allowed in training sessions and friendly matches (Pons et al., 2019). Furthermore, body fat percentage (BF%) and fat mass (FM) is shown to be a factor field tests performance (Alvero-Cruz et al., 2019; Campa et al., 2019).

Different field tests can be linked to match performance, and body composition can be linked to field tests, but there is limited research on a direct link between body composition and match performance. There is one study indicating that players with lower fat mass cover greater total distance, high-speed running distance, and sprint-speed running distance official matches (Radzimiński et al., 2019). When directly comparing body composition to match performance in official matches on professional players this is, to the best of my knowledge, the only study published to date Thus, there is clearly a research gap in this area. The aim of this study was therefore to investigate the association between body composition and external load performance in official football matches in professional football players.

Methods

Subjects

A local professional football club was invited to participate. There were 26 professional male footballers who initially gave their written informed consent to participate in the present study. To be included in the analysis of this study, the participants needed to complete both the DXA scans, play ≥ 3 matches with ≥ 60 minutes and be a part of the first team. We excluded seven due to not having both the DXA scans, six for not having played ≥ 3 matches with ≥ 60 minutes in the data gathering period and one for not being a first team player. Thus 12 players (24.8 ± 3.4 yrs, 184.2 ± 4.6 cm and 78.3 ± 4.3 kg) were included in the analysis.

The project was approved by the local ethical committee of the University of Agder and by Norwegian Centers for Research Data. The research was completed in accordance with the Declaration of Helsinki

Design

To investigate the relationship between body composition and match performance, data were collected from two Dual-energy X-ray absorptiometry (DXA) scans and seven matches over a period of five weeks, where the mean data from the DXA scans and matches was used in the analysis.

Methodology

All athletes were instructed to prepare for the DXA scan as they would for a regular competition in terms of nutrition, hydration, and sleep, and to abstain from strenuous exercise the day prior. The subjects were scheduled one by one with 10 min intervals.

Before undergoing the DXA scan body mass and height were measured wearing only underwear. Nutritional intake, if any, and a subjective restitution measure from 1-10 was also noted. We scheduled the same time for each participant for both tests. The DXA scanning timepoints for each subject between the two test periods was within ± 30 min. Body mass was measured using a Seca weight scale, to the closest 0.1 kg (Seca 1; model 861, Seca, Germany). Height was measured without shoes using a wall-mounted centimeter scale (Seca Optimera, Seca, UK) to the closest 0.1 cm. Body composition was measured by a skilled technician using dual-energy X-ray absorptiometry (GE-Lunar Prodigy, Madison, WI, USA) at the University in Agder (Kristiansand, Norway) lab. No jewelry or other ornaments were allowed to be worn during the DXA test. The participants laid in a supine position in the scanning area, with their feet and legs in a natural position and kept straight using Styrofoam molds and straps. Similarly, the participants hands were put alongside, slightly away from the body, in a natural position with palms in a midprone position with the thumbs upwards using Styrofoam molds. The subjects were scanned from head to toe.

In the matches, players were equipped with a GPS and IMU unit (S7 Vector, Catapult Sports, Melbourne, Australia). The manufacturer's software was used to extract the external load performance variables. External loads were measured using GPS with a sample frequency of 10 Hz and an IMU consisting of an accelerometer, gyroscope, and magnetometer, all collecting data at 100 Hz. Players wore vests with a custom pouch between their shoulder blades for the unit. The size of the unit is 81x43.5x15.9 mm and weighs approximately 53 grams. Each participant wore the same unit in every match to reduce inter-unit error.

The Openfield software (Catapult Sports, version 2.5.0) was used to extract total distance (TD), distance in speed zones, max velocity (max vel), PlayerLoad™, PlayerLoad™ per min, PlayerLoad™ per meter, accelerations (ACCs), decelerations (DECs), and change of directions (CODs). The sum of ACCs, DECs, and CODs is displayed as high intensity events (HIEs). Speed zones thresholds were chosen and divided into low-speed running distance [LSR (0–14.4 km/h)], moderate-speed running distance [MSR (14.4–19.8 km/h)], high-speed running distance [HSR (19.8–25.2 km/h)], and sprint-speed running distance [SSR (> 25.2 km/h)]. Briefly, PlayerLoad™ is calculated by taking the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors (x, y, and z axes), divided by 100. PlayerLoad™ per min and PlayerLoad™ per meter is calculated by dividing PlayerLoad™ by the duration of the activity and TD, respectively. ACCs, DECs, and CODs is a summary of identified movements in the respective direction with an intensity > 2.5 m/s. Only time on pitch were included in the analysis. Data were extracted from the manufactures software and organized in Microsoft® Excel® for Microsoft 365 MSO (Version 2203 Build 16.0.15028.20218) 64-biters.

