# The effect of Aerobic Base Training on Heart-Rate Variability and Performance in Elite Youth Football Players.

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## ABSTRACT

**Background**: It is vitally important to monitor training load, especially for elite athletes. Monitoring training load means an athletes load can then be manipulated in order to avoid undertraining or overtraining. There are many methods that can be used to monitor training load and differing ways of manipulating training load. Training load is monitored in order to ensure athletes do not over train as well as undertrain. Commonly used methods of training load monitoring include; Global positioning systems (GPS), heart rate and rated of perceived exertion (RPE) and metabolic parameters such as lactate thresholds. Heart rate variability (HRV) is a monitoring tool which shows the internal impact on the body caused from training and competition. Training at high intensity causes HRV to drop due to changes in the Autonomic nervous system (ANS), meaning a drop in parasympathetic activity and an increase in sympathetic activity in the ANS. Research has shown that steady state exercise (60-70% of maximum heart rate) can increase parasympathetic activity in the ANS which would increase HRV (Borghi-Silva *et al.*, 2009). This suggests that the impact on HRV could be used to an athletes' advantage when trying to recover internally from a training session, post session steady state exercise could increase the parasympathetic tone of the ANS quicker than naturally and therefore recover from the training session. The reliability of using HRV as a training load monitoring tool has yet to have been fully explored in a real life setting. Research has shown the impact and differences in HRV due to exercise (Kiviniemi *et al.*, 2007; Martinmäki *et al.*, 2008; Castello-Simões *et al.*, 2013) but this has been in a controlled laboratory setting and not in an applied environment.

**Purpose**: To assess the reliability of using HRV as a training load monitoring tool in a real life field environment. To analyse the effect of aerobic base training on HRV and performance in elite youth football players. To see whether aerobic base training has a direct effect on the autonomic nervous system and the subsequent change in HRV. Furthermore, whether the change in HRV has an effect on footballing performance.

**Methods**: 18 elite academy football players (Male, 17 ± 1 yrs.') training load was tracked through GPS, heart rate and HRV over a 12-week period. $VO_2$max and time to exhaustion tests were completed pre and post study in order to establish any fitness changes. All 18 completed 6 weeks of their normal football training schedule; for the second 6 weeks the participants were randomised in to two groups of 9 participants, one control and one intervention group. The intervention group completed tri-weekly aerobic base training sessions on an exercise bike at 60-70% of HRmax, each sessions duration being 30 minutes, this was in addition to their normal training schedule, the control group continued with their normal training schedule.

**Results**: There was low reliability for all HRV indices in a field setting, the most reliable indices were MeanRR, rMSSD and SDNN. There were no significant differences between groups for any parameters, including HRV (<0.05). Although not significant there was an increase in time to exhaustion for the intervention group (effect size 1.17).

There was a positive correlation between changes in MeanRR and distance covered/high intensity distance covered for the intervention group (effect size >0.6).

**Conclusion**: Aerobic base training did not have a significant effect on HRV in elite youth footballers. It did have had a positive effect on time to exhaustion and improved performance for distance covered and high intensity distance covered. A longitudinal study with greater participants is needed in this area as significant changes may not have been found due to the study being underpowered. Future research should further investigate the use of steady state exercise and its use in recovery from high training load. Furthermore, the use of HRV and monitoring systems in relation to Chronic Vs Acute training load and Chronic Vs Acute ratio.

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# Chapter 1

# Introduction

## 1. Introduction

Elite sport continues to move forward and develop, with increased financial backing and worldwide interest in sport at an elite level. Athletes are expected to compete at the highest level possible and generally all year around, very rarely breaking from training and competitions. The need to be constantly ready to compete at this high level and the level of training required has a cumulative stress on the body, which is why athletes track their training load in order to quantify the amount of training and its impact on their body (Malone *et al.*, 2015). Tracking training load is an important area in elite sport, with whole sports science departments now being common place in professional outfits. Over the past twenty years, the technology available in order to aid the tracking of training load and its impact on the athletes has been developed and become more readily available. Companies such as Prozone were the pioneers of global positioning systems (GPS) technology in sport, who were founded in 1995 and since have been constantly producing tracking devices for elite athletes. The amount of technology and companies producing training load tracking devices has increased over the last 10-15 years with GPS tracking systems have been more readily available and utilised by elite sportsmen and teams. Since 2006 more companies have produced tracking devices such as Catapult (est,2006) and StatSports who have been producing technology since 2007.

An increase in technology has allowed for further understanding in to the impact of training on the body and many different methods can now be used in order to track these impacts. Training Load is the cumulative amount of stress placed on an individual from a single workout or over a period of time; Training load = Training intensity X Training duration (Banister and Calvert, 1980). Training load can be tracked using Rate of perceived exertion (RPE) (Gomes *et al.*, 2015), heart rate monitoring (Plews, Laursen, Kilding, *et al.*, 2013), GPS tracking (Malone and Drust, 2014) , heart rate variability (HRV)(Edmonds, Sinclair and Leicht, 2013) among others. It is important to track training load to monitor how athletes are responding to training, where extreme training responses can lead to maladaptation and injury (Casamichana *et al.*, 2013). Monitoring of individuals within a team environment is important as external loads will have differing internal loads on individuals (Flanagan and Merrick, 2013). Team sports often use tracking systems in order to quantify training load, GPS tracking becoming common place in many sports, with companies creating sport specific technology i.e. Prozone in football (Buchheit *et al.*, 2014; Castellano, Alvarez-Pastor and Bradley, 2014). As GPS only tracks external exertion, this is often coupled with internal monitoring such as the use of heart rate tracking which allows for internal load on the body along with static exertion. Duration of the session should also be taken in to account due to psychological fatigue.

Training load tracking devices such as GPS monitoring is a measurement of the external load being placed on the athletes whereas other tracking devices assess the internal impacts the training has on the body. The internal tracking most commonly used is heart rate responses; this is used though either tracking heart rate throughout the session and can be quantified as a percentage of maximum heart rate or post-exercise analysis of heart rate variability. GPS tracking can produce many performance parameter outputs to give coaches objective data as to the intensity of the training session or match. Coaches can set targets/goals from these different performance parameters, for example it has been suggested that in football coaches should look to achieve 2.5 times a player's GPS game output throughout a week of training (Thorpe *et al.*, 2015). It is important to track training load to avoid overtraining/fatigue and a reduction in performance; also to avoid undertraining and subsequently the athlete not being able to perform to the standard required (Halson, 2014). Overtraining/undertraining can also increase the likelihood of sustaining an injury (Rogalski *et al.*, 2016).

As well as external tracking of training load, the internal impact of training should be monitored and manipulated. Having the technology to track training load and the data to show how far an athlete has run is one thing, but knowing the internal impacts and then trying to manipulate it is another. Heart rate variability (HRV) is the variation in the time interval between heartbeats. HRV is not a modern invention. The first written mention of Heart rate variability (HRV) was in ancient China by physician Shu-he Wang (265 to 317 AD) who described how heart rhythm can be an indicator of disease; "if the pattern of the heart beat becomes as regular as the tapping of a woodpecker or the dripping of rain from the roof, the patient will be dead in 4 days" (Lui et al., 1988). A decrease in HRV can be detrimental to and a reduced HRV has been shown to be a predictor of morality. HRV originates from a clinical setting and has been used to monitor individuals with disease and used to track the progress when rehabilitating patients recovering from diseases (Pagkalos *et al.*, 2008; Castello-Simões *et al.*, 2013; Herbsleb, Mühlhaus and Bär, 2014). HRV has been shown to be effected by exercise, heart rate variability is directly affected by high intensity exercise (Thorpe *et al.*, 2015), an increase in high intensity exercise has a subsequent decrease in heart rate variability (Bricout, DeChenaud and Favre-Juvin, 2016). Heart rate variability drops due to an increase in sympathetic activity in the autonomic nervous system (ANS) and a subsequent reduction in parasympathetic activity. It is clear that HRV has a direct relationship with ANS activity, therefore, manipulating the ANS activity would have an effect on HRV. Athletes may want to manipulate their HRV in order to aid recovery from high intensity training sessions and recover internally before their next session. As previously mentioned high intensity training has a negative effect on heart rate variability, causing HRV to decrease after training. This post-training effect on HRV can last up to 4 days until HRV returns to its pre-exercise level (Edmonds, Sinclair and Leicht, 2013). Speeding up this recovery process or reducing the effect that high intensity exercise has on HRV would be beneficial to athletes as it would reduce cumulative effects of many high intensity training sessions in a short period of time. Using HRV is an appropriate monitoring tool for the internal impact of exercise on an athlete and manipulating the internal impacts may be of benefit.

HRV can be a tool to track fatigue and recovery (Plews, Laursen, Stanley, *et al.*, 2013). A decrease in HRV would demonstrate an internal impact from training, an athlete's HRV returning to pre exercise values would show that the athlete is fully recovered (Kiviniemi *et al.*, 2007). When an athletes HRV does not fully recover after exercise before the next training session/match, then this could cause cumulative fatigue if this continues to happen over a season. When an athlete does not have time to sufficiently recover or is not aided in their recovery through the season, then performance may be affected (Garet *et al.*, 2004). Low intensity exercise can stimulate the parasympathetic nervous system (PSNS) and increase the tone in the ANS (Kiviniemi *et al.*, 2007; Castello-Simões *et al.*, 2013). Increasing the PSNS activity may be beneficial to an athlete to help increase their HRV post-exercise. As mentioned earlier, the manipulation of the ANS and therefore HRV could be beneficial to athletes as an aided recovery would mean the athlete would be an a less fatigued state when performing their next exercise session.

The use of additional sessions in order to manipulate the ANS activity of athletes has not been fully investigated. Team sports, such as football, focus on training for a short period of time each day, but usually with large amounts of high intensity periods that replicate game conditions. Training usually aims to get athletes working in their "red zone" i.e. at a high intensity. Elite football training will last for typically between 1-2 hours each day, with the percentage of time in the red zone varying depending on match schedule. These high intensity sessions will cause a reduction in HRV due to the stress on the body causing changes in the ANS. Post-competitive match HRV may be reduced even further due the high psychological stress of a game situation coupled with the high physical demands on the body (Kiviniemi *et al.*, 2007; Edmonds, Sinclair and Leicht, 2013; Plews, Laursen, Stanley, *et al.*, 2013).

Literature then, has suggested that low intensity exercise will increase HRV (Kiviniemi *et al.*, 2007; Castello-Simões *et al.*, 2013), which could potentially help recovery after training sessions and manipulate HRV. Reducing the internal impact that training sessions or matches have on athletes would be beneficial as it can help reduce cumulative fatigue throughout a competitive season or allow coaches to increase the intensity of sessions, knowing that players will have aided recovery after their session and fatigue can be managed. Fatigue has been seen to significantly decrease physical and technical performance in elite soccer players (Rampinini *et al.*, 2009). Fatigued individuals have an increased risk of injury due to a decrease in ability to balance, avoidance of fatigue and preconditioning may prevent injury occurrence (Johnston *et al.*, 1998). Soccer players performance has been seen to be affected negatively by fatigue (Lyons et al. 2006; Rampinini et al. 2008). This previous literature has highlighted the importance of avoiding fatigue due to its detrimental impact on performance, thus suggesting that any way to hinder fatigue or speed up the recovery process after athletes become fatigued would be beneficial.

Training load is usually tracked to highlight any players that may need their load manipulating in order to achieve a balance between the adaptations needed to prepare for matches the detrimental consequences of undertraining or overtraining. Preparation for matches varies throughout a competitive season as the training and match demands in team sports can vary dramatically depending on the quality of the opposition, the time scale between matches as well as the distance and team has to travel to the match. Training load should be prescribed with all the mentioned variables being taken in to consideration (Kelly and Coutts, 2007). Training load can be manipulated through the use of training periodisation. This requires alternating training load and recovery in order to avoid excessive fatigue and overtraining. Long term periodisation plans are split in too Macro-, Meso- and microcycles aiming to provide peaks in performance at the relevant times. Avoiding and imbalance between training load and recovery should then avoid excessive fatigue and a negative effect on performance (Smith, 2003). It has been made clear from previous research that training load should be manipulated and that excessive fatigue should be avoided as well as athletes recovering from inevitable fatigue from training sessions and matches.

Any possible intervention that could improve recovery time or reduce fatigue caused by training sessions would be beneficial in sport. This area has only recently been researched in sport, but the practical application and potential performance benefits to athletes has not been defined and new research should aim to investigate the use of certain types of exercise or protocols in order to improve fatigue and manage training load.

The purpose/aims of this research:

- Assess the reliability of HRV in a field setting.
- Can aerobic base training aid recover and increase HRV?
- Does manipulating HRV have an impact on GPS statistics in footballers?

# Chapter 2

# Literature Review

## 2. Literature Review

### 2.1 – Background/advancements of monitoring in Football

Football is the most popular sport in the world and attracts interest from all over the globe, the World cup final 2014 had over 20 million viewers in the UK alone and over 1 billion people worldwide (FIFA, 2014). The game has progressed significantly in the last 15-20 years, with the introduction of the Premier League and the increased money investment by big deals coming from high TV demand and companies such as Sky and BT. Sky have paid £4.2 billion in a three-year deal to broadcast premier league games from 2016 onwards. The cost of TV rights has increased 71% from 2012-13 season and now costs TV broadcasting companies pay on average £10.19 million per game they show live on TV. The rise in Premier league TV income has risen from 1992; rights for 1992-97 cost £191 million and now rights for 2016-19 costs £5.136 billion. These figures have slowly risen from 1992; although there was a plateau from 2001-2013 and the cost of TV rights was between £1.2-1.8 billion, this was until recent years with two jumps in price for 2013-16 and then 2016-19(BBC, 2015, http://www.bbc.co.uk/news/business-31379128).
The development of commercial and marketing aspects of the game has been reflected by changes in the physical and psychological demands of training and matches. In the past ten years there has been an increased importance placed on the physical capabilities of football players, with attributes such as speed, endurance, strength and power are of great importance (Suchomel, Nimphius and Stone, 2016). During elite level games players will cover on average 11,393m, ranging from 5,696m to 13,746m depending on position played along with other extraneous variables (Di Salvo *et al.*, 2007). The demands on individuals is very position specific; central midfielders on average cover the most overall distance whereas wide midfielders on average cover the most distance at high intensities (Di Salvo *et al.*, 2007).

A standard training week for a professional football team consists of four training days. Usually, training days are Monday, Tuesday, Thursday and Friday with a rest day on Wednesday; with the game taking place on a Saturday followed by a rest day on Sunday. Training load varies week to week, this can be due to periodisation of training load from coaches (Smith, 2003), or due to some weeks being harder than other because of fixture location and difficulty (Kelly and Coutts, 2007). Regardless of the teams differing situation it is recommended that players achieve two and a half times the average distance a player covers in a 90 minutes' competitive match throughout the week (Thorpe *et al.*, 2015). This includes the distance covered at the game (i.e. if a player usually covers 10,000m in a game, coaches would be looking for the player to cover 25,000m in a week with one game and four training sessions. This may be adapted due to stage of the season and if teams are following a periodisation model (Thorpe *et al.*, 2015).

The football schedule for League 1 and League 2 teams in England means a minimum of 49 games throughout the season. The league consists of 46 games, originally scheduled to be completed in 46 weeks, meaning one game every seven days. In addition to this, the teams must compete in various cup competitions; meaning a minimum of an extra 3 games, potentially rising to 72 games if the final is reached in all competitions. Although Premier league teams play 8 less league games than the other English divisions the amount of games played in a season can be even higher still with the most successful teams also playing in Europe; the champions league can add up to 13 extra games and the Europa league potentially adding up to 15 extra games on the an already intense season. The differing number of games at different levels should be considered but as well as the level that the games are being played at (Kelly and Coutts, 2007). Kelly & Coutts found that there is a higher demand (training load) when the match difficulty is higher due to the increased physical and psychological demands. They also found that travel had an impact on the load on the body and these factors should be considered. This high training load needs to be monitored to the best of the player/coach's ability and resources, where recovery protocols should be followed as well as conditioning to meet the demands of the season. There are many different recovery protocols; ice baths can reduce muscle damage/discomfort as well as speed up the recovery of the neuromuscular function (Ascensão *et al.*, 2011), increased protein intake, either using supplementation or diet adaptation can aid recovery in professional footballers (Bettonviel et al. 2016). Sleeping post-match can help recovery for professional footballer. Sleep deprivation has a negative effect on recovery time, resulting in impaired muscle glycogen repletion, impaired muscle damage repair and an increase in mental fatigue (Nedelec *et al.*, 2015). Professional football players usually need 48 hours to recover from a competitive match (Djaoui *et al.*, 2016).

Due to the high performance demands footballers go through in games it is essential that training load is monitored correctly and recovery protocols are followed in order to avoid fatigue and a reduction in playing performance along with increased chance of injury occurrence. With this high amount of physical and psychological demand on the body throughout the season it is essential that training load is monitored by coaches and support staff.

## 2.2 - Training Load

Quantifying training load has long been of interest to coaches/scientists and how it can be tracked, managed and manipulated, especially in elite sports (Smith, 2003; Casamichana *et al.*, 2013). The demand for staff to monitor, control and manipulate training load has become higher in recent years coinciding with increased game and training demands (Henderson *et al.*, 2015). Monitoring training load is important so coaches know whether training targets are being met or whether athletes are under-training / over-training (Henderson *et al.*, 2015).

A precise quantification of training load for an individual/team allows coaches to further understand the impacts of training/competition on the athlete/team and then make any alterations accordingly. It is very hard for athletes and coaches to judge between the fine line of undertraining and overtraining, the ideal state of an athlete being at 'peak' for competition in terms of optimum training adaptations and fitness but with little fatigue (Issurin, 2010). Coaches and athletes try to monitor the impacts of training, especially at a high intensity and then this can be manipulated in such ways to avoid fatigue and strive for optimum performance (Halson, 2014). It is important to track internal (i.e. Heart rate) and external (i.e. GPS) training load in both training and competition to ensure that targets are being met in terms of replicating a competition environment (Malone, 2014).

Athletes are exposed to higher internal and external loads when in competition rather than training (Henderson *et al.*, 2015). It is essential that this load is managed and optimal physiological and psychological health is maintained. Training load needs to be evaluated in one form or the other usually over several tools recording certain parameters to define training load, it is important to report internal and external measures of training load (Lovell *et al.*, 2013). External training load is defined as work completed by the athlete, measured independently of his or her internal characteristics (Wallace, Slattery and Coutts, 2009). While external training load is important to track i.e. the distance covered/number of sprints/accelerations/decelerations in a session, the internal impacts of covering this distance should also be monitored. Internal training load is the physical and psychological stress caused from the external load i.e. time spent in certain heart rate zones. Zones usually split in to percentages of maximum heart rate (MHR) such as 85-100% of MHR. Many individual characteristics can affect the internal impact of training such as fatigue status of the athletes, as well as individual differences; completing a certain training task will have a range of different physical and psychological requirements for each athlete. If training load is reported correctly and then managed appropriately then load can be manipulated to enhance the performance of athletes (Halson, 2014). Training load needs to be managed and manipulated in order to try and keep player availability as high as possible throughout the season. Injuries have a significant effect on a team's performance. Lower injury burden and higher player availability were associated with a higher league ranking (Hägglund *et al.*, 2013) thus stressing the importance of injury prevention and a high player availability in elite football. Leicester City, the current Premier league champions were second lowest in the league for days missed through injury (Injury league). Undertraining or overtraining can both be a reason for injury occurrence, hence the importance of putting players under the correct load. Research has shown that a lower injury burden and higher match availability were associated with increased points per league match, suggesting that player availability has a significant influence on performance for male professional footballers (Hägglund *et al.*, 2013). Having lower injury incidents has been seen to not only correlate with games won but also other aspects of performance. Lower injury occurrence strongly correlated with team ranking position, more games won, more goals scored, greater goal difference and total points (Eirale *et al.*, 2013).

Coaches need feedback in order to modify sessions in order to avoid undertraining or overtraining. The quantifying and tracking of training load can help with identifying when players are at higher risk of injury as well as being physically prepared to compete. There are many different ways of monitoring training load and tracking external and internal changes in order to understand impacts on the athletes. Many different methods are used in elite sport - the following sections are an overview of measures of training load and impact of training load including; RPE, Heart Rate monitoring, GPS and HRV.

2.2 (1) Rating of perceived exertion

Using perceptual methods to quantify training load is not a new concept in the sporting world. The Borg Scale (Borg, 1970) has been used and adapted over recent years and is widely used in sport to monitor training and competitions (Lovell *et al.*, 2013; Lupo, Capranica and Tessitore, 2014; Gomes *et al.*, 2015). Rating of perceived exertion (RPE) is a term frequently mentioned with training load (Gomes *et al.*, 2015). The Borg scale was originally designed for and used in clinical and medical settings and can be used when patients are performing tests as well as a modified CR10 scale which was used to give feedback for patients with conditions such as angina, dyspnoea and musculo-skeletal pain. This scale has been used in a sporting context to rate the intensity of a training session or competition (Lovell *et al.*, 2013). The athlete is asked to state a number to indicate how hard they are perceiving their session to be and is used as a tool to track how hard an individual is finding exercise. The original Borg Scale was rated 6-20, 6 being easy and 20 being maximal; this was to replicate heart rate by multiplying the score by ten. i.e. maximal exercise at a scale of 20 would suggest a maximal heart rate of around 200bpm. The Borg Scale 6-20 RPE would be used when exercise is taking place and participants/athletes are asked during exercise to rate how hard they are currently finding performing the exercise. This has since been modified in (Foster *et al.*, 2001) and is commonly used with a scale of 1-10, where 1 is at rest and 10 is maximal. This form of RPE is taken directly after the training session has finished, rather than during the training itself. The athletes are asked to immediately reflect on the session they have just finished and how hard they found the overall session to be, this is known as “session RPE” when used in a sporting context with a 1-10 scale. Using the same principles as the original Borg scale, the higher the number then the harder the athlete has perceived the session to be, 1 would indicate not hard at all and 10 would indicate maximal exertion.

RPE is widely used in sport and has been shown as a practical method to quantify training load, due to the method being cheap, easy to implement and time efficient (Lovell *et al.*, 2013). There have been many studies in to the use of perceived exertion and how accurate it can be for measuring training load in different sports (Lupo, Capranica and Tessitore, 2014; Gomes *et al.*, 2015; Rodríguez-Marroyo and Antoñan, 2015). RPE can be used in individual sports for the athlete to be monitored and training load to be periodized in order to avoid fatigue or overtraining. RPE has been found to be a valid and practical method of quantifying training load in professional tennis players (Gomes *et al.*, 2015),and has been validated as an accurate easy-to-use, non-invasive method for measuring training load in swimming (Wallace, Slattery and Coutts, 2009). RPE was consistent with other standard training load methodologies such as heart rate zone based analysis (Lupo, Capranica and Tessitore, 2014). Furthermore, session RPE has been shown to quantify training load in many team sports. This is highly beneficial for team sports as the cost of other monitoring equipment can be high, heart rate and especially GPS hardware and software will cost teams thousands of pounds to obtain and then run; it has been found that using session RPE is a useful and effective way of tracking internal training load in youth water polo players (Lupo, Capranica and Tessitore, 2014).

RPE is a method that can be used when trying to quantify not only the physical impact a training session or competition had but also its psychological impact on the athletes (Rodríguez-Marroyo and Antoñan, 2015; Djaoui *et al.*, 2016). Using internal monitoring such as the commonly used method of tracking heart rate only takes in to account the physiological impact placed upon the athlete (Rodríguez-Marroyo and Antoñan, 2015). A training session could have showed relatively low impact on internal factors I.e. the session did not provide a great deal of time in the high intensity zone; however, the athlete may have perceived the training session to be hard and may have found it stressful or psychologically challenging, this is where RPE can become an effective tool. RPE has been shown to accurately show both the physical and psychological impact of a training session (Rodríguez-Marroyo and Antoñan, 2015).

The use of RPE in a sporting context has been widely researched, the use of perceived stress on the body can be assessed against actual stress on the body which can be calculated in a number of ways such as Heart rate monitoring or GPS tracking. Elite youth football players have been found to perceive the training load significantly higher than that which the coach intended, this can lead to maladaptation of training (Brink *et al.*, 2014) , which is why it is of great importance that coaches monitor some kind of session RPE in order to avoid over training. Furthermore, it has been noted that session RPE is a good indicator in terms of the how a session has impacted youth elite football players psychologically. Using RPE gives the coaches an indication of the impact both physically and psychologically the session had, rather than just physical indicators such as heart rate (Rodríguez-Marroyo and Antoñan, 2015). RPE has been shown to be largely associated with GPS distance covered and is valid to use as a method of assessing training load (Casamichana *et al.*, 2013). Although session RPE has been shown to be a useful tool in assessing training load of a session and it a cheaper option rather than using GPS technology, the GPS provides additional performance data which can be evaluated. RPE only provides training load quantification and cannot be used to track performance like GPS technology.

<u>2.2 (2) HR monitoring</u>

Monitoring training load by looking at changes in heart rate is not a new concept in sport. The use of zones calculated from percentage heart rate was first proposed by (Banister and Calvert, 1980), where using a score based on heart rate and a 'Training Impulse' (TRIMP) score for exercise intensity can be given. A TRIMP calculates the fitness/fatigue of an athlete by rating each training session with a score of 1,2 or 3 depending on what heart rate zone the athlete was working in. This was adapted in later research by classifying heart rate zones due to ventilatory thresholds i.e. 1= low intensity (<VT1), 2= moderate intensity (VT1-VT2) and 3= high intensity (>VT2). Ventilatory threshold during short-term exercise is defined as the $O_2$ uptake immediately below the $VO_2$ at which pulmonary ventilation increases disproportionally relative to $VO_2$. During long-term exercise it is defined as the $VO_2$ immediately below the $VO_2$ at which the pulmonary ventilation continues to increase with time rather than attain a steady state (Reybrouck *et al.*, 1986). Time spent in each is then multiplied by the relevant coefficient in order to provide a TRIMP score (Lucia *et al.*, 2003). A TRIMP calculation was first used by (Banister and Calvert, 1980), where the intensity of the session was multiplied by the duration. However, using this generic equation may not suit certain sports, especially intermittent sports such as football as a HR average may not be the best way to analyse due to near maximal bursts followed by low intensity (Ascensao *et al.*, 2008). Banister's generic formulas do not take in to account any individual differences in athletes that could effect training load, only gender (Impellizzeri, Rampinini and Marcora, 2005).This research suggested a modified equation to produce a TRIMP score; modified TRIMP calculations have been used in more recent studies (Brink *et al.*, 2014). Coaches have monitored the intensity of training by setting heart rate zones as a percentage of heart rate maximum. High intensity training would be classified by how long athletes are in their "red zone" for during the session. Red zone thresholds can be set generically by coaches I.e. >80% of maximum heart-rate (MHR), or can be set individually by using individual thresholds as mentioned earlier (Lucia *et al.*, 2003). Coaches and athletes aim to use interval type training at a high intensity i.e. >80%. High intensity interval type training has been shown to be more effective in increasing $VO_2$max and stroke volume compared to lactate threshold or at 70% of HRmax. Lactate threshold is the exercise intensity at which the blood concentration of lactate and/or lactic acid begins to exponentially increase (Helgerud *et al.*, 2007).

Heart rate monitoring and the use of "zones" to track heart rate once playing sport/doing exercise is now readily available to the general public, but is still one of the prime training load monitoring systems used in most elite sports (Lupo et al. 2014; Owen et al. 2015; Stanula et al. 2016). Working at different intensities provides different physiological adaptations and the proportions in energy delivery from the different energy systems changes. Working below 70% of HR max will for most players predominately be using the aerobic system (Gilman, 1996), whereas working in a zone of >85% of HR max will be using the anaerobic system. Heart rate monitoring when performing football specific exercise has been found to be a valid indicator of actual exercise intensity (Hoff *et al.*, 2002).

Heart rate can be used to predict potential injury risk (Owen et al. 2015). Coaches can use the time spent in high intensity zones for set periods of time and reduce training load for certain athletes or groups of athletes due to their training load being too high. Owen et al's study over two years on training intensity and injury incidence in elite-level professional soccer players, found that there was a significant correlation between training volume at a high intensity (>85% MHR) and injury incidence (Owen et al. 2015). Furthermore, it was found that increased training volume at high intensity did not increase the odds of injury occurrence when training, but did increase the odds of injury occurrence in matches (Owen et al. 2015).

Research on heart rate response during a competitive game has found that the average exercise intensity during a competitive match is 80-90% of maximum heart rate. Approximately 65% of the total match duration is spent at an intensity of 70-90% of HR Max and rarely drops below 65% of HR Max (Alexandre *et al.*, 2012). It has been found that heart rate response during competitive matches is position specific in terms of exercise intensity (Gonçalves *et al.*, 2014). Generally, midfield players show the highest load for heart rate response; followed by forwards and full backs, then central defenders (Di Salvo *et al.*, 2007; Gonçalves *et al.*, 2014). Research has suggested that in order to emulate match play in terms of heart rate responses, coaches should consider interval type training and small-sided games as this type of training can improve both aerobic capacity and the ability to repeat high-intensity actions (Henderson *et al.*, 2015).

Due to these studies, this has led to football clubs using either >80% or >85% as a marker to hit to be achieving high intensity training, associated with emulating match day demands (Gilman, 1996; Alexandre *et al.*, 2012; Gonçalves *et al.*, 2014). The suggestion of training at the average intensity of a competitive game, may not be the optimum way to train in order to avoid fatigue and have players ready to perform and meet the demands of a game. Research states that the mean average of intensity in a game is between 70-90%, however, this suggests that there are times where the intensity will exceed 90% of MHR and may be close to maximum and during match play intensity rarely drops below 65% of HR max (Alexandre *et al.*, 2012).

Training zones can change throughout a competitive season. An athletes training zones worked out on ventilatory and lactate thresholds at the start of pre-season will be occur at different heart rate percentages at the end of pre-season due to physiological adaptations from training and matches (McMillan *et al.*, 2005). Research has shown that lactate thresholds in youth football players changed over the football season, running velocity at the first blood lactate inflection point and the point at which blood lactate reached 4mmol $l^{-1}$ significantly increased over the pre-season period (McMillan *et al.*, 2005). Research has shown that variations in fitness will occur throughout a competitive football season and fitness may not be maintained over this period (Brady and Maile, 1996). It has been suggested that this is due to changes in match and training intensity/volume and that coaches should track training load in order to tailor training volume and intensity to strive to maintain fitness throughout the season (Brady and Maile, 1996).

This raises the debate of whether working at an intensity of 80-90% in training is beneficial to the coaches and players. Working in this ‘middle zone’ so neither low intensity or very high intensity, may result in cumulative fatigue over a long ten-month season. It may be physiologically more beneficial to work in a ‘low intensity zone’ and a ‘very high intensity zone’, thus reducing fatigue while also training to meet the very high intensity bursts needed in a game situation. It has been suggested that training mainly at a low intensity with only short periods of high intensity work could be beneficial in endurance athletes (Seiler and Tønnessen, 2009). Evidence suggests that an 80:20 ratio of low to high intensity training gives long-term results among endurance athletes and that low intensity training is effective in stimulating physiological adaptations and is not wasted time (Seiler and Tønnessen, 2009). The study also found that an increase in training duration and volume by adding longer periods of low intensity training correlated positively with improvements in physiological variables and performance.

Although the value of low intensity exercise has been seen in endurance sports such as distance running, rowing, cross-country skiing, cycling and swimming (Seiler and Tønnessen, 2009), it has not been used in team sports such as football where there is more focus on high intensity periods of exercise and at other times being in a “middle zone”, where heart rate rarely drops below 65% with the majority being between 70-90% of HR max (Alexandre *et al.*, 2012). The previous research showing benefits of low intensity exercise raises the question of implementing low intensity sessions in to team sports such as football. Although an 80:20 split of low and high intensity may not be beneficial due to football not being as endurance based as the sports in Seiler & Tønnessen’s study the implementation of extra low intensity sessions or changing some of the “middle zone” training to low intensity could be investigated due to the potential benefits.

2.2 (3) Global Positioning System (GPS) Tracking

The most recent monitoring system introduced to football has been the use of global positioning system (GPS) tracking systems in order to analyse training load (Malone, 2014). GPS use satellites to track movements of athletes and provide performance parameters such as; total distance covered, high intensity distance covered, accelerations, decelerations and work to rest ratio (Henderson *et al.*, 2015). GPS is a tool used by many professional football clubs (Massa *et al.*, 2013) and there has been extensive research in to the use of GPS in team sports and specific studies on its use in football (Buchheit *et al.*, 2013, 2014; Arruda *et al.*, 2015; Mallo *et al.*, 2015; Malone *et al.*, 2015; Rampinini *et al.*, 2015). It has been found that certain parameters can be used to predict fatigue/training load in different parts of the season as well as spotting when an athlete has a higher chance of a soft tissue injury. It has been found that during congested schedules where there are lots of matches in a short space of time, accelerations is the variable that is most effected by the busy competition schedule (Arruda *et al.*, 2015). It was found that other variables such as total distance covered, high speed running and running speed were not affected by the increased load due to matches (Arruda *et al.*, 2015). Accelerations per minute significantly dropped over the match schedule (Arruda *et al.*, 2015). However, when looking at a normal footballing schedule when playing a match once every seven days and training 4 days a week it has been found that high intensity running is linked strongly to internal training load in individual athletes (Scott *et al.*, 2013). Using high intensity running as a marker of training load may be more reliable than using perceptual method such as RPE. Perceptual methods of training load may be underestimated when it comes to training days due to the recovery time in between high intensity bouts. A large amount of training constitutes standing, walking or working at a low intensity, this extended recovery can lead to athletes perceiving the session to be easier than it was in terms of internal impacts on the body. High speed running then may be more appropriate to use when quantifying the internal load of a training session (Scott *et al.*, 2013).