Statistical analysis

To examine the relationship between the DXA scans and external load variables, a Bayesian correlation analysis with non-parametric Kendall's Tau-b correlation coefficients was conducted in JASP version 0.16.1.0. The results were reported as Bayes factor (BF_{10}) and Kendall's Tau-b. The BF_{10} value was interpreted according to the recommendations of Quintana & Williams (2018). The magnitude of BF_{10} is divided into extreme ($BF_{10} \leq 0.01$), very strong (BF_{10} = 0.01-0.03), strong (BF_{10} = 0.03-0.1), moderate (BF_{10} = 0.1-0.33) and anecdotal (BF_{10} = 0.33-0.1) evidence for the null hypothesis and extreme ($BF_{10} \geq 100$), very strong (BF_{10} = 30-100), strong (BF_{10} = 10-30), moderate (BF_{10} = 3-10) and anecdotal (BF_{10} = 1-3) evidence for the alternative hypothesis. The magnitude of Kendall's Tau-b correlation coefficient was classified in accordance Hopkins et al., (2009): Trivial (τ_b = <0.1), small (τ_b = 0.1-0.3), moderate (τ_b = 0.3-0.5), large (τ_b = 0.5-0.7), very large (τ_b = 0.7-0.9) and nearly perfect (τ_b = >0.9). Descriptive results were calculated using Microsoft® Excel® for Microsoft 365 MSO (Version 2203 Build 16.0.15028.20218) 64-biters. Data are presented as mean ± SD.

Results

Descriptive data of the external load- and body composition variables are presented in *Table 1*. The results of the Bayesian correlation analysis are shown in *Table 2* and the Kendall's tau correlations are shown *Table 3*. The results from the Bayesian correlation analysis show moderate evidence for the correlation between Total BF% and SSR, between Leg FM and SSR, and between Leg F% and PL per minute. The results from Kendall's Tau-b correlation show a large correlation between Total BF% and SSR, a moderate correlation between Leg FM and SSR, and a moderate correlation between Leg F% and PlayerLoad^{TM} per minute (PL per min).

Table 1: Results for measures of external load performance and body composition

Match data variable	Mean ± SD
Total PL	11.0 ± 1.4
PL per minute	1078.5 ± 141.5
PL per meter	0.103 ± 0.008
Total distance (m)	10525 ± 1088
Low speed running distance (m) (0-14.4 km/h)	8029 ± 713
Moderate speed running distance (m) (14.4-19.8 km/h)	1789 ± 507
High-speed running distance (m) (19.8-25.2 km/h)	589 ± 130
Sprint speed running distance (m) (> 25.2 km/h)	118 ± 54
Maximum Velocity (m/s)	8.2 ± 0.4
HIEs	287 ± 47
ACCs (>2.5 m/s)	113 ± 20
DECs (>2.5 m/s)	116 ± 22
COD (>2.5 m/s)	58 ± 12
Total tissue mass (kg)	75.5 ± 4.2
Total LM (kg)	67.6 ± 4.3
Total FFM (kg)	71.5 ± 4.5
Total FM (kg)	7.9 ± 1.9
Total fat tissue (%)	10.4 ± 2.6
Legs total mass (kg)	27.9 ± 2.2
Legs tissue mass (kg)	26.3 ± 2.0
Legs LM (kg)	23.2 ± 1.8
Legs FM (kg)	3.0 ± 0.9
Legs fat tissue (%)	11.5 ± 3.0
Legs FFM (kg)	24.8 ± 1.9

Total PL = Total PlayerLoad™; PL per min = PlayerLoad™ per minute; PL per meter = PlayerLoad™ per meter; TD = Total distance; LSR = Low speed running; MSR = Moderate speed running; HSR = High speed running; SSR = Sprint speed running; HIEs = High intensity events; ACCs = Accelerations; DECs = Decelerations; COD = Change of directions; Total LM = Total lean mass; Total FFM = Total fat free mass; Total FM = Total fat mass; Legs LM = Legs lean mass; Legs FM = Legs fat mass; Legs FFM = Legs fat free mass.