When using GPS, it is important to take in to account possible error (Rampinini *et al.*, 2015). It has been found that devices that use a higher sampling rate are more accurate. GPS that has a sampling rate of 10Hz has been found to be 30-50% more accurate that a rate of 5Hz when tracking total distance, high speed running (>4.17 m/s) and very high speed running (>5.56) (Rampinini *et al.*, 2015). Similarly, different systems are not interchangeable, when tracking a team over a long period of time. Moderate differences were found between four different GPS monitoring systems and these differences should be taken in to account when using different systems (Buchheit *et al.*, 2014).

<u>2.2 (4) HRV</u>

HRV described in its simplest form is 'the variation in time intervals of heartbeats'. HRV can be analysed by measuring the time between points R-R of the QRS complex of the ECG wave.

HRV is controlled by the autonomic nervous system (ANS) (Aubert, Seps and Beckers, 2003), which is made up of three components; the parasympathetic nervous system, sympathetic nervous system and the Enteric nervous system (Jänig, 1989). The sympathetic and parasympathetic components oppose each other in their physiological effects on the body, with the sympathetic nervous system responsible for stimulating activities and is part of the 'fight or flight' response (Nakamura, Yamamoto and Muraoka, 1993), the sympathetic nervous system accelerates bodily functions and is associated with stress upon the body (Uusitalo *et al.*, 1996). The parasympathetic nervous system is responsible for relaxation and helps the body rest and recover (Berntson *et al.*, 1997). A fluctuation in HRV is due to the influences of the parasympathetic and sympathetic factors. Sympathetic factors are raised when the body is under physical or psychological stress and this affects the balance of the sympathetic and parasympathetic nervous systems, thus having an effect on the individuals HRV (Kiviniemi *et al.*, 2007). Individuals who exercise regularly generally have lower resting heart rates and higher HRV than sedentary individuals (Vesterinen *et al.*, 2013).

There has been a significant increase in research into HRV in recent years (Winsley, 2002; Schroeder *et al.*, 2004; Kaikkonen *et al.*, 2010; Castello-Simões *et al.*, 2013; Saboul, Pialoux and Hautier, 2013). Many studies on HRV have used HRV for individuals with illness/disease (Pagkalos *et al.*, 2008; Castello-Simões *et al.*, 2013; Herbsleb, Mühlhaus and Bär, 2014). Using exercise in the rehabilitation of patients has been widely used and investigated, research has found that; exercise increases

HRV in morbidly obese individuals after undergoing gastric bypass surgery (Castello-Simões *et al.*, 2013) , increases HRV values in type 2 diabetes patients (Pagkalos *et al.*, 2008), along with patients suffering from mental illness such as schizophrenia (Herbsleb, Mühlhaus and Bär, 2014).

HRV has also been researched in a sporting context, with much of the research in sport focused on the effect that exercise has on an individual's HRV (Aubert, Seps and Beckers, 2003; Kaikkonen *et al.*, 2010; Edmonds, Sinclair and Leicht, 2013). In recent years there has been a greater importance placed on looking at internal monitoring of training load using various forms of biofeedback, one of which being HRV. Biofeedback has been used to monitor the internal physiological responses to exercise in the body that cannot be consciously controlled (Tanis, 2012). It is known that physical or psychological stress put upon the body provides a heart rate response (Winsley, 2002). One of the physiological responses to stress is a change in HRV.

High intensity training and especially competitive matches has an effect on HRV (Thorpe *et al.*, 2015). There is a decrease in parasympathetic activity as the parasympathetic tone is lowered and there is a decrease in R-R intervals and pNN50. pNN50 is defined as the mean number of times an hour in which the change in successive normal sinus (NN) intervals exceeds 50ms. This drop in parasympathetic nervous system activity and the subsequent increase in sympathetic activity mean an increased stress on the body, one of the effects being decrease in HRV (Bricout, DeChenaud and Favre-Juvin, 2016).

Heart rate response has been shown to be one of the best ways to measure training responses (Plews *et al.*, 2012). Plews et al found that there was a strong correlation between training load and wellness measures such as HRV in Australian Rules football players during a pre-season camp with daily high intensity training. It has been found that there was certain HRV parameters that showed correlations with increased training intensity. It was found that for every 300m increase in high intensity running meant a decrease by 1 unit of HRV, meaning that the higher the training load then the greater the sympathetic dominance in the ANS. A significant correlation was found between daily fluctuations in HRV (rMSSD) and high intensity running (Thorpe *et al.*, 2015), rMSSD is the root mean square of successive differences. Thorpe et al concluded that future research is needed to investigate the using HRV as a monitoring tool in team sports and that a longer term study is needed to understand long-term fluctuations in fatigue variables in relation to load in elite soccer players. Even though Thorpe et al, were monitoring elite soccer players in an applied environment, they still had access to a laboratory setting, which a lot of clubs will not have access too. The study looked at short term use of HRV as the football team was monitored for 17 days and stated that a longer term study should follow this research. Thorpe et al states that future research should look at the usefulness of HRV as a monitoring tool in team sports.

HRV is usually analysed using various hardware and software specifically developed to calculate HRV. Software built to analyse HRV usually produces time-domain, frequency domain and nonlinear results. The time-domain results are of interest in most research with MeanRR; which is the average time in milliseconds between each “R point” of the QRS Complex. This is essentially heart rate, the larger the gap between the R points then the lower the heart rate., SDNN; which is the standard deviation of the NN intervals. SDNN reflects the cyclic components responsible for variability over a certain time period. SDNN shows short-term high-frequency variations and lowest-frequency components over a 24-hour period. Five minute recordings are appropriate when using SDNN (Berntson *et al.*, 1997), rMSSD; which is the root mean square differences of successive R-R intervals., NN50; which is the mean number of times per hour in which the change in consecutive normal sinus (NN) interval exceeds 50 milliseconds and Pnn50; which is the proportion of NN50 divided by the total number of NNs widely reported in research (Aubert, Seps and Beckers, 2003; Schroeder *et al.*, 2004; Pagkalos *et al.*, 2008; Parrado *et al.*, 2010; Scott *et al.*, 2013; Flatt and Esco, 2015).

As previously mentioned, different HRV parameters are effected by different exercise intensities and various stresses placed on the body. High intensity training increases sympathetic activity in the ANS causing HRV to drop (Borghi-Silva *et al.*, 2009), whereas training as low intensity such as aerobic base training could have a positive effect on HRV by increasing the parasympathetic tone in the ANS.

<u>2.2 (5) Aerobic Base Training</u>

Aerobic base training is training at a low/moderate intensity where an individual is working at an intensity where oxygen is readily available to the working muscles and the body is not in oxygen debt. This level of work is below the anaerobic threshold and is usually around the 60-70% of maximum heart rate. The effect lighter training sessions have on HRV has not been explored as frequently in research as higher intensity sessions even though increased HRV has been linked with decreased stress on the body. As mentioned earlier when an individual undergoes high intensity exercise HRV drops; there is then a subsequent rebound above the pre-exercise level, this rebound occurs during a lighter training period (Kiviniemi *et al.*, 2007). Lighter training periods are needed in order to recover from the previous high intensity exercise.

Aerobic training has been shown to improve parasympathetic activity and reduce sympathetic activity at rest and during sub maximal exercise after a 6-week aerobic training program (Borghi-Silva *et al.*, 2009). Training >70% of HR Max decreases HRV and all HRV indices (Martinmäki *et al.*, 2008). This suggests that training <70% of HR Max seems to be beneficial to HRV values. However, >70% seems to increase sympathetic activity and therefore increase stress on the body which in turn decreases HRV.

Exercise and its effect on HRV has been widely researched (Kiviniemi *et al.*, 2007; Martinmäki *et al.*, 2008; Castello-Simões *et al.*, 2013; Cabral-Santos *et al.*, 2016; Panissa *et al.*, 2016). Many studies have found that, as mentioned above, that high intensity exercise has a negative effect on HRV, increasing the sympathetic tone and therefore decreasing HRV (Pichot et al. 2000; Lellamo et al. 2002). However, there is a lack of research on how this HRV response to exercise can be modified/reversed. There have been studies indicating that lighter training sessions help increase parasympathetic tone and stop the decrease in HRV (Pichot *et al.*, 2000; Kiviniemi *et al.*, 2007). These studies suggest that high intensity exercise causes HRV to drop due to an increase in SNS activity, however, HRV can rebound past the pre high intensity exercise level during lighter sessions, this suggests that the use of micro-cycles and day-to-day periodisation could benefit athletes. Following a high intensity session with a low intensity training session could help HRV recover to its pre-training values, it has also been found that ANS activity has an impact on performance in swimmers (Garet *et al.*, 2004). Swimming performance was at its best when parasympathetic indices of HRV were highest, similarly a decrease in parasympathetic tone was correlated with a loss in performance. Garet et al found that the duration in which it took individuals to recover from a decrease in PSNS activity and for the "rebound" to occur varied between swimmers. The study suggested that optimising the duration in which the rebound in the ANS occurs would be beneficial from a performance point of view in athletes (Garet *et al.*, 2004). This research would suggest that parasympathetic nervous system reactivation after high intensity training is essential when it comes to performance. The importance of the ANS rebound is highlighted here and poses the question of the duration of the rebound and that the quicker the rebound then the shorter time an athlete may suffer from a decrease in performance. This is an area that needs studying further in to how this can be used in an applied sporting setting and how athletes could work on optimising the time it takes to reactivate the PSNS.

It is clear from literature that exercise has a direct effect on HRV. Several studies have shown that high intensity exercise increases sympathetic nervous system activity and therefore decreases the parasympathetic tone; this in turn decreases post-exercise HRV (Buchheit *et al.*, 2010; Gladwell, Sandercock and Birch, 2010; Castello-Simões *et al.*, 2013; Edmonds, Sinclair and Leicht, 2013; Cabral-Santos *et al.*, 2016). However, there seems to be limited research on how this drop in HRV can be manipulated or what training/precautions can be taken to decrease the impact of high intensity exercise on the autonomic nervous system. Furthermore, the research on football players, especially at an elite level, is very limited and therefore feel there is an opportunity to add to research in this area. Research has shown that the use of low intensity exercise and its positive effect on HRV may have an effect on performance (Kiviniemi *et al.*, 2007), and therefore whether manipulation of HRV through low intensity exercise has any effect on performance in athletes is pertinent. Furthermore, this positive increase in HRV from low intensity exercise has been seen at sub-elite level, we do not yet know if this is true at an elite level. Any small gains at an elite level is vital and any improvements in recovery i.e. an increased HRV and any possibility of this needs to be explored.

Training load and performance parameters such as GPS tracking, HR tracking, RPE scales and HRV can all be used to quantify training load. Quantifying training load has been widely researched, but how the impact caused by training can be managed is an area with a lot of questions still unanswered. As mentioned above, research has shown that a drop in HRV is caused by an increase in sympathetic activity in the Autonomic nervous system, caused from high stress placed on the body when performing (Da Silva *et al.*, 2014). If the parasympathetic tone is not once again increased in the ANS after training and the SNS continues to be prominent then over time this could lead to accumulative fatigue and in turn a drop in level of performance (Garet *et al.*, 2004).

Research has suggested that the use of aerobic base training, where an individual works at a moderate intensity of 60-70% of their HR max at a steady state in order to reinstate the parasympathetic tone in the ANS and rebound the ANS back to pre-high intensity training values (Pichot *et al.*, 2000; Kiviniemi *et al.*, 2007). This suggests that the drop in HRV from high intensity training could be manipulated with extra low intensity training in this zone, total training load would also need to be tracked. This, along with the lack of research on HRV manipulation in elite football is where this study idea and subsequent research has stemmed from.

The study will aim to assess the reliability of measuring HRV measures with the Polar V800 watch along with the reliability and validity of the various HRV parameters. The hypothesis for this study is that individuals taking part in aerobic base training will experience lower internal impact in terms of HRV from high intensity training sessions than those not in the intervention group. The intervention group may also recover from high intensity sessions quicker and more effectively than the control group due to the increase in parasympathetic tone i.e. post-exercise rebound in HRV should be seen in the intervention group compared to the control group.

# Chapter 3

# Pilot: The reliability of HRV Measurements in an Elite Football Academy

## 3.1 Introduction

There has been research in to HRV measuring devices and their reliability and validity, including app based measures along with watch based HRV measures. App based “ithlete” has been found to be reliable and a valid short term measurement (Flatt and Esco, 2013, 2015) along with the Polar S810 HRV measuring watch (Nunan *et al.*, 2009; Parrado *et al.*, 2010). It is important that the equipment used in research is measuring what the researcher is intending i.e. has a high validity and that these measurements are consistent with each other i.e. has high reliability. Reliability and validity of any new equipment being used in research should be checked before being used, in order to make sure any changes interpreted are genuine and that the equipment has an acceptable level of variance.

There has been much research in recent years in to the use of HRV as a means of monitoring training load and fatigue in athletes (Plews, Laursen, Kilding, *et al.*, 2013; Thorpe *et al.*, 2015). Many studies have taken HRV analysis in a controlled laboratory based setting (Gladwell, Sandercock and Birch, 2010). Analysis in to validity and reliability of HRV measures such as HRV watches and app based HRV collection has been assessed (Parrado *et al.*, 2010; Quintana, Heathers and Kemp, 2012). There has been limited research in to the validity of using HRV analysis in real life applied situations which have added extraneous variables.

Previous literature has found that rMSSD has the least variance in terms of HRV indices and therefore is the most reliable to use for coaches tracking training load changes and effects on athletes. The study showed that supine rMSSD analysis was the most sensitive to training load changes in women soccer players over a three-week period (Flatt and Esco, 2015). This research has suggested that rMSSD showed changes in training load due to its sensitivity to internal changes in the ANS, these findings suggest that any training interventions used in football can be evaluated using rMSSD as any changes should be shown in these HRV readings. The study was over a three-week period so can conclude that rMSSD is a good indicator of the changes internally due to short-term training load, new research should look to investigate this on a more longitudinal basis.

Research has shown that exercise has a direct impact on HRV when monitored during rehabilitation settings such as diabetes patients (Pagkalos *et al.*, 2008), gastric bypass patients (Castello-Simões *et al.*, 2013) and sufferers of schizophrenia (Herbsleb, Mühlhaus and Bär, 2014). HRV has been used in studies taking place in controlled laboratory settings (Kaikkonen, Nummela and Rusko, 2008; Martinmäki *et al.*, 2008) however, it is important to establish whether HRV can be used in a “real life” applied setting. Research has shown that HRV is reliable in a controlled environment but this may not be applicable when in the field with many extraneous variables potentially having an effect.

Research has found that HRV measurements using the Polar S810 and accompanying software has no significant bias or random error in comparison to criterion measures (Nunan *et al.*, 2009; Parrado *et al.*, 2010). However, it was found that 1-week measuring intervals were unreliable, suggesting that multiple 5-minute short term measurements should be taken throughout the week (Nunan *et al.*, 2009). Research has found that the repeatability and validity of short term HRV measures increases over time (Schroeder *et al.*, 2004). Ultra-short term HRV measures of 10 seconds had the lowest repeatability and taking a mean value of several measures is suggested. Six minutes recording times produces a ICC of 0.7 and 2-minute recordings a ICC of 0.5. The study supported the use of over 5-minute recording time for HRV (Schroeder *et al.*, 2004).

Previous literature seems to have contrasting evidence as to whether HRV is a reliable training load tool and which HRV indices is most reliable, the variability of all HRV indices should be considered when interpreting changes in training status (Buchheit *et al.*, 2010). There is limited literature on whether monitoring HRV in a field based setting is reliable and valid along with, as mentioned earlier, whether the Polar V800 is both reliable and valid. Any error in HRV readings in an applied setting need to be investigated in order to be taken in to account when collecting data. The aim of this chapter was to assess the variability of each HRV measure in order to only use the most reliable HRV measures in Chapter 4 of the study.

**3.2 Methods**

19 youth team scholars at an English league two professional football club were recruited having volunteered after responding to poster adverts. The group were male and of a similar age (17 ± 1 yrs.') and at the time of applying for the study all cleared as fit to train as normal and participate in the study by the football club's physiotherapist. The research was approved by the ethics committee at Oxford Brookes University. All 19 participants gave written informed consent before taking part in the study.