Table 2: Bayes factor between body composition and match external load

	Height	BM	Total tissue mass	Total LM	Total FM	Total BF%	Total FFM	Legs LM	Legs FM	Legs F%	Legs FFM	Legs tissue mass	Legs Total mass
Total PL	0.36	0.36	0.37	0.42	0.72	0.56	0.39	0.38	0.72	0.76	0.38	0.39	0.38
PL per min	0.38	0.38	0.37	0.38	0.55	0.45	0.37	0.42	0.55	0.57	0.42	0.45	0.42
PL per meter	0.39	0.36	0.36	0.37	0.85	1.01	0.38	0.45	1.82	3.31	0.45	0.85	0.70
TD	0.38	0.45	0.49	0.45	0.63	0.49	0.42	0.45	0.49	0.65	0.45	0.42	0.45
LSR	0.59	1.23	1.01	0.63	0.45	0.41	0.55	0.85	0.45	0.57	0.85	0.55	0.63
MSR	0.40	0.45	0.42	0.37	0.49	0.41	0.38	0.45	0.42	0.45	0.45	0.42	0.45
HSR	0.68	0.39	0.38	0.37	1.23	0.76	0.38	0.39	0.63	0.65	0.39	0.49	0.45
SSR	0.52	0.37	0.36	0.37	1.91	4.15	0.38	0.39	3.17	2.76	0.39	0.63	0.55
Max velocity	0.45	0.43	0.47	0.43	0.94	1.27	0.40	0.52	1.40	1.22	0.52	0.79	0.68
HIEs	0.94	0.49	0.45	0.49	0.45	0.41	0.55	0.63	0.45	0.45	0.63	0.72	0.63
ACCs	0.94	0.42	0.39	0.42	0.39	0.36	0.45	0.49	0.39	0.39	0.49	0.55	0.49
DECs	1.14	0.72	0.63	0.55	0.42	0.39	0.63	1.01	0.42	0.42	1.01	0.85	0.72
COD	0.40	0.42	0.45	0.49	0.45	0.45	0.45	0.38	0.45	0.65	0.38	0.37	0.38

0.01	0.03	0.1	0.33	1	3	10	30	100

BF_{10} strength (range: <0.01 to >100) is displayed by graded color backgrounds.

Total PL = Total PlayerLoad™; PL per min = PlayerLoad™ per minute; PL per meter = PlayerLoad™ per meter; TD = Total distance; LSR = Low speed running; MSR = Medium speed running; HSR = High speed running; SSR = Sprint speed running; HIEs = High intensity events; ACCs = Accelerations; DECs = Decelerations; COD = Change of directions; BM = Body mass; Total LM = Total lean mass; Total FM = Total fat mass; Total BF% = Total body fat percentage; Total FFM = Total fat free mass; Legs LM = Legs lean mass; Legs FM = Legs fat mass; Legs F% = Legs fat percentage; Legs FFM = Legs fat free mass.

Table 3: Kendall's Tau-b correlation between body composition and match external load.

	Height	BM	Total tissue mass	Total LM	Total FM	Total BF%	Total FFM	Legs LM	Legs FM	Legs F%	Legs FFM	Legs tissue mass	Legs Total mass
Total PL	-0.02	0.00	0.03	0.12	-0.27	-0.22	0.09	-0.06	-0.27	-0.28	-0.06	-0.09	-0.06
PL per min	-0.08	-0.06	-0.03	0.06	-0.21	-0.15	0.03	-0.12	-0.21	-0.22	-0.12	-0.15	-0.12
PL per meter	-0.10	0.00	0.00	0.04	-0.30	-0.33	0.07	-0.15	-0.42	-0.49 *	-0.15	-0.30	-0.27
TD	0.08	0.15	0.18	0.15	-0.24	-0.18	0.12	0.15	-0.18	-0.25	0.15	0.12	0.15
LSR	0.23	0.36	0.33	0.24	-0.15	-0.12	0.21	0.30	-0.15	-0.22	0.30	0.21	0.24
MSR	-0.11	-0.15	-0.12	-0.03	-0.18	-0.12	-0.06	-0.15	-0.12	-0.16	-0.15	-0.12	-0.15
HSR	-0.26	-0.09	-0.06	-0.03	-0.36	-0.28	-0.06	-0.09	-0.24	-0.25	-0.09	-0.18	-0.15
SSR	-0.20	0.03	0.00	0.03	-0.42	-0.52 *	0.06	-0.09	-0.49 *	-0.47	-0.09	-0.24	-0.21
Max velocity	-0.15	-0.14	-0.17	-0.14	-0.32	-0.37	-0.11	-0.20	-0.38	-0.36	-0.20	-0.29	-0.26
HIEs	-0.32	-0.18	-0.15	-0.18	-0.15	-0.12	-0.21	-0.24	-0.15	-0.16	-0.24	-0.27	-0.24
ACCs	-0.32	-0.12	-0.09	-0.12	-0.09	-0.02	-0.15	-0.18	-0.09	-0.09	-0.18	-0.21	-0.18
DECs	-0.35	-0.27	-0.24	-0.21	-0.12	-0.08	-0.24	-0.33	-0.12	-0.13	-0.33	-0.30	-0.27
COD	-0.11	0.12	0.15	0.18	-0.15	-0.15	0.15	0.06	-0.15	-0.25	0.06	0.03	0.06

-1 0.0 1

Kendall's Tau-b (τ_b) correlation coefficient (range: -1 to 1) is displayed by graded color backgrounds.

Total PL = Total PlayerLoad™; PL per min = PlayerLoad™ per minute; PL per meter = PlayerLoad™ per meter; TD = Total distance; LSR = Low speed running; MSR = Medium speed running; HSR = High speed running; SSR = Sprint speed running; HIEs = High intensity events; ACCs = Accelerations; DECs = Decelerations; COD = Change of directions; BM Body mass; Total LM = Total lean mass; Total FM = Total fat mass; Total BF% = Total body fat percentage; Total FFM = Total fat free mass; Legs LM = Legs lean mass; Legs FM = Legs fat mass; Legs F% = Legs fat percentage; Legs FFM = Legs fat free mass.

** = Bayes factor > 3*

Discussion

The aim of this study was to investigate the association between body composition and external load performance in official football matches. This is, to the knowledge of the authors, the first to investigate this association using the DXA-scan. We found moderate to large correlations with moderate evidence between the total BF%, leg FM, and leg F% with external load performance. The results of this study provide practitioners with information about the importance of monitoring body composition for professional football players.

The correlations between total BF%, Leg FM and SSR in this study are comparable to the results in Radzimiński et al., (2019). They found that players with lower total FM covers greater TD, HSR, and SSR ($r = -0.19$, $r = -0.38$ and $r = -0\text{-}57$, respectively). Radzimiński et al., (2019) did, however, classify HSR as 14.4-23.0 km/h and SSR as > 23 km/h which could impact the comparison of results. These results are expected because BF has a strong negative association with performance in activities where the body must be moved through space (Can et al., 2004).

Clemente et al., (2019) investigated the dose-response relationship between external load variables and body composition in professional football players during a 10-week period (4 weeks of pre-season and 6 weeks during the early season). They analyzed the results using magnitude-based inferences and found a large positive correlation between the sum of TD and % difference in BM [0.53, (−0.34;0.91)], and a large negative correlation between the sum of TD and % difference in FM [−0.60, (−0.93;0.25)] and LM [−0.63, (−0.93;0.21)]. They also found large positive correlations between the sum of SSR and % difference in BM [0.70, (−0.09;0.95)] and very large negative correlations between the sum of SSR and % difference in FM [−0.79, (−0.96; -0.11)] and LM [−0.71, (−0.95;0.06)], thus higher FM and LM would lead to longer running distances. These results disagree with the finding in the present study. Firstly, we did not find a meaningful correlation between BM and LM, and TD and SPR. Further, we found anecdotal evidence indicating that FM is negatively correlated to both TD and SPR ($BF_{10} = 0.63$; $\boldsymbol{\tau}b = -0.24$ and $BF_{10} = 1.91$; $\boldsymbol{\tau}b = -0.42$, respectively). A part of the findings in Clemente et al., (2019) is surprising, given that higher FM levels have been linked to decreased athletic performance (Alvero-Cruz et al., 2019; Campa et al., 2019). Therefore, other supplementary processes may explain the findings, such as significant increased VO_2 max during the pre-season period could explain the results (Vasileios et al., 2018). It is also worth noting that the confidence interval of correlations exceeds the positive threshold. Consequently, the results are uncertain regarding inference.

The results of this study can be further discussed using field tests as an intermediary between body composition and external load performance in matches. Firstly, there is a strong negative correlation between BF% and Total fat mass with VO_2 max (Silvestre et al., 2006). Greater VO_2 max and lower FM can lead to faster times in longer running distances (27km) and better repeated sprinting ability (Alvero-Cruz et al., 2019; Campa et al., 2019). Further, repeated sprinting ability has been strongly related to Yo-Yo Intermittent Recovery Test Level 1 performance (Campa et al., 2019). Better performance in Yo-Yo test is significantly related to factors such as number of HIEs, HSR, SSR and TD in matches using both GPS and time–motion analysis (Redkva et al., 2018; Castagna et al., 2010; Krustrup et al., 2003; Bradley et al., 2011). Moreover, Helgerud et al., (2001) found that as maximal oxygen uptake increased (from a mean 58.1 to 64.3 ml/kg/min) TD and number of sprints during football matches increased by 20% and 100%, respectively. This is supported by the dinding in the current study which indicate that lower levels of BF lead to external load performance in football matches by improving VO_2 max.