All 19 participants had their HRV readings taken on three separate occasions in week 1 and another three separate occasions in week 2. Participants were asked to report first in the morning immediately after reporting to the training ground, between 8:30-9:30 before the participants had college and then training. Participants' were asked to be fasted overnight, had no alcohol in the previous 24 hours, keep caffeine in intake to a minimum and to have not performed any vigorous exercise; before reporting to a quiet room which had gym mats laid out on the floor for comfort, with space between each participant so they could lay down without any contact with each other and could lay flat on their back with the participant's hands by their side and legs stretched out. Each mat was accompanied with a Polar V800 (Polar, Finland est.1977) watch and heart rate strap. The participants were asked to lay down in a supine position on a mat and place the heart rate strap across the sternum, just below the line of the nipples and place the watch on their wrist. All watches were set to record R-R intervals. Participants were asked to remain in a supine position, while relaxing and breathing normally for a total of seven minutes. Following the HRV recording, the data was downloaded by connecting the Polar V800 watch to a PC and downloading to Polar Flow software (Polar, Finland est.1977) to produce RRI data in milliseconds. Once downloaded, artefacts were removed using a correction protocol, disregarding data more than 30% different from the previous data point and any duplicate data (Gilder, 2008). Once artefacts had been removed, 256 RRI recordings were taken after disregarding the first two minutes of data in order to allow heart rate to stabilise after being in the supine position. The data were then opened in HRV analysis software ("Kubios" 2.2, Finland est.2004) for the construction of time domain, frequency domain and Poincare plot measures.

Data Analysis:

In order to establish HRV reliability, the same day from week one and two (i.e. Tuesday week 1 and Tuesday week 2) were analysed in SPSS version 22. With data analysed for mean and standard deviation and reliability assessed using ICC repeated measures and coefficient of variation calculated. Significance was accepted at P<0.05.

## 3.3 Results

The results consist of mean, standard deviation, coefficient of variance (CV), interclass correlations (ICC) and confidence intervals.  Results from the ICC analysis are displayed in Table 1

*Table 1: Repeated measures analysis on HRV measures.*

| HRV Measure | Interclass Correlation (ICC) | 95% Confidence Intervals | |
|---|---|---|---|
| | | **Lower Bound** | **Upper Bound** |
| **Mean RR (ms)** | .482 / .650 | -.081 / -.176 | .809 / .895 |
| **SDNN (ms)** | -.148 / -.348 | -.660 / -3.881 | .414 / .586 |
| **rMSSD (ms)** | -.126 / -.288 | -.607 / -3.088 | .417 / .589 |
| **NN50** | .082 / .152 | -.501 / -2.010 | .585 / .738 |
| **pNN50** | -.005 / -.010 | -.531 / -2.266 | .515 / .680 |
| **TINN (ms)** | -.029 / -.059 | -.545 / -2.399 | .496 / .663 |
| **SD1** | -.126 / -.288 | -.607 / -3.089 | .417 / .589 |
| **SD2** | -.077 / -.168 | -.625 / -3.333 | .474 / .644 |

The following guidelines were produced to use when interpreting ICC's; ,0.40= Poor, 0.40-0.59= Fair, 0.60-0.74= Good, 0.75-1.00= Excellent (Cicchetti, 1994). Here, most of the HRV measures fall in to the "poor" catergory, except for MeanRR which is "fair"/"good".

Table 2 below displays the mean, standard deviation and Coefficient of variation for all the different HRV indices.

*Table 2: Mean, standard deviation and Coefficient of variation for HRV measures.*

| HRV Measure | Mean (Standard Deviation) | CV |
|---|---|---|
| **Mean RR (ms)** | 1060.2 (111.5) | 11% |
| **SDNN (ms)** | 87.5 (43.3) | 49% |
| **rMSSD (ms)** | 111.7 (55.0) | 49% |
| **NN50** | 112.8 (39.7) | 35% |
| **pNN50** | 53.8 (19.1) | 36% |
| **TINN (ms)** | 464.1 (278.7) | 60% |
| **SD1** | 79.2 (38.9) | 49% |
| **SD2** | 93.8 (49.6) | 53% |

Coefficient of variation measures shows what percent of the results are equal to the mean of the data. Here the higher percetages are SDNN, rMSSD, TINN, SD1 and SD2.

## 3.4 Discussion

The aim of this chapter was to analyse the reliability of each HRV measure. HRV was taken on two separate days, a week apart, providing two sets of HRV results for the same day of the week. The key findings for Chapter 3 are that all the HRV measures are highly variable but MeanRR, SDNN and rMSSD are the most reliable.

After running reliability analysis on HRV data it has shown that all the HRV measures demonstrate low reliability to use as they show high variability between days. This contradicts previous research which stated that HRV measures showed high reliability and validity when used several times across a week with footballers (Flatt and Esco, 2015). This could be due to participants taking their HRV immediately in the morning when they woke up at home, this was due to collection of HRV being from an app based method. As the HRV collection was at the participants' homes, this could have been an environment similar to a laboratory with little extraneous variables, unlike this current study where participants completed the study at the football training ground with many extraneous variables. The ICC shows that the least variable HRV measure is MeanRR. MeanRR is the time between heart beats i.e. heart rate. In HRV the MeanRR is the time in milliseconds between two R points on the QRS complex. Due to it being the least variable output from the HRV analysis, MeanRR was analysed in chapter 4 of the study.

As MeanRR does not show how variable HRV is SDNN and rMSSD will also be used in chapter 4 when looking at any changes to HRV. These measures were the next most reliable measures shown from the ICC analysis, the low ICC score should be taken in to account when interpreting results in chapter 4 as the measures have shown to have high variance in chapter 3.

These variance scores from the ICC in this current study contradicts previous work. It has been shown that HRV readings being collected over 6 minutes had ICC score of 0.7, indicating they are reliable and not too variable when collection is over this period of time (Flatt and Esco, 2015). Reliability will always range between 0 and 1, showing the estimate of how much the change is true and how much it is due to error, a score of 0.7 would indicate 70% chance it is true and 30% chance its due to error.  In this current study the ICC score for rMSSD is 0.2, indicating a high variability in the measure. The results contradict each other from the ICC and also Flatt's study was on 9 women's soccer players. The fact that both studies were in an applied footballing environment suggests that there would be similar extraneous variables from being in the field, this rules out differences due to the environment. However, Flatt's study used iThlete for HRV data collection, a smart phone based application. Although research has shown that the iThlete was not significantly different to EMG recordings (Flatt and Esco, 2013), there could be a difference between the Polar V800 and the iThlete. Furthermore, the women's soccer players in Flatt's study were left to record their HRV at home and not in a controlled environment as it was in the current study.

It has been suggested that rMSSD is the best HRV indices to use as it is the least effected by breathing rates (Saboul, Pialoux and Hautier, 2013). Research suggests that rMSSD and SD1 were not affected with either controlled breathing or spontaneous breathing and suggests that other frequency markers of HRV are more variable than rMSSD or SD1. This would suggest that that using rMSSD or SD1 may be the best HRV indices to use in an applied environment with many extraneous variables as it is hard to control breathing rate in a field based environment. In this current study, participants were asked to relax and breathe normally, but this may have been effected slightly by extraneous variables. The environment was controlled as much as possible, but in a working environment there will always be background noise which cannot be prevented. Due to rMSSD not being effected by breathing rate changing and also the ICC scores, it is one of the HRV indices which will be used in Chapter 4.

For chapter 4, three different HRV indices will be investigated. MeanRR will be used as it was by far the highest in terms of reliability for the ICC scores. Due to MeanRR not measuring the variability of heart rate then rMSSD and SDNN have also been selected for analysis in Chapter 4. Both these measures were selected due to being least variable from the ICC analysis compared to the other indices. Furthermore, although not seen in Chapter 3 for this current study, rMSSD has been used extensively in previous research due to its high reliability and not being effected by breathing rate.

# Chapter 4

# Main Study: The effect of aerobic base training on HRV and performance in elite youth footballers

## 4.1 Introduction

High training loads, especially at high intensity has a negative impact on HRV (Bricout, DeChenaud and Favre-Juvin, 2016) and that low intensity steady state exercise stimulates the parasympathetic tone in the ANS (Borghi-Silva *et al.*, 2009). In theory, increasing the parasympathetic tone and reducing the sympathetic tone in the ANS, would increase HRV or reduce the deficit in HRV induced by high intensity training. As well as its potentially benefits on HRV, this could affect performance (Garet *et al.*, 2004). Garet at al's study found that the reduction in HRV caused by high intensity had a negative effect on swimming performance, similarly, those who increased their HRV showed positive gains in performance. The increase in HRV after a reduction due to high intensity exercise is known as the HRV "rebound", this is where HRV returns to the pre-exercise level and at times can exceed the pre-exercise level. The speed of the rebound differed between individuals in the study, but it has been suggested that the quicker an athlete can rebound back to a higher HRV the better (Garet *et al.*, 2004). A reduced impact from high intensity training may mean that players can push themselves harder in training without additional negative effects on their body and this previous research suggests that increasing HRV may have positive effects on performance.

It is clear from previous research that physical and psychological stress on the body causes an increase in SNS activity which in turn decreases HRV (Bricout, DeChenaud and Favre-Juvin, 2016). Professional sportsmen will train for many hours throughout the week and a lot of their work will be at high intensities in order to hit conditioning aims and replicate competition scenarios (Casamichana *et al.*, 2013; Thorpe *et al.*, 2015).Recovering after these high intensity sessions is required and fatigue to be limited were possible in order to be ready for the next training session/ competition.

Previous literature has shown that aerobic training at a low intensity steady state to improve parasympathetic activity and reduce sympathetic activity, when implementing a 6-week training program (Borghi-Silva *et al.*, 2009). Improving parasympathetic activity could be beneficial to athletes after completing training. The sooner an athlete can reactivate their PSNS then the sooner they will be able to recover internally from the training load stress placed on the body. Athletes will be looking for their HRV to "rebound" back to at least the level they were before high intensity training, if not higher than their pre-training status. This rebound occurs during a lighter training period (Kiviniemi *et al.*, 2007), this is where the reduction in HRV caused by the activation of the SNS is counteracted and HRV is increased due to the reactivation of the PSNS. Although this previous research states that low intensity exercise can improve HRV it is not clear what effect this has on performance. Borghi-Silva et al found these HRV improvements in patients with chronic obstructive pulmonary disease (COPD) and so it cannot be assumed that this would be the same for elite sportsmen, this is due to elite sportsmen such as footballers already having a training schedule in place with high training loads already being placed on their body.

The effect on HRV would depend on the training load placed on the athlete. As previously outlined there are many differing ways of tracking training load, mainly external ways of measuring the intensity of the session. GPS has been shown to be an effective tool to measure training load, providing coaches with quantitative data from training sessions and matches such as total distance covered, high intensity distance covered and the number of sprints performed. It is important to track external load of football players in order to quantify the physical stress being placed upon them through training session and matches.

It is important that there are no significant differences in training load between any participants as this could have an effect on the results. As previously mentioned, high intensity running has a negative effect internally on the body and parasympathetic activity in the ANS decreases, if an individual does significantly more high intensity running than another then this could cause different internal impacts from the training. GPS parameters can be used to achieve the balance between undertraining and overtraining, both of which can cause fatigue and increase the chance of injury occurrence. It has been suggested that footballers should aim to achieve 2.5 times a game for GPS parameters in a week (Thorpe *et al.*, 2015). GPS data allows any performance increases or decreases can be easily supported by quantitative data and any changes through an intervention can be highlighted with any deviation from the norm after collecting baseline data. Only GPS 10Hz have the level of accuracy for quantifying distance covered at high speeds (Rampinini *et al.*, 2015). As well as GPS, heart rate can be used to help quantify training load. Heart rate zones have been shown to strongly correlate with session RPE when quantifying training load (Lupo, Capranica and Tessitore, 2014). Heart rate percentage of heart rate maximum can be used to define the intensity of the session, which is achieved by setting out heart rate zones due to HR percentage.  Many practitioners in sport use >80/85% as an indication of high intensity exertion (Alexandre *et al.*, 2012; Stanula *et al.*, 2016b).

$VO_2$ max tests are frequently used to assess fitness and aerobic capacity in athletes (Hoppeler *et al.*, 1985; Pollock *et al.*, 1987). There are many ways of calculating $VO_2$ max, either through direct $VO_2$ measurement by using lab based direct gas analysis or indirect $VO_2$ measurements, which can be done through shuttle run tests such as the Yo-Yo test or sub-maximal tests such as the step test (Ramsbottom, Brewer and Williams, 1988; Krustrup *et al.*, 2003). Using direct $VO_2$ measurements are accurate: whereas indirect $VO_2$ measurements such as a multi-stage 20m shuttle run test are not accurate when measuring $VO_2$ in junior football players (Kavcic *et al.*, 2012). Although a Yo-Yo test has been seen as a valid way to measure $VO_2$ (Krustrup *et al.*, 2003; CASTAGNA *et al.*, 2006), the direct measurement of $VO_2$ has been seen to be more accurate, when studying elite athletes, small changes can be invaluable and so increased accuracy to pick up small changes would be beneficial.

Previous literature has suggested that low intensity training can aid internal recovery but this has not been applied to many in field sporting scenarios, especially in football. The research suggests that if players were able to do extra low intensity training after their high intensity bouts of exercise then this would have a positive effect on their HRV and therefore aid recovery (Pichot *et al.*, 2000; Kiviniemi *et al.*, 2007). It has also been suggested that working at a low intensity may have performance benefits (Garet *et al.*, 2004), in swimmers. Garet et al stated that the greater the increase in parasympathetic and subsequent increase in HRV, then the greater the performance gains. In team sports such as football, performance changes could be measured with field based tracking such as GPS and heart rate along with $VO_2$ max analysis. This theory was the basis for the current study in to investigating if low intensity exercise can aid recovery in elite youth footballers. The aim of Chapter 4 is to establish the impact of low intensity aerobic base training on HRV and performance.

## 4.2 Methods

19 Youth Team scholars from a League 2 Professional Football Club (Male, aged 17 ± 1) who were all passed as fit to train by the club physiotherapist volunteered to take part in the 12-week data collection.

All participants filled in a PAR-Q in order to establish that they were not going to be put at risk when participating in the study. Applicants would not be able too participant if they had any of the exclusion criteria listed i.e. heart issues. Ethical clearance was granted by the Oxford Brookes Ethical Committee. Before the study all participants signed a consent form along with being given a participant information sheet outlining all the procedures within the study.

## 4.3 Study Design

All Participants completed a $VO_2$max and Yo-Yo test for pre and post study fitness testing. All participants then had baseline data collected for weeks 1-6 of the study. Data was collected in a number of ways; GPS, Heart rate, RPE and HRV. After baseline data collection the participants were split in to two groups using a Random Control method. The control group continued with protocols from weeks 1-6 whereas the intervention group had additional 30 minutes' aerobic base training sessions too complete tri-weekly. There was no significant difference between the control and intervention groups in terms of age (17 ± 1-year Vs 18 ± 1-year; P>0.05) or in terms of baseline aerobic fitness in pre testing (P>0.05).

### 4.3 (1) $VO_2$ Testing

The week before the study began, the participants travelled to Oxford Brookes University to complete a $VO_2$ max test in order to evaluate aerobic capacity and fitness. The group was split in half and both completed the test over a two-day period.

$VO_2$ Max testing has been a gold standard measure in terms of tracking any changes in aerobic fitness and was measured directly on a treadmill (Leon *et al.*, 1981). The treadmill was set at a 1% gradient and on a ramp setting, where the treadmill started at 8Kph and increased 1Kph per minute. Using a treadmill with a gradient of 1% has been reported to represent outdoor running (Jones and Doust, 1996).

Prior to testing participant's completed a Physical activity readiness questionnaire (PAR-Q) in order to make sure they had no physical reasons that could put them at risk by completing the test. Participants height and weight were measured using a stadiometer and Seca scales and recorded.

Prior to all sessions the metabolic system was calibrated following manufacturers guidelines. Once the participant was ready the recording began, the treadmill was stationary for one minute in order to collect a resting sample. After one minute the treadmill was raised by 1% and started off at 8Kph and increased by 1kmh each minute in a ramp fashion. The participants ran to exhaustion and heart rate, $VO_2$ l-min$^{-1}$, $VCO_2$ and respiratory exchange ratio were measured continuously throughout the test. The identical protocols were repeated one-week post-study.