In the present study many different body composition variables was investigated. We found a BF% of 10,.4 ± 2.6 % which is the same as the mean 8-11% body fat range reported in Japanese, Singaporean, Greek, Serbian and English professional players, but lower than reported in Italian and Croatian professionals (Hoshikawa et al., 2005; Aziz et al., 2005; Papaevangelou, 2012; Ostojić, 2000; Milsom et al., 2015; Suarez-Arrones et al., 2019; Matković et al., 2003). The LBM found found in this study was 67.6 ± 4.3. This is similar to Greek, English and Croatian Professional players (Papaevangelou, 2012; Milsom et al., 2015; Matković et al., 2003) and higher than seen in a National Collegiate Athletic Association Division I team (Silvestre et al., 2006). The total FM in this study was 7.9 ± 1.9 kg which is similar to that reported in English professionals and lower than reported in Italian, American, and Croatian professionals (Milsom et al., 2015; Silvestre et al., 2006; Suarez-Arrones et al., 2019; Matković et al., 2003). Milsom et al., (2015) reported 3.1 kg leg FM and 23.3 kg leg LM in English professionals which is similar to the present study. The FFM reported in this study was 71.5 ± 4.5 kg and is much higher than that reported in Italian professionals (Suarez-Arrones et al., 2019). These results indicates that our subjects, in terms of body composition, is representable for professional players, nevertheless the players in the present study may have higher LBM and FFM, and lower total FM.

External load variables were also investigated. TD in this study was similar to what is reported other professional leagues (Bradley., 2009; Barnes et al., 2014; Rampinini et al., 2007). We also observed similar distance in ≥ 14.4 km/h (equal to summing MSR, HSR and SSR) compared to the English Premier League, but slightly lower than observed in a professional European club (Bradley., 2009; Rampinini et al., 2007). Further, we found considerably lower distance in ≥ 19.8 km/h (equal to summing HSR and SSR) when comparing to previous Premier League seasons and to a professional European club (Gregson et al., 2010; Bradley, 2009; Barnes et al., 2014; Rampinini et al., 2007). Moreover, SSR is perhaps the biggest difference in external load performance between the Premier League and the second tier in Norway. SSR was a great deal longer in previous English Premier League season compared to the present study (Gregson et al., 2010; Bradley, 2009; Barnes et al., 2014). The shorter HSR and SSR compared to players at a higher level, could be a reason for not finding a stronger correlation between body composition and external load performance.

These findings are somewhat like those found in Radzimiński et al., (2020), where they found a significant correlation between FM% and TD, HSR and SSR of r =-0.19, r = - 0.38 and r = - 0.57, respectively. They did however define HSR as 14.4-23.0 km/h and SSR as < 23 km/h which could affect the comparison of results. Radzimiński et al., (2020) also used the bioimpedance analysis (Tanita MC-780) method to assess body composition, which can have systematic bias and/or proportional bias (McLester et al., 2020).

Limitations

A limitation of this study was that we could not have all the athletes fasted during the DXA scan, despite the literature indicating that acute food and fluid intake can affect DXA measurement reliability (Nana et al., 2015). This was especially hard for the players with DXA scans later in the day. Also, the study design chosen can be seen as a limitation in that the timeframe chosen could impact results, and we can speculate if we would have gotten other results in a different timeframe. This is exemplified in Trewin et al., (2017) where they found that situational and environmental factors can affect running performance in football matches. In addition, this study investigated a relatively small sample size consisting of professional football players. Therefore, the extrapolation of our findings to other populations and/or sport types must be done with caution. Future studies should try to eliminate these limitations by investigating multiple clubs over the span of a season.

Practical applications

Our findings support previous studies that players with a lower fat mass percentage cover longer distances in SSR. A reasoning for this could be because players with lower body fat levels have higher aerobic capacity (Silvestre et al., 2006). Furthermore, Lago-Peñas et al (2011) discovered that successful teams were leaner than unsuccessful teams, measured as top half of the table vs bottom half of the table. All these associations highlight the importance of monitoring body composition, specifically body fat, in professional football players.

Conclusion

The results of this study provide information for coaches and scientists of top-level football. Specifically, this study demonstrated that body composition, especially fat related variables, are important for external load performance in official matches. This study used the DXA scan to measure body composition which to date has not been investigated in similar studies. Our results show a large correlation between Total BF% and SSR, a moderate correlation between Leg FM and SSR, and a moderate correlation between Leg F% and PL per minute.

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Part III

Appendix

Contents:

Hans-Petter Øiseth Moen

University of Agder

May 2022

Appendix

Appendix 1

Ultrasound

The subjects firstly went through an ultrasound scan on the test day. The ultrasound equipment used in this project was an Artus EXT-1H/LogiScan 128 CEXT- 1Z from Telemed (Vilnius, Lithuania). The images from baseline (pre-testing) were compared with the images from post-testing, to unveil possible changes in certain parameters. After this, all participants performed a standardized 10-min warm-up procedure on a treadmill.

30-meter sprint test

The sprints were measured using MuscleLabs Wireless optical timing gates (ML6TPC02, Stathelle, Norway). Each athlete was given 2-4 sprints with 4 minutes recovery between each attempt. The number of sprits were based on whether their last trial was faster than the previous or they felt they could beat their best time.

Countermovement jump test

Countermovement jumps were measured with the AMTI AccuPower-Optimized multi-axis force platform (AMTI; Advanced Mechanical Technology, Inc Waltham Street, Watertown, USA). Each athlete was given 3 sets with 3 minutes rest between. Each set consisted of 3 attempts with 20 second’s rest between each trial. The jumps were performed with their hands on their hips, and they were instructed to jump as high as possible. Jump height was calculated using the velocity at take-off and flight time. If the height of the best jump increased during the last trial, athletes could decide to try to improve their highest jump with one last set.

Leg press test

The Keiser Air300 horizontal pneumatic leg press equipment with an A420 force and velocity measuring unit (Keiser Sport, Fresno, CA) was used to measure force and velocity on the leg press. The subjects performed a 10-repetition FV-test pre-programmed in the Keiser A420 software. The full test-procedure is described elsewhere (Lindberg et al., 2021).

Appendix 2

Activation before match is a program that was used before each match to prepare for the match. The easy program was used every time it was close between matches, and they had short recovery. Only 1 or 2 sets per exercise were used here. Normal is the full training program that was used when there was a large enough period between the matches (at least 5-7 days). Here, 1, 2 or 3 sets were undertaken. In the 10-week intervention period the self-selected and objective autoregulated groups performed on average 10.56 (±1.01) and 10.57 (±0.79) workouts, respectively. Of these the self-selected group performed 5.33 (±1.12) sessions with the normal program with a mean 12.0 (±3.57) sets per workout and 5.22 (±1.56) sessions with the easy program with a mean 9.56 (±3.0) sets per workout. The objective group performed 5.0 (±0.0) sessions with the normal program with a mean 10.29 (±2.21) sets per workout and 5.57 (±0.79) sessions with the easy program with a mean 10.0 (±1.41) sets per workout.

Easy and normal are the two programs that were adjusted using autoregulation. Meters run in the high-intensity zone (> 5.5 m/s) determined how many sets the players in this group should have. 3 thresholds were used: <420 meters, between 420 and 687 meters & >687 meters

For the objectively autoregulated group, this means that the < 420 meters had 3 sets for normal program and 2 sets for easy program, the between 429 and 687 meters had 2 sets for normal program and 2 sets for easy program, and the >687 meters had 1 set for normal program and 1 set for easy program.

The self-selected (subjectively ART) group could at each session decide whether they wanted to run a normal or easy program and how many sets they wanted to complete. However, they could not choose 3 sets when they had less than 5 days between matches due to load management.

Activation before match workout:

Name of exercise	Sets	Reps	% Of 1RM
Back squat - 45˚ with barbell	3	3	80-90%
Jump squat with manuals	3	2-3	30-40%
Bench press with barbell	3	3-4	80-90%

Easy workout:

Name of exercise	Sets	Reps	RIR	Min rest
Back squat - deep with barbell	1-2	6	1-2	1-2
Assisted band jumps (Reset and wait a couple of seconds in the bottom of the jump)	1-2	4		
Glute bridge	1-2	6	1-2	1-2
Deep squat into box jump (jump as high as possible)	1-2	4		

Normal workout:

Name of exercise	Sets	Reps
Back squat – deep with barbell	1-3	6
Glute bridge	1-3	6
Bulgarian split squat	1-3	6
Seated calf raises	1-3	6
Side plank with kick	1-3	8
Pallof press	1-3	8

Appendix 3

NSD NORSK SENTER FOR FORSKNINGSDATA

NSD sin vurdering

Prosjekttittel

Hurtighetsbasert styrketrening og en longitudinell oppfølging av belastning i trening og kamp

Referansenummer

464080

Registrert

28.01.2020 av Per Thomas Byrkjedal - per.byrkjedal@uia.no

Behandlingsansvarlig institusjon

Universitetet i Agder / Fakultet for helse- og idrettsvitenskap / Institutt for folkehelse, idrett og ernæring

Prosjektansvarlig (vitenskapelig ansatt/veileder eller stipendiat)

Thomas Bjørnsen, thomas.bjornsen@uia.no, tlf: 4798619299

Type prosjekt

Forskerprosjekt

Prosjektperiode

15.02.2020 - 31.12.2021

Status

17.02.2020 - Vurdert

Vurdering (1)

17.02.2020 - Vurdert

Det er vår vurdering at behandlingen av personopplysninger i prosjektet vil være i samsvar med personvernlovgivningen så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet den 17.02.2020 med vedlegg, samt i meldingsdialogen mellom innmelder og NSD. Behandlingen kan starte.