<u>4.3 (2) GPS</u>

Throughout the study, Catapult GPS Optimeye X4 units (Catapult Group LTD, Australia 2006) were worn in all training sessions, as well as games. GPS was sampled at a 10Hz sampling rate and taken for the first 6 weeks in order to establish standard training session load and to monitor any performance changes that may be seen in weeks 6-12. From the GPS, 5 training load indicators were taken; Distance covered, high intensity distance covered (>4 m/s), Work: Rest ratio, player load and maximum velocity (m/s). High intensity running was set at >4m/s as in (Rampinini *et al.*, 2015)

GPS units were individualized according to each participant's maximum heart rate, whereas other parameters were generic across all participants i.e. high speed running. Heart rate was individualized in order to analyse how intense the training sessions/games were on an individual. When heart rate is estimated, 220-Age is generally seen as the best way to estimate maximum heart rate if no testing protocols are used and has been used as an estimation for decades (Fox, Naughton and Haskell, 1971). When comparing heart rate responses between groups and within groups in the study, estimations or generic heart rate zones will not be reliable and any changes seen in heart rate could not be seen to be reliable due to any individual differences in maximum and heart rate and zones not being accounted for. Having generic zones would not be a valid measure as certain individuals would be working harder than others but would have the same load recorded.

The GPS fitness parameters were generic values in order to reliably quantify training load and allow comparisons to be made within and in between training groups. Using generic zones in the GPS i.e. high speed running being classified as >4.5 m/s allows training to be reliably tracked and standardized allowing the intensity of the weeks to be recorded accurately.

4.3 (3) Aerobic Base Training

In order to establish cause and effect of using aerobic base training, all players completed the identical training protocols for the first six weeks of the study which did not include aerobic base training, just field based training and gym based training set by the coaching staff and medical team within the football club. After six weeks, nine participants were selected to be in the intervention group using random selection while ensuring no significant differences between the groups for fitness measures using pre-study $VO_2$ max scores. The participants were ranked in terms of ml.kg.min, then an even spread was taken to ensure one group was not significantly different to the other in terms of $VO_2$ ml.kg.min ($p<0.05$). This was to eliminate any bias that may occur if the two groups were significantly different to begin with. There were nine participants in the control group and continued with their normal schedule of field training and gym based training. The fitter an athlete is to begin with then the harder it will be to make a fitness gain.

Aerobic base training sessions took place three times a week, these were in the afternoon after all training for the day had been finished. Before the session, participants were asked to place their individual heart rate strap around there chest and attach their own polar team 2 heart rate pod. On the Polar Team 2 software, “Online Training” was selected in order to show a real time display for the participants, the display showed their heart rate as percentage of maximum.

The participants completed the aerobic base training on spin bikes, set up with a low level of resistance, the level was set at an appropriate intensity for each individual. The intervention was completed on spin bikes rather than a treadmill to offload the joints, extra running would have an additional load through the ankles and knees, which the physio at the club advised against. The participants kept the resistance low for the whole session and kept their RPM as high as possible without exceeding the appropriate heart rate percentage. The participants were asked to keep their heart rate at 60-70% for the whole duration of the session; the session was 30 minutes in duration once the participants entered the required zone. Aerobic base training sessions were monitored to ensure participants remained within the required zone for the full 30-minute session, training was tracked with heart rate monitors.

The session took place tri-weekly over a six-week period, totalling 18 aerobic base training sessions. The intervention training was as an extra to the participants normal training routine at the club, the participants in the control group also did their normal training routine just with the absence of the aerobic base training sessions.

4.3 (4) HRV

All 19 participants had their HRV taken a minimum of three times a week throughout the study. Protocol was followed as described in Chapter 3 section 3.2.

4.3 (5) Data Analysis

T-Tests were used to analyses the significance of any chances throughout the study. T-Tests were used to evaluate any changes in values in the study along with in study differences for HRV and GPS data. A 95% confidence was set for this study ($p>0.05$).

Two-way ANOVA tests were used to analyse whether the independent variables i.e. the aerobic base training made a difference between the control and the intervention groups. As well as between group differences, within group analysis was calculated and displayed in a pairwise table in SPSS, highlighting any differences between weeks within a group.

Where appropriate effect size was used to determine whether a change in mean scores for a group were significant or not. Effect size rates the magnitude of change between two means. Magnitude of effect size can be rated from trivial to extremely large as seen in (Hopkins, 2000). However, these parameters were then modified to take in to account the training status of the individuals involved. The parameters were changed so smaller absolute changes in a highly trained individuals were taken to have a greater magnitude than the same absolute change in untrained individuals (Rhea 2004). For the statistical analysis for the study, the participants were classified as "highly trained" due to being full time training at a professional football club. For this study the effect sizes were classified as follows; Trivial <0.25, small 0.25-0.50, moderate 0.50-1.0 and large >1.0.

**4.4 Results**

Data collection was analysed for all parts of the study, all training load parameters within the study have been analysed along with the pre and post study fitness performance indicators.

**4.4 (1) HRV**

Tables 3 shows any differences between groups i.e. Control and intervention and then any differences between weeks. There are no significant differences ($p>0.05$) between the groups in all the weeks for MeanRR, however, there were differences in MeanRR between some weeks (i.e. weeks 2&7 and 5&7). There were no differences between groups in all weeks for SDNN and rMSSD. There were differences within group for rMSSD.

*Table 3: Mean and Standard Deviation for MeanRR/SDNN/rMSSD between groups. *indicates differences between weeks.*

| **HRV Measure** | **Week** | **Mean (SD)** | |
|---|---|---|---|
| | | **Control** | **Intervention** |
| Mean RR | 1 - 6 | 1034.5 (70.2) | 1182.7 (414.0) |
| | 7 | 1054.1 *(86.8) | 1055.8 * (73.6) |
| | 8 | 1006.0 (97.3) | 986.7 (71.7) |
| | 9 | 995.9 (80.5) | 1026.8 (64.7) |
| | 10 | 1072.9 (42.1) | 1034.0 (104.8) |
| | 11 | 1057.9 (177.7) | 1075.2 (84.3) |
| | 12 | 959.8 | 992.2 |
| SDNN | 1-6 | 81.2 (67) | 88.5 (29.5) |
| | 7 | 158.1 (306) | 135.9 (178.6) |
| | 8 | 373.9 (636) | 178.1 (194.6) |
| | 9 | 239.2 (547) | 130.0 (144.0) |
| | 10 | 95.8 (32) | 118.3 (40.3) |
| | 11 | 1003.5 (1760) | 483.4 (671.8) |
| | 12 | 290.9 (508) | 269.5 (365.3) |
| rMSSD | 1-6 | 125.5 (81.1) | 130.9 (56.4) |
| | 7 | 92.4 (42) | 117.6 (56.3) |
| | 8 | 171.8 (170.3) | 158.4(114.5) |
| | 9 | 821.7 *(1904.9) | 291.1 (445.6) |
| | 10 | 77.9 (12.7) | 94.0 (19.8) |
| | 11 | 324.4 * (611.9) | 191.6 (187.8) |
| | 12 | 192.8 (283.9) | 164.4 (160.3) |

## 4.4 (2) GPS

Typically, the two highest days in terms of load, total distance covered and high intensity distance covered were Tuesdays and Thursdays, due to them both being Game day +3 and game day -3 respectively. Mondays and Fridays are lower in terms of total distance covered and especially high intensity distance covered in the interest of recovery on the Monday (game day +1) and the Friday (Game day -1) to avoid residual fatigue on the day of competition. This average was seen over the full 12-week period of data collection (See Figures 1&2).

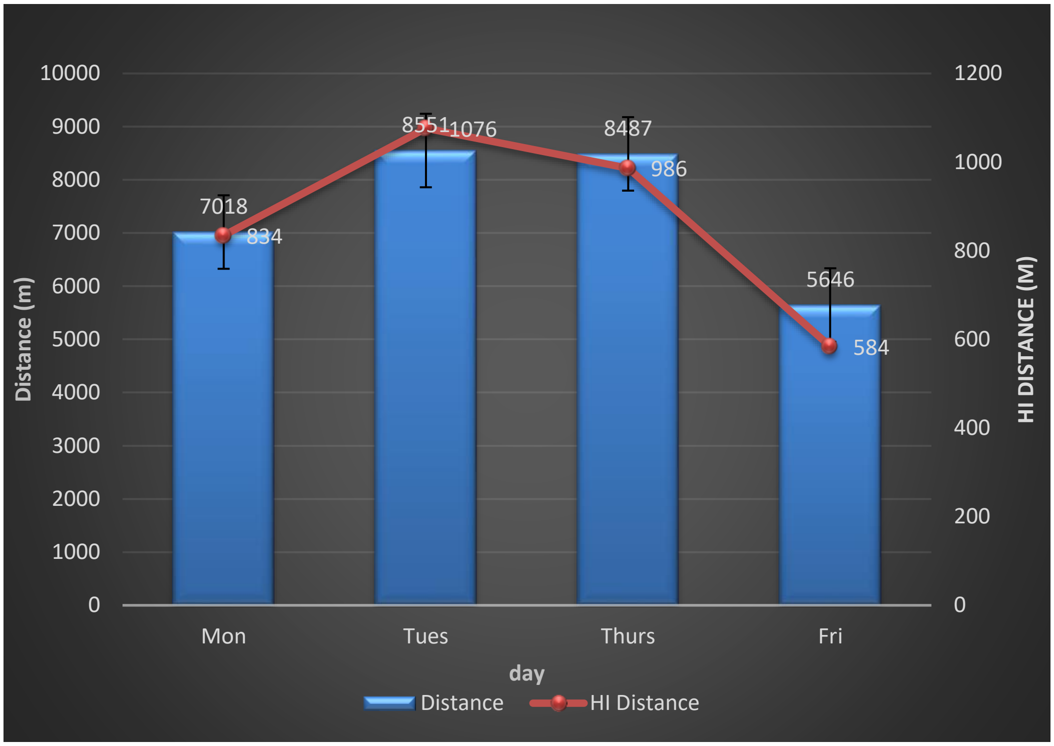


*Figure 1: The average distance and high intensity distance covered by the whole of the participants over the full 12-week study.*

Figure 1 shows that the Tuesday is on average the highest in terms of total distance covered and high intensity distance covered. Total distance covered on Tuesday is 31% higher and significantly different (P<0.05) than distance on a Monday, 37% higher and significantly different (P<0.05) than distance on a Friday and 7% higher but not significantly different (>0.05) than distance on a Thursday. High intensity distance on a Tuesday was higher than a Monday (49%), Thursday (32%) and Friday (50%), all of which are not significant differences (P>0.05).

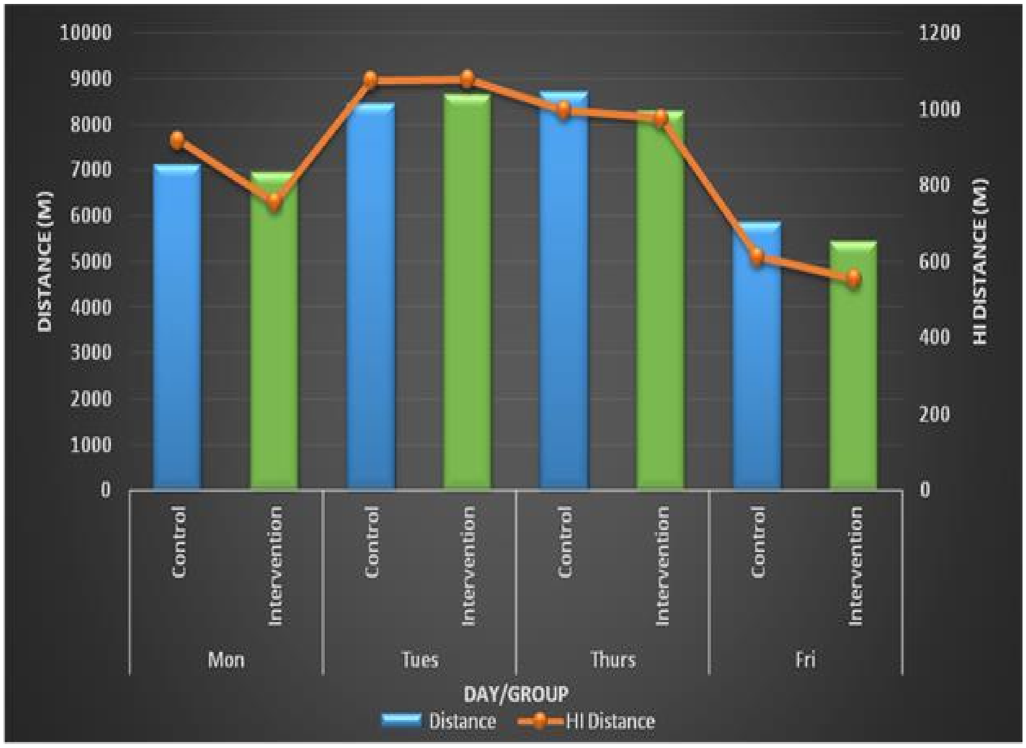


*Figure 2: The average distance and high intensity distance covered for both groups over the full 12-week study.*

Figure 2 shows the average distance and average high intensity distance covered each day over the full 12-week study. There were no significant differences between groups (>0.05) for both average distance and average high intensity difference.

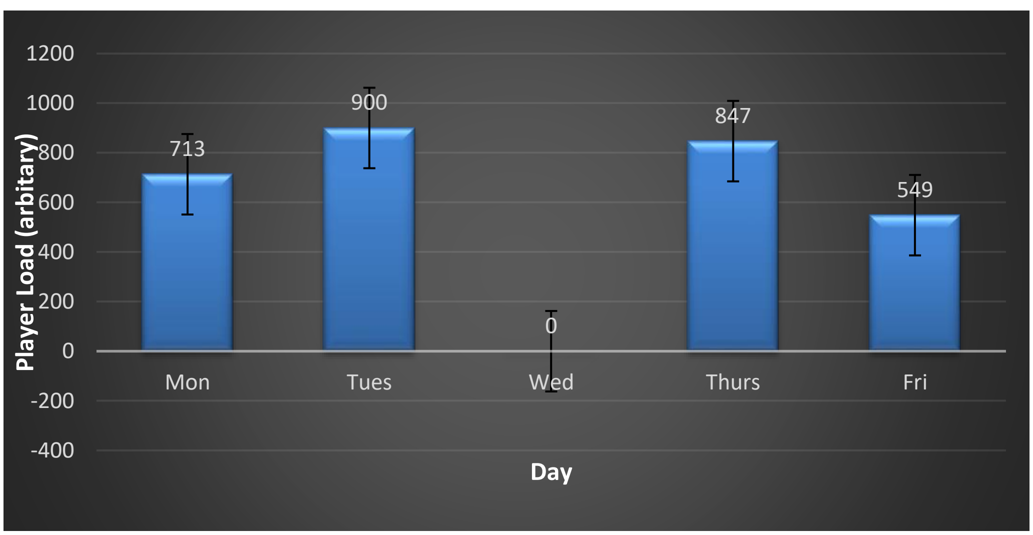


*Figure 3: The average player load for all of the participants over the 12-week study.*

Figure 3 shows player load values to match the trend in distance and high intensity distance through the week. Tuesday and Thursday having the two biggest loads, and Monday and especially Friday (day before a game) having reduced loads on the players.

Although on average the days were different in terms of players' load, these differences were not statistically significant (>0.05).

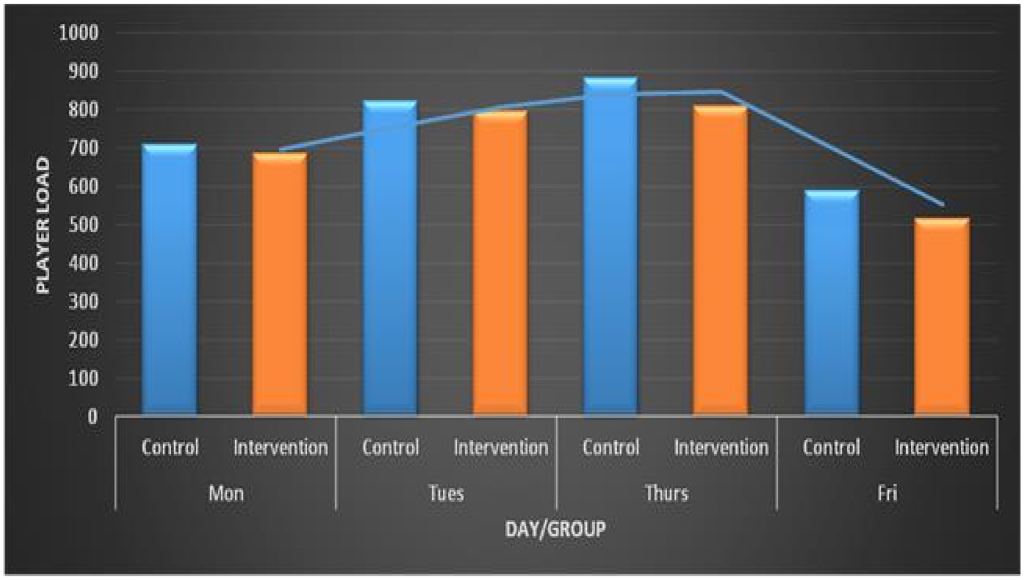


*Figure 4: Average Player Load per day, per group.*

Figure 4 shows the average GPS player load per day, per group. There were no significant differences between groups for any day (p>0.05).