MELD VESENTLIGE ENDRINGER
Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til NSD ved å oppdatere meldeskjemaet. Før du melder inn en endring, oppfordrer vi deg til å lese om hvilke type endringer det er nødvendig å melde:
https://nsd.no/personvernombud/meld_prosjekt/meld_endringer.html
Du må vente på svar fra NSD før endringen gjennomføres.

TYPE OPPLYSNINGER OG VARIGHET
Prosjektet vil behandle særlige kategorier av personopplysninger om helseopplysninger og alminnelige kategorier av personopplysninger frem til 31.12.2021. Data med personopplysninger oppbevares deretter

internt ved behandlingsansvarlig institusjon frem til 31.12.2026, dette til forskningsformål.

LOVLIG GRUNNLAG
Prosjektet vil innhente samtykke fra de registrerte til behandlingen av personopplysninger. Vår vurdering er at prosjektet legger opp til et samtykke i samsvar med kravene i art. 4 nr. 11 og art. 7, ved at det er en frivillig, spesifikk, informert og utvetydig bekreftelse, som kan dokumenteres, og som den registrerte kan trekke tilbake.

Lovlig grunnlag for behandlingen vil dermed være den registrertes uttrykkelige samtykke, jf. personvernforordningen art. 6 nr. 1 bokstav a, jf. art. 9 nr. 2 bokstav a, jf. personopplysningsloven § 10, jf. § 9 (2).

PERSONVERNPRINSIPPER
NSD vurderer at den planlagte behandlingen av personopplysninger vil følge prinsippene i personvernforordningen om:

- lovlighet, rettferdighet og åpenhet (art. 5.1 a), ved at de registrerte får tilfredsstillende informasjon om og samtykker til behandlingen
- formålsbegrensning (art. 5.1 b), ved at personopplysninger samles inn for spesifikke, uttrykkelig angitte og berettigede formål, og ikke viderebehandles til nye uforenlige formål
- dataminimering (art. 5.1 c), ved at det kun behandles opplysninger som er adekvate, relevante og nødvendige for formålet med prosjektet
- lagringsbegrensning (art. 5.1 e), ved at personopplysningene ikke lagres lengre enn nødvendig for å oppfylle formålet

DE REGISTRERTES RETTIGHETER
Så lenge de registrerte kan identifiseres i datamaterialet vil de ha følgende rettigheter: åpenhet (art. 12), informasjon (art. 13), innsyn (art. 15), retting (art. 16), sletting (art. 17), begrensning (art. 18), underretning (art. 19), dataportabilitet (art. 20).

NSD vurderer at informasjonen som de registrerte vil motta oppfyller lovens krav til form og innhold, jf. art. 12.1 og art. 13.

Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har behandlingsansvarlig institusjon plikt til å svare innen en måned.

FØLG DIN INSTITUSJONS RETNINGSLINJER
NSD legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og konfidensialitet (art. 5.1. f) og sikkerhet (art. 32).

Catapult Sports er databehandler i prosjektet. NSD legger til grunn at behandlingen oppfyller kravene til bruk av databehandler, jf. art 28 og 29.

For å forsikre dere om at kravene oppfylles, må dere følge interne retningslinjer og eventuelt rådføre dere med behandlingsansvarlig institusjon.

OPPFØLGING AV PROSJEKTET
NSD vil følge opp underveis (hvert annet år) og ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet/pågår i tråd med den behandlingen som er dokumentert.

Lykke til med prosjektet!

Kontaktperson hos NSD: Mathilde Hansen
Tlf. Personverntjenester: 55 58 21 17 (tast 1)

Appendix 4

Per Thomas
Byrkjedal

Besøksadresse:
Universitetsveien 25
Kristiansand

Ref: [object Object]

Tidspunkt for godkjenning: : 28/02/2020

Søknad om etisk godkjenning av forskningsprosjekt - Hurtighetsbasert styrketrening og en longitudinell oppfølging av belastning i trening og kamp

Vi informerer om at din søknad er ferdig behandlet og godkjent.

Kommentar fra godkjenner:
FEK godkjenner søknaden under forutsetning av at prosjektet gjennomføres som beskrevet i søknaden.

Hilsen
Forskningsetisk komite
Fakultet for helse - og idrettsvitenskap
Universitetet i Agder

UNIVERSITETET I AGDER
POSTBOKS 422 4604 KRISTIANSAND
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www.uia.no

FAKTURAADRESSE:
UNIVERSITETET I AGDER,
FAKTURAMOTTAK
POSTBOKS 383 ALNABRU 0614 OSLO

Appendix 5

Do you wish to participate in the research project “velocity-based strength training and a follow-up of training- and match load”?