*Table 4: The mean and standard deviation for distance and high intensity distance for both groups.*

| GPS Measure | Week | Mean (SD) | |
|---|---|---|---|
| | | | |
| | | Control | Intervention |
| Distance (m) | 1 - 6 | 6532 (767) | 6862(1182) |
| | 7 | 8460 (1567) | 8073 (2215) |
| | 8 | 6852 (1145) | 6442 (1192) |
| | 9 | 7134 (1006) | 6935 (1416) |
| | 10 | 5778 | 6246 |
| | 11 | 6377 | 4626 |
| | 12 | 7198 (2532) | 6679 (1255) |
| | | | |
| HI Distance(m) | 1 - 6 | 837 (224) | 892 (148) |
| | 7 | 1304 (486) | 1075 (398) |
| | 8 | 831 (236) | 809 (362) |
| | 9 | 733 (287) | 787 (297) |
| | 10 | 690 | 775 |
| | 11 | 703 | 392 |
| | 12 | 839 (368) | 771 (222) |

Table 4 shows that there was no difference between groups for both total distance and high intensity distance. There are also no differences in-between weeks.

**4.4 (3) HRV Vs GPS**

Any correlations and trends were explored between the GPS statistics and the HRV indices to investigate any possible effects between measures.

MeanRR

The following figures explore the relationship between HRV measure MeanRR and GPS data.

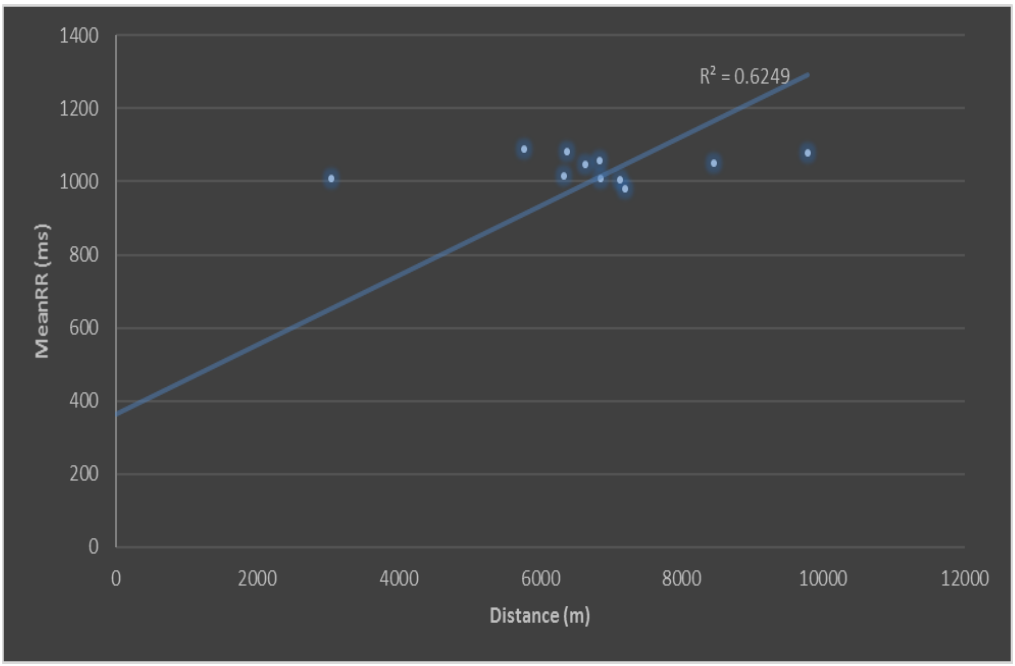


*Figure 5: The relationship between average total distance covered and average Mean RR intervals of HRV for the control group.*

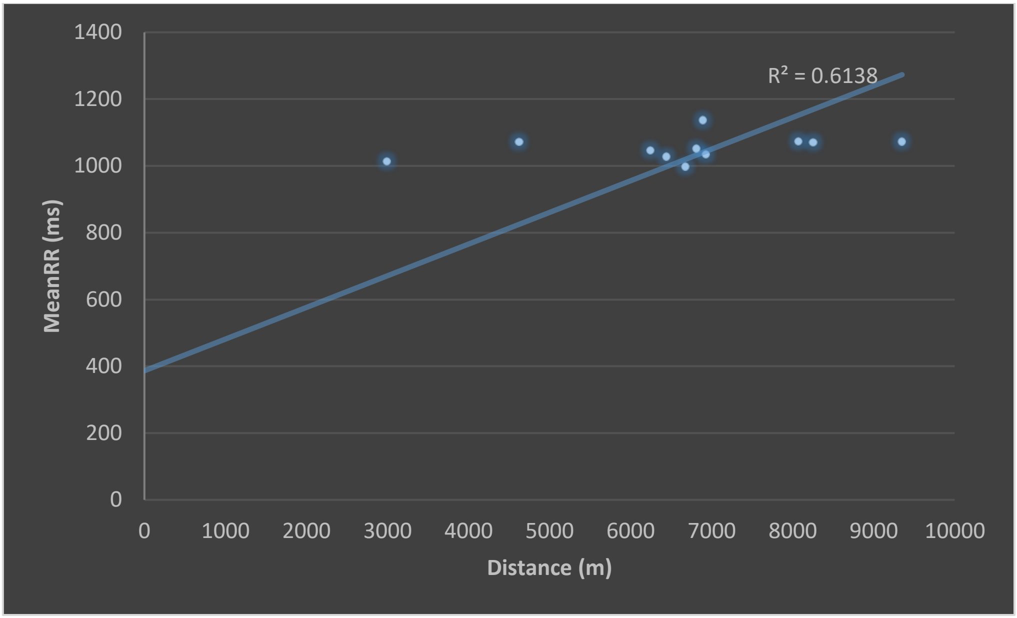


*Figure 6: The relationship between average total distance covered and average Mean RR intervals of HRV for the intervention group.*

Figures 5 and 6 show correlations between MeanRR and Distance covered in training. Both R values are between 0.60-0.79, which classifies the correlation between the measures as "strong" (Evans, 1996). This suggests that a change in overall distance has a direct effect on MeanRR. There were also no significant differences between groups (>0.05).

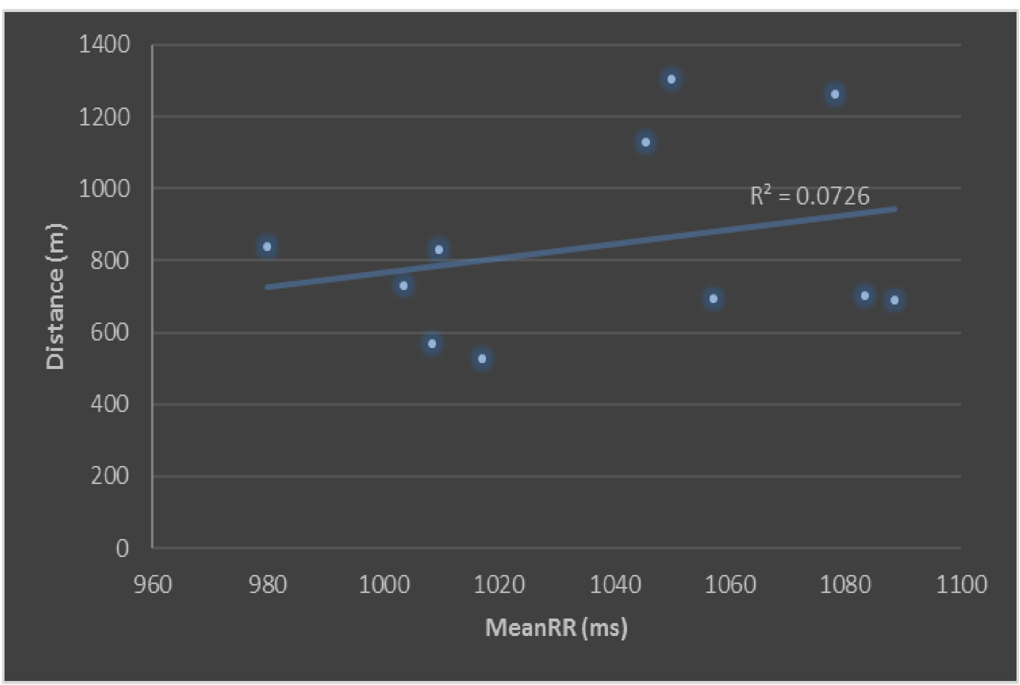


*Figure 7: The relationship between MeanRR and HI distance for the control group.*

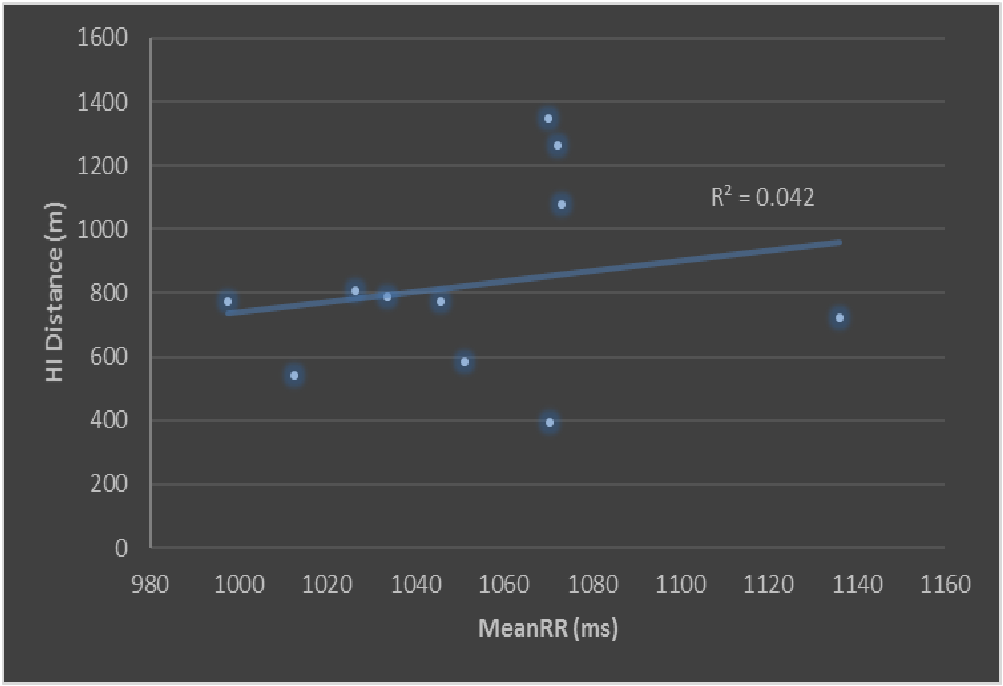


*Figure 8: The relationship between MeanRR and HI distance for the Intervention group.*

Both figures 7 and 8 have a R value between 0.00-0.19, which classifies the relationship between the two measures as “very weak” (*Evans., 1996).* This suggests that there is no relationship between high intensity difference and therefore do not directly affect each other. There were also no significant differences between groups (>0.05).

rMSSD

The following figures explore the HRV measure rMSSD and the relationship with GPS data.

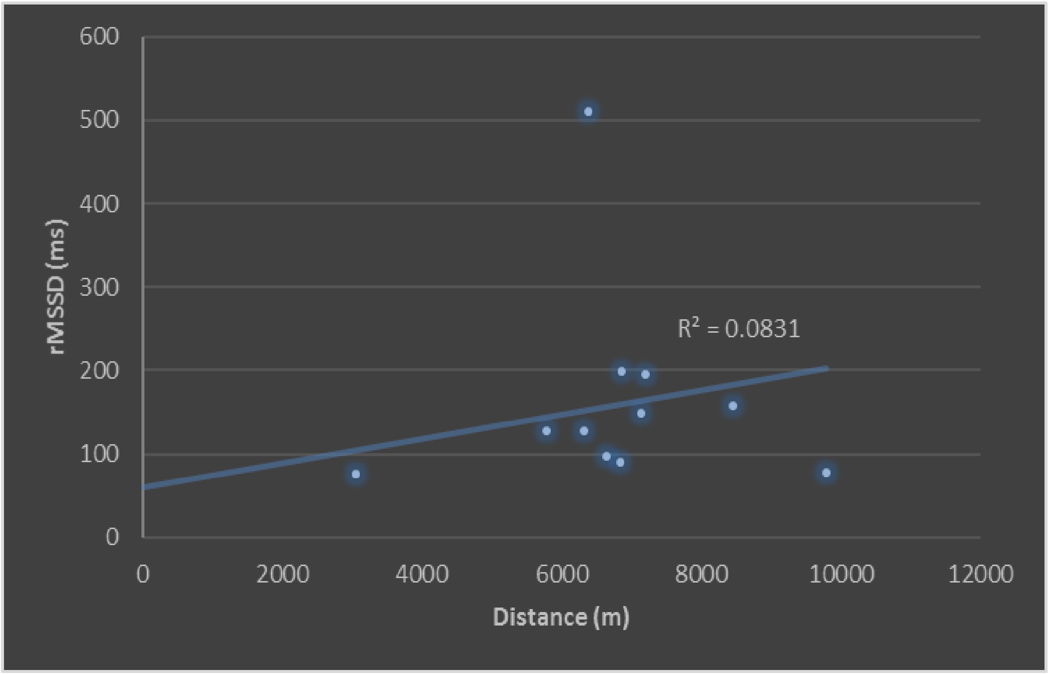


*Figure 9: The relationship between rMSSD and distance for the control group.*

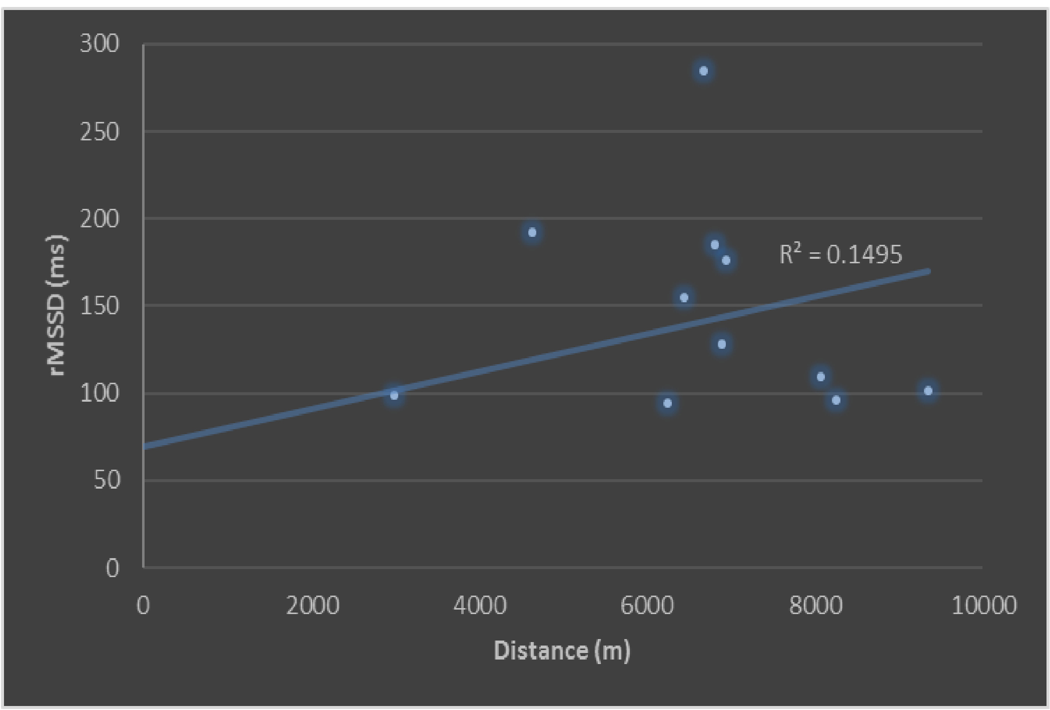


*Figure 10: The relationship between rMSSD and distance for the intervention group.*

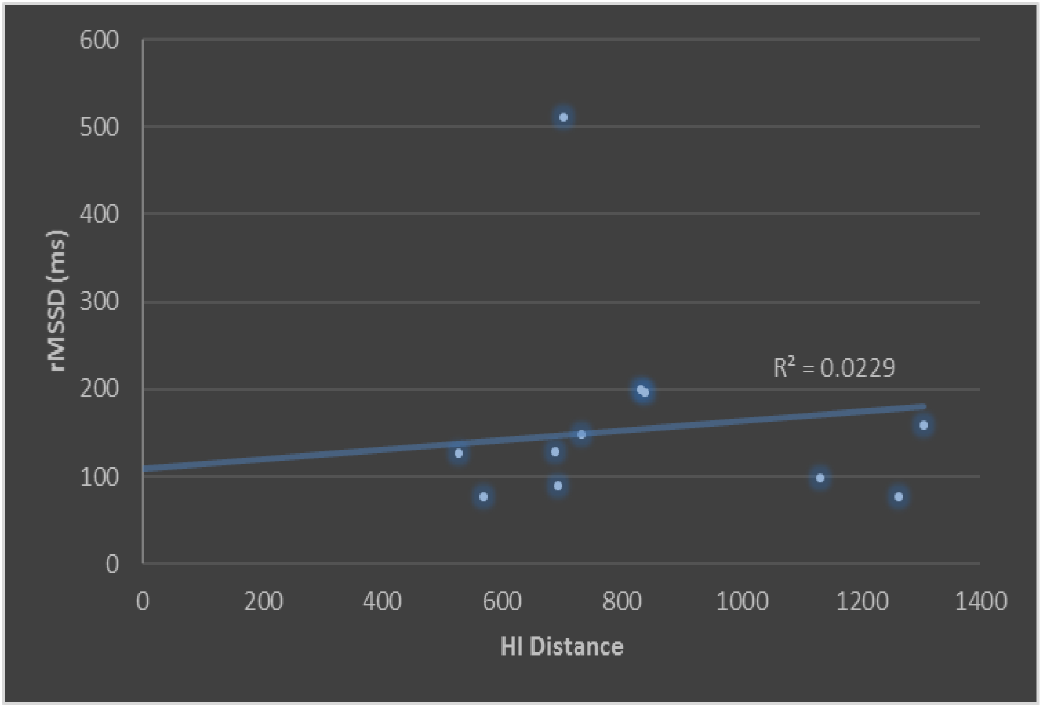


*Figure 11: The relationship between* rMSSD *and high intensity distance for the control group.*

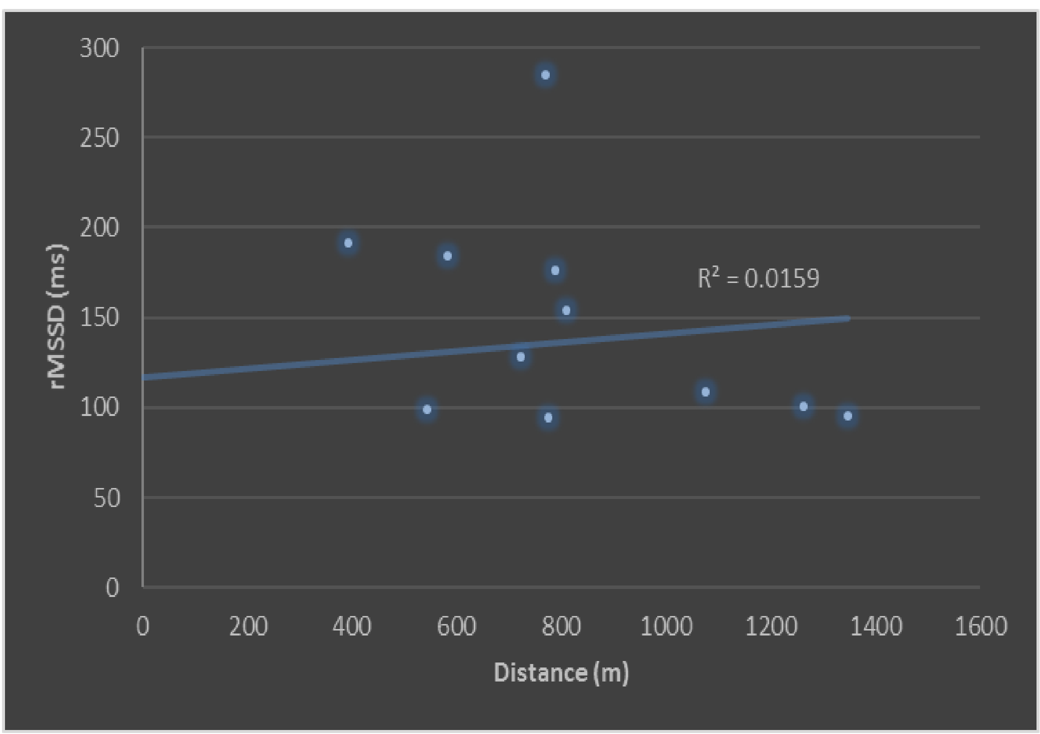


*Figure 12: The relationship between rMSSD and high intensity distance covered for the intervention group.*

SDNN

The following figures explore the relationship between HRV/SDNN and GPS data.

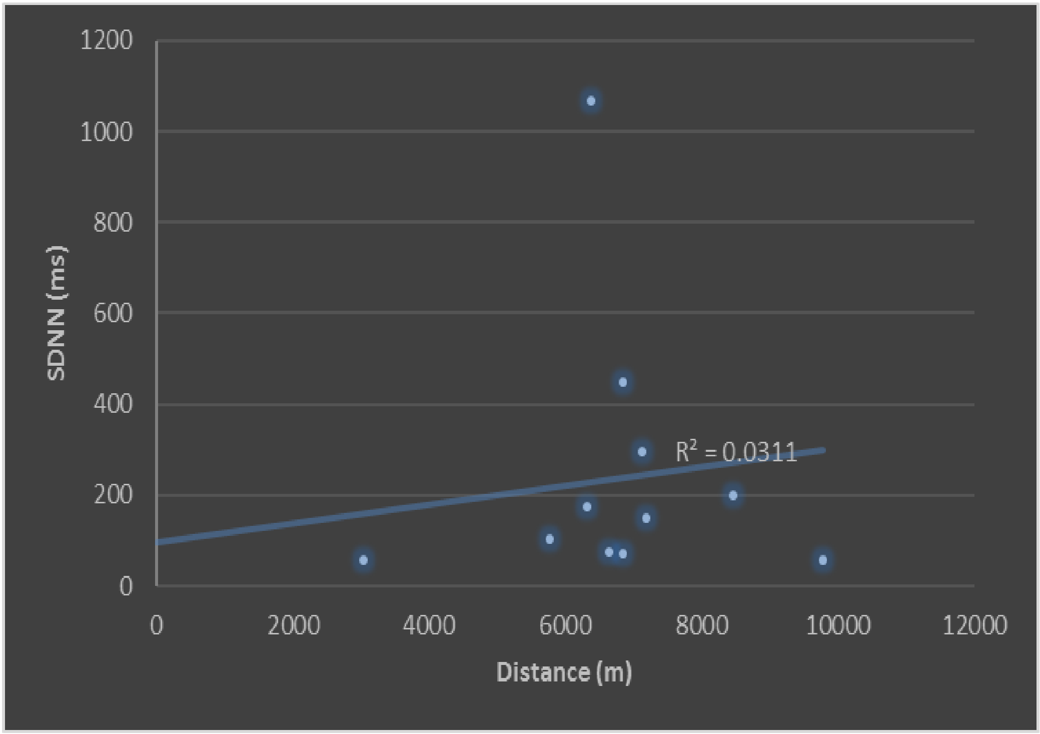


*Figure 13: The relationship between SDNN and distance for the control group.*

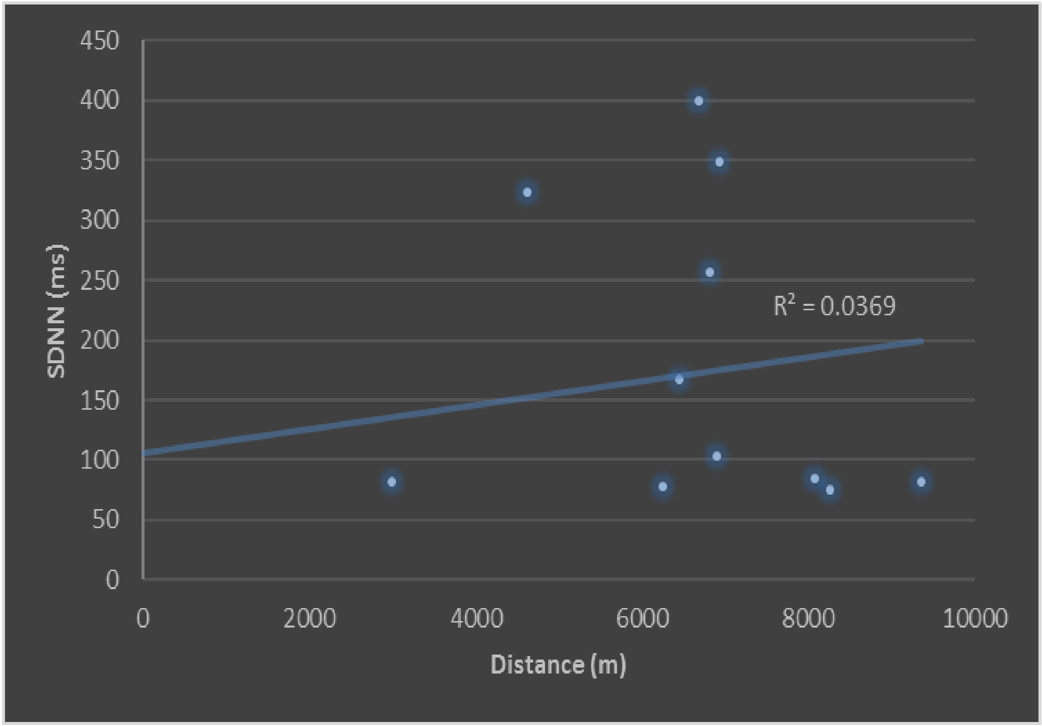


*Figure 14: The relationship between SDNN and Distance covered for the intervention group.*

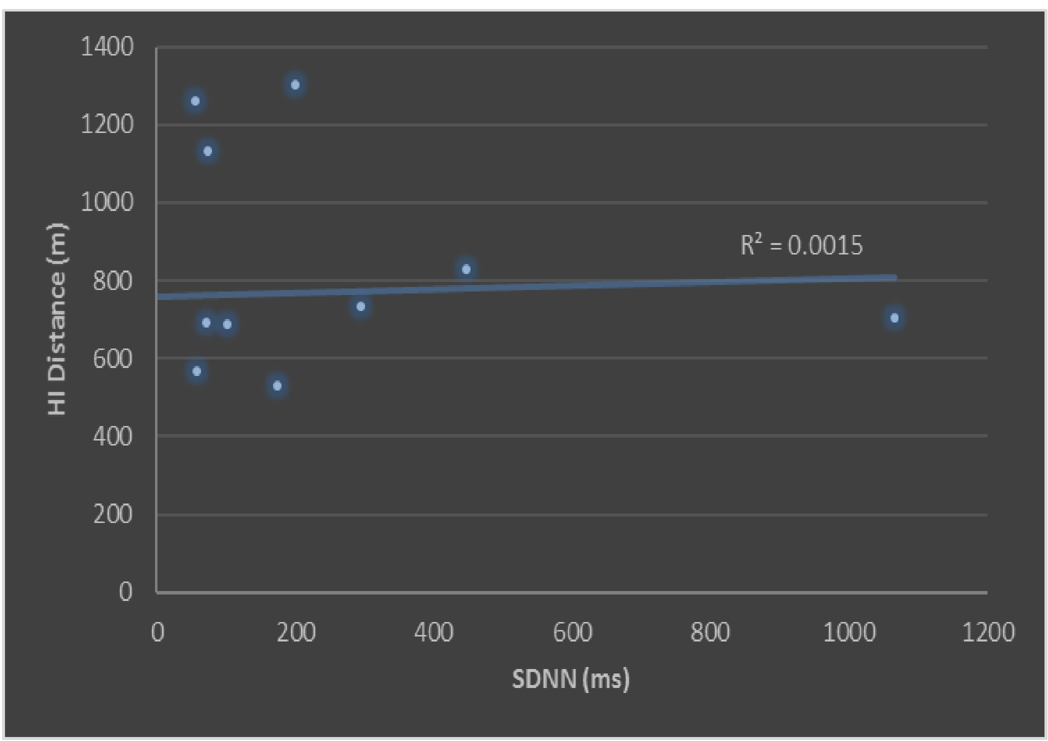


*Figure 15: The relationship between SDNN and high intensity distance covered for the control group.*

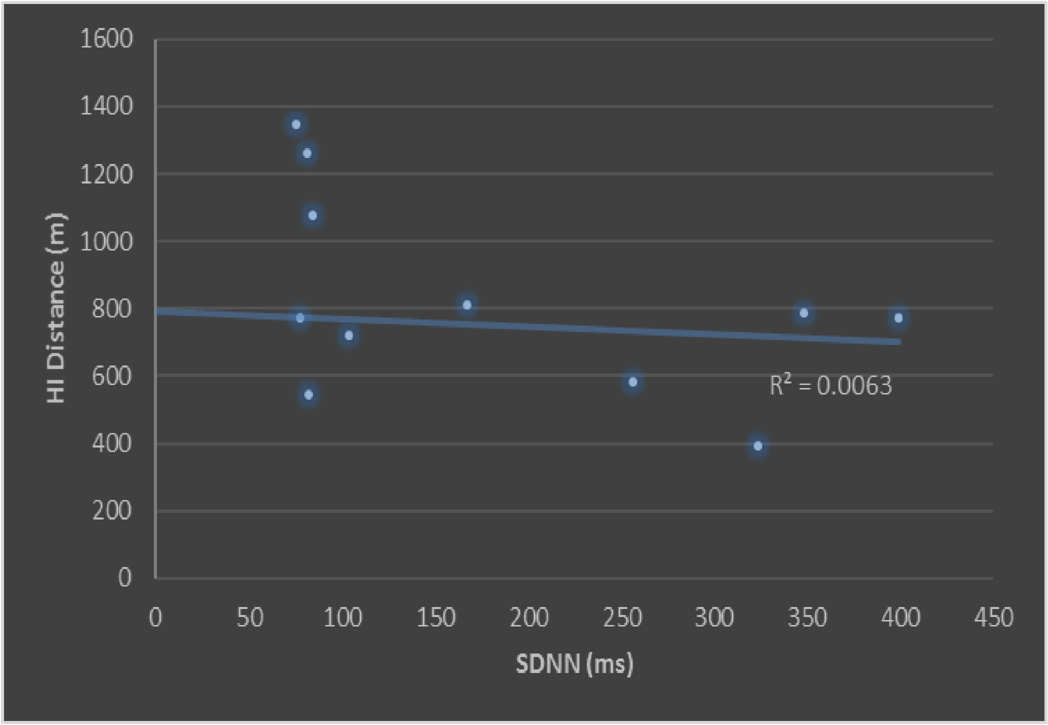


*Figure 16: The relationship between SDNN and high intensity distance for the intervention group.*

**4.4 (4) $VO_2$**

On average for all the participants in the study their $VO_2$ max ml.kg.min increased by 7%, this consisted of a 11.7% increase for the control group and a 2.0% increase for the intervention group. For the control group this has an effect size value of 0.80, which is defined as a moderate magnitude of change pre-post study. The intervention groups change has an effect size value of 0.23, which is defined as a trivial magnitude of change pre-post study.

In terms of time to exhaustion (TTE) all participants decreased in their TTE by 6%, this consisted of a 3.2% increase for the control group and an 8.8% increase for the intervention group. For the control group this has an effect size value is 0.31, which is defined as a small magnitude of change pre-post study. For the Intervention group this has an effect size value is 1.17, which is defined as a large magnitude of change pre-post study When working out effect size participants were classified as highly trained athletes (RHEA, 2004).

*Table 5: The Mean (SD) and effect size for pre and post $VO_2$ max scores and time to exhaustion.*

| | **TTE (mins) Control** | | | **TTE (mins) Intervention** | | | **$VO^2$ (L-min$^{-1}$) Control** | | | **$VO^2$ (L-min$^{-1}$) Intervention** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **PRE** | **POST** | **Change** | **PRE** | **POST** | **Change** | **PRE** | **POST** | **Change** | **PRE** | **POST** | **Change** |
| **Mean (SD)** | 10.8 (1.3) | 11.1 (1.2) | 3.2% | 10.2 (0.9) | 11.1 (0.8) | 8.8% | 3.6 (0.6) | 4.0 (0.5) | 11.7% | 3.7 (0.4) | 3.8 (0.4) | 2.0% |
| **Effect Size** | 0.31 | | | 1.17 | | | 0.80 | | | 0.23 | | |

There were no significant differences between the control and intervention groups for both TTE and $VO_2$ for pre and post study analysis. There were also no significant differences when comparing pre-post results in-groups.

A power analysis was used to a degree of 0.8, showing that the study was underpowered and would need 25 participants (rather than 18) to show differences for TTE and around 75 participants would be needed to see differences in $VO_2$.