The goal of this research-project is to explore how team players performance can change throughout a season. As a team sport player, we invite you to participate in this study. The following information is provided to inform you on the risks, benefits, and rights if you should choose to participate in this project.

AIM

A change in strength has for a period of time been perceived to have an influence on match and training performance. However, few have actually explored this potential influence. As time has evolved, the use of micro electronical measurement units (MEMS) (equipped with GPS and accelerometers), has been quite common across several elite and sub-elite team sports. These devises provide information on speed and distances, as well as short, high-intensity moves such as jumps, change of directions, decelerations and accelerations. Our aim is to explore the association between physical performance (assessed through testes) and training and match performance, measured through MEMS. In additions, we wish to assess how this develops over time (season).

WHAT DOES PARTICIPATION IN THIS STUDY MEAN FOR YOU?

By participating in this study, you consent to assess your physical performance in the following tests;

- Body composition (iDXA-scan)

- Sprint

- Jump

- Leg press

The tests mentioned, will be included as standard-tests, and can be used to assess performance at additional test-points (e.g. before, during and after a season). Completion of these tests are estimated to take 1,5 hours. Scheduled test-points are September 2020 and January 2021.

In addition to the physical performance tests, your training- and match load data will be sampled by wearing a MEMS unit. This is a small device and it’s worn inside a tight fitted west on your upper trunk. Your physical coach/a team representative will gather the data from these devices and the information will be anonymized to ID-numbers before its shared with the University of Agder. Only the project leader will have access to the decryption code (link to Name and ID). Information will be gathered until end of January 2021.

PRO’s AND CON’s ASSOCIATED WITH PARTICIPATION IN THIS PROJECT

As a participant in this project, you will be provided and given insight to scientific test-results of your physical performance. However, there are some potetial disadvantages if you choose to participate in this project:

- You have to make time (ca 1,5 hours) for each test day. Time you may wished to spend at your own choosing.

- Testing and training may be associated with muscle soreness and a discomfort.

- There always a risk of injuries during training and testing, but the risks are not expected to proceed the risks experienced during your daily training regime.

- A body composition scan (iDXA) is performed by X-ray and includes a small dose of radiation. This radiation dose is equivalent to the dose you experience during an intercontinental flight.

WHAT WILL HAPPEN TO YOUR PERSONAL INFORMATION?

We will only use the information as described in this letter. Your information will be treated confidentially and in accordance with the guidelines for personal data protection. All personal information will be anonymized. No information will be saved under your name, but under an ID-code, only decryptable by a decryption-key stored locally in a safe at the Institute of Sport Science and Physical Education offices at the University of Agder, Kristiansand. Only the project leader will have access to this safe. Your personal information will not be identifiable in research publications.

The project is scheduled to be terminated 31.01.21 an all data will thereby be anonymized. Your anonymized data will be stored for 5 years as we are obligated to store this and a decrypted name-lists for 5 years after termination of the project. This is for verification and control of the results. After these 5 years, all data from the project will be deleted.

Your rights; as long as you can be identified in the data-material, you have a right to;

- Have insight in personal material registered on you.

- Have your information corrected

- Have personal information deleted

- Have access to a copy of your personal information

- Make a complaint to a data protection official or the Norwegian data protection Authority regarding the processing of your personal information

Who gives us (the University of Agder) a right to process your personal information?

- We process your personal information by your written consent.

The Norwegian center for research data has on request by the University of Agder concluded that the processing of your personal information is in accordance with the personal information privacy policy.

VOLUNTARY PARTICIPATION

Your participation in this project is voluntary and you can at any point and for any reason withdraw yourself from the study without giving any reason for this. All your information will then be anonymized. There is no negative consequence for you if you choose not to participate or withdraw yourself from the project.

If you have any questions to the study, or wish to use your rights, please contact the project-leaders Per Thomas Byrkjedal (Doktorgradsstipendiat: per.byrkjedal@uia.no / 93498951) or Thomas Bjørnsen (thomas.bjornsen@uia.no / 986 19 299), our data protection official Ina Danielsen, Universitetet i Agder, ina.danielsen@uia.no, phone +47 452 54 401 or Norwegian center for research data (NSD) (personverntjenester@nsd.no / 55 58 21 17). The institution responsible for the project is the University of Agder.

Best regards

Thomas Bjørnsen & Per Thomas Byrkjedal

CONSENT-FORM

I have received and understood the information related to participation in the project velocitybased strength training and a follow-up of training- and match load and I've been given the chance to ask questions. I hereby consent to

• participate in the study

• that my personal information can be procced in an anonymized form until all data related to the project is deleted 31.01.26

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(Date)　　　　　　　　　　　　　　　　(Signature participant)