## 4.5 Discussion

The aim of this study was to investigate the effect of tri-weekly aerobic base training on heart rate variability and football performance. A 6-week training intervention was implemented after taking 6 weeks previous of baseline measures. The intervention consisted of tri-weekly 30 minutes' steady state aerobic base training at 60-70% of the participant's maximum heart rate, this was in addition to their normal weekly training load, the control group did not participate in these extra sessions. As well as HRV, pre and post study data was taken for $VO^2$max using a ramp treadmill test. Throughout the study including the baseline period, performance parameters were recorded including GPS and RPE.

It was found that there was no significant difference between groups for HRV. There was also no significant difference in parameters (distance, high speed running and player load) along with no significant differences between groups for $VO^2$max data (TTE and L/min.kg). There were certain non-significant positive trends in the data i.e. an 8.8% increase for TTE in the intervention group (effect size = 1.17). Although this is a non-significant change, power analysis has indicated that the study was slightly underpowered and this may need to be explored with increased participation for future research. An outlier can be seen in Figures 10, 11 ,12 and 13. This is due to individual differences and is the same participant in each case.

### 4.5 (1) HRV

The reliability analysis in chapter 2 showed that most of the HRV parameters had a large variability and were classified as "very poor" and therefore NN50, Pnn50, TINN, SD1 and SD2 were not used in analysis. The most reliable HRV parameter was the

MeanRR with a score of 0.6 followed by the two variable parameters of SDNN and rMSSD.

There were no significant differences ($p>0.05$) for MeanRR between groups for all weeks of the study. Which suggests that HRV was not affected by the differences in training protocols between the control and the intervention group i.e. the introduction of aerobic training sessions.

Martinmaki et al. 2008 reported that training at >70% of maximum heart rate has a negative effect on HRV and working at high intensity decreases HRV and all HRV indices. An increased stress placed on the body by high intensity training or competitive matches has a direct effect on the ANS, due to the increase in sympathetic tone and the decrease in parasympathetic tone; this has a direct effect on HRV as an increase in SNS activity decrease HRV (Martinmäki *et al.*, 2008). The increased physiological and psychological stress placed on the body from high intensity work and especially match play causes an increase in sympathetic tone and subsequently a decrease in parasympathetic tone of the ANS (Edmonds, Sinclair and Leicht, 2013). This increase in stress in the body and increased sympathetic tone causes a decrease in HRV (Bricout, DeChenaud and Favre-Juvin, 2016). The results from this study shows both a positive linear relationship between an increased distance with an increase in MeanRR (*Figures 5 & 6)*. The control group and the intervention group both were 0.6 on the R Value for correlation between MeanRR and overall distance travelled. The R value for both groups for correlation between MeanRR and high intensity distance covered were both very weak as they were between 0.0 and 0.19 (intervention = 0.04 , control = 0.08). This would suggest that the increasing overall distance covered, at any intensity causes meanRR to increase meaning that the resting heart rate had dropped. This trend has been seen in many other research papers showing that the more trained an individual then the lower their resting heart rate (Aubert, Seps and Beckers, 2003; Sandercock, Bromley and Brodie, 2005). This current research suggests that working at a high intensity will not directly affect or change MeanRR.

It has been shown that there was strong correlation between training load and HRV with daily high intensity training (Plews *et al.*, 2012). Further research found that certain HRV parameters had correlations with a change in training intensity. The greater the high intensity distance covered the greater the sympathetic dominance in the ANS, this was shown as for every additional 300m of high intensity running ran HRV indices dropped by one unit (Thorpe *et al.*, 2015).

Thorpe et al found that specifically the rMSSD HRV indices correlated strongly with an increase in training load stress on the body and concluded that this showed promise as a possible none-invasive measure fatigue in elite soccer players. In chapter 3 it was found that rMSSD had poor reliability as a daily measure of HRV, and that MeanRR had the best reliability of all the time domain HRV measures from the Kubios output. MeanRR does not measure the variability of the heart rate and instead how frequently the heart beats (i.e. heart rate). Therefore, SDNN was used in this study as it was the HRV parameter that was least variable after running ICC analysis in SPSS. This may be the reason why results from this study did not match with Thorpe's study in terms of the correlation between high intensity distance and HRV was not as strong in this study despite both participant numbers being similar in both studies. However, due to rMSSD being regularly used in studies and seen as one of the best HRV measures to analyse (Flatt and Esco, 2015) also, rMSSD was the second most reliable measure behind the SDNN. There were no significant differences between groups or between weeks for rMSSD.

The rMSSD findings seem to contradict previous research papers, some of which have stated that rMSSD could be used on a daily basis to monitor fatigue caused by high training load (Flatt and Esco, 2015). This may not have been seen in this study due to a number of reasons. As stated earlier, in the reliability stage (chapter 3) of the study the rMSSD was categorized as poor validity (1.0-3.0). The findings from this study may contradict Flatt & Esco (2015) due to using different methods of HRV data collection in the studies. Flatt & Esco (2015) gave participants a smartphone based HRV reading app "iThlete", which comes with a clip which can be attached to either the participants finger or ear in order to take a HRV reading. Although it has been seen in previous research that app based HRV collection techniques were valid when compared to electrocardiograph measures in a laboratory setting (Flatt and Esco, 2013), there could be differences in readings from iThlete and the Polar V800 watches. iThlete has not been compared to the Polar V800 in previous research and therefore the validity has not yet been analysed. Furthermore, the validity and the reliability of the Polar V800 watch has not been explored in previous research, hence the need for Chapter 3 in this current research in order to establish this. The use of different HRV collection methods, along with the validity of rMSSD being contradictory between collection methods may be reason for contrasting results.

Most studies showing a relationship between high intensity training causing changes in the ANS and the increased sympathetic tone leading to a reduction in HRV indices are done in controlled laboratory conditions. The current study aimed to determine whether this could be transferred in to real life working situation inside a football club where there is less control over a range of variables. HRV has been seen to be a reliable measure of stress on the body in laboratory and other more easily controlled setting such as hospitals (Pagkalos *et al.*, 2008; Castello-Simões *et al.*, 2013; Herbsleb, Mühlhaus and Bär, 2014). There are so many extraneous variables for the footballers on a day to day basis, type of training/schedule can change week on week along with what extra activities they have to do on any given day i.e. gym sessions/ prehabilitation sessions; these sessions change per day and change due to match schedules. Studies have shown that psychological stress has an impact on the balance of the tone of the SNS and the PSNS in the ANS. This psychological stress has the same impact on HRV as physiological stress (Winsley, 2002; Bricout, DeChenaud and Favre-Juvin, 2016). The psychological wellbeing of footballers can fluctuate day-to-day and week-to-week due to professional reasons i.e. being selected/not selected for the team and also personal reasons i.e. change in situation away from the club.

This psychological stress may have had an impact on the HRV results and meant that the aerobic base training did not have an impact in terms of reintroducing the parasympathetic tone of the ANS due to sympathetic tone being stimulated by psychological stress. The intervention may have had an impact on a participants HRV in terms of introducing the parasympathetic tone in the ANS, but his could have been eradicated by psychological stress increasing the sympathetic tone/increasing the parasympathetic tone. As previously mentioned, psychological stress has the same impact on the ANS as physical stress (Winsley, 2002; Bricout, DeChenaud and Favre-Juvin, 2016), therefore any psychological stress would affect the results and may make any benefits from the aerobic base training undetectable.

There are many different methodological approaches to the interpretation and analysis of HRV, leading to inconsistent finding in literature. Many studies have found that rMSSD is the most reliable HRV indices to use (Plews, Laursen, Stanley, *et al.*, 2013; Flatt and Esco, 2015). Plews et al chose to use rMSSD as the indices to measure HRV, as it was found in the study that it has a lower co-efficient of variation when compared to other indices. This supports the use of rMSSD in this study, although the variability was still high and the ICC was classified as "poor".

The HRV was utilised in this study due to absolute values and day-to-day variations in HRV being useful indicators of any progression towards maladaptation or over-reaching. rMSSD has been seen to decline with more overreached athletes when preparing for a competition (Plews *et al.*, 2012). Overreaching may be tracked through HRV or other indicators such as GPS, HR and RPE, which were all used in the current study. The findings from this study support those of Plews et al in terms of HRV decreasing the greater the training load calculated from the performance measures such as GPS high speed running. Figures 9-16 show the correlation between rMSSD and Distance/high intensity distance along with the relationship between SDNN and distance/high intensity distance. This contradicts previous literature stating that an increased training load can be seen internally by tracking HRV (Plews *et al.*, 2012). The increased training load increases sympathetic and decreases parasympathetic tone of the ANS, this is then seen from a change in HRV by a decrease in HRV indices. In this current study there is a very poor correlation between HRV parameters SDNN and rMSSD and GPS training load (i.e. distance/HI distance). Previous literature would suggest that an increase in stress on the body would cause a decrease in HRV (Plews *et al.*, 2012; Edmonds, Sinclair and Leicht, 2013). Therefore, in this current study it would be expected that HRV indices decrease as GPS data increases, this is not the case as can be seen in Figures 9-16.

The current study may have contradicted previous studies due to methodological issues. Due to the data collection being at the football clubs training ground, the room in which the data was collected was not the same as laboratory conditions. It was ensured as much as possible that the room was quiet and the conditions were the same each day of data collection but this not as easy to do as a lab setting and this could have led to the contradictory results from previous studies. Previous literature had stated that certain HRV indices, especially rMSSD, was a valid and reliable parameter to use when tracking training load (Plews, Laursen, Stanley, *et al.*, 2013). As previously mentioned, Chapter 3 of this current study did not coincide with these findings as the ICC for rMSSD was 0.2, which shows poor validity, compared to strong validity found on Plew's previous work (0.8)

It has been found that HRV is highly variable and much previous work in to HRV contradicts itself (Plews, Laursen, Stanley, *et al.*, 2013). Changes in vagal-indices i.e. the low frequency (PSNS) and high frequency (SNS), have been seen to have both positive and negative effects in HRV. Due to its high variability, when analysing HRV in athletes it is beneficial to track changes longitudinally in order to understand the athletes unique HRV finger print (Plews, Laursen, Stanley, *et al.*, 2013). The current study attempted to achieve this by collecting 6 weeks of baseline data in order to establish "normal" values for each participant and then track any deviations from the norm in the intervention part of the study. The 12-week span of the study may not have been long enough to collect a reliable baseline sample and similarly the second 6-week part of the study may not have been enough time to elicit any changes in HRV. There were trends found in the data (figures 4,5), if the study was more longitudinal then these trends could have become significant changes. As mentioned earlier the study was underpowered and again could have contributed to no significant changes being seen in this intervention. Future studies should look at increasing the number of participants along with the length of the study.

An 8-week aerobic training intervention has been seen to improve 10km running time in moderately trained participants (Buchheit *et al.*, 2009). The study found that there was a correlation between changes in HRV indices and changes in 10km running time. HRV correlated strongest with those participants who improved their 10km time. This suggested that HRV indices could be used for assessing and predicting the impact of aerobic training on endurance performance (Buchheit *et al.*, 2009). These findings are supported by the current study. There was an 8.8% increase in time to exhaustion for the intervention group compared to 3.2% increase to time to exhaustion for the control group. Although not statistically significant, this would suggest that the addition of aerobic base training to participants in the intervention group may have had a positive impact on performance. Buchheit et al found that there was a correlation between HRV and an increased output in performance. However, the current study does not show significant changes between groups for field based performance such as GPS distance and fitness testing i.e. the $VO^2$max test. This could be due to the highly trained nature of the participants in this study, having high intensity training/competition 5 days a week means that the participants were already highly trained and were starting with high baseline values. The more trained an athlete is then the harder it will be to elicit changes than lesser trained participants/athletes (Aubert, Seps and Beckers, 2003; Sandercock, Bromley and Brodie, 2005). Using moderately trained individuals means that the participants have a good aerobic base to work from but still have vast room for improvement. Any improvements in this current study will have been small due to the training status of all the participants pre-study, this could be a reason as to why no significant changes were found, due to any gains being so small.

Furthermore, the none-significant results may be due to the recovery of the participants being greater due to, as just mentioned, their highly trained status. It has been found that cardiac autonomic recovery occurs more rapidly in individuals with greater aerobic fitness (Stanley, D'Auria and Buchheit, 2015). Heart rate recovery after exercise (cardiac autonomic recovery) is commonly used to reflect autonomic activity of an individual and can predict autonomic activity and mortality. The recovery time is characterised by the withdrawal of the SNS and the subsequent reactivation of the PSNS, an individual who is highly aerobically conditioned is likely to have a quicker heart rate recovery time than others (Okutucu *et al.*, 2011) We know from literature that exercising causes an increase in the tone of the SNS and the subsequent decrease in the tone of the PSNS (Vesterinen *et al.*, 2013; Bricout, DeChenaud and Favre-Juvin, 2016). This means that post exercise, in order to internally recover from the exercise, the parasympathetic tone must be reactivated. Analysis of parasympethetic activity post exercise is useful for indiviualising training programmes. Recovery time may be different between individuals so should be taken in to account when making exercise plans, individual biofeedback would aid this. The biofeedback received by coaches in an indication of cardiovascular recovery i.e. the internal physiological respnses to training have been contereatced and recovered from once the parasympathetic nervous system is reactivated. It has been found that recovery times vary per indivual and due to training status but generally recovery from low intensity exercise is up to 24 hours, moderate intensity exercise 24-48 hours and high intensty can be anything up too and over 48 hours (Plews, Laursen, Stanley, *et al.*, 2013). The recovery time for low intensity exercise in Stanley's work has been backed up in this study. There was no physiological response to the increased work load on the intervention group by completing additional training to their usual training load, completed by the control group. HRV indices were not significantly diifferent between the groups, even the morning after the additional aerobic base training session had been completed the afternoon before. This suggests that any potential negative impacts from additional training load from low intensity exercise were not found. Therefore, additional low intensity work can be set by coaches without any internal impact on the athelete and risk fatigue for training the next day as there were no negative impacts found from the additional training. Aswell as the additonal training not having an impact on internal biofeedback, it also was not prevalent in the external monitoring parameters such as distance covered or high intensity distance covered. There was no signficant differences between groups for both distance covered and high intensity between groups. This suggests that the extra training load from the intervention did not have a negative effect on the physical performance of players in training or in games. This again means that coaches can add to the training load without fear of negative effects aslong as the extra training is at a low intensity. This supports previous literature which states that low intensity aerobic training does not increase sympathetic tone in the ANS i.e. decrease HRV, but instead has been seen to increase HRV (Borghi-Silva *et al.*, 2009; Castello-Simões *et* *al.*, 2013). Although the current study does not show improvements in HRV through aerobic exercise, it does strengthen the findings that there are no negative effects in terms of impact on the ANS, meaning coaches could increase training duration without having an effect on the ANS, aslong as the work is at a low intensity. However, coaches should be aware as stated that psychological stress has an effect on HRV so the mental aspects of the extra training should be considered.

There has been further research in the use of HRV as a predictor/assessment of fitness levels in sport and specifically youth football players. It has been found that a decrease in HRV meant that there was an increase in fitness test scores in youth football players (Kavcic *et al.*, 2012). A decrease in HRV would be due to high intensity training, which literature here suggests that working at a high intensity and the subsequent decrease in HRV results in an increase in fitness scores. This study has shown an increase in time to exhasution for both the control (+3.2%) and intevention (+8.8%) groups. Although both these increases are not significant it supports (Kavcic et al. 2012) claims that fitness scores increase after high intensity exercise and a subsequent decrease in HRV. The results also suggests that the addition of aerobic base training may elicit increased fitness gains in terms of time to exhaustion.

<u>4.5 (2) GPS</u>

Using GPS tracking devices to quantify training load is a useful tool when used to feedback to coaches how intense the session was on their players and the possible physiological effects it has (Malone and Drust, 2014). Quantifying training load allows coaches to set target values for varying parameters such distance covered or number of sprints. There were no significant differences between groups for all GPS parameters; Distance, high intensity distance and player load ($p>0.05$). There were differences in distance covered and high intensity distance between weeks but none were significant ($p>0.05$).

There was a positive linear relationship between distance covered and MeanRR along with high intensity distance covered and MeanRR. This suggests that the more distance a footballer covers in training then the lower their resting heart rate. Research has found that individuals who exercise regularly have a lower resting heart rate than sedentary individuals (Vesterinen *et al.*, 2013). Although the relationship between GPS distance and MeanRR was not significant, the positive trend suggests that even highly trained individuals who have a low resting heart rate (RHR) can make improvements to their RHR through training. Participants who covered more distance and covered more high intensity distance had a greater impact on their MeanRR, this would suggest that if an individual who trains at a greater intensity then this will have an effect on resting heart rate.

Previous research has stated the correlation between GPS and RPE as parameters to analyse and assess training load in team sports (Casamichana *et al.*, 2013; Scott *et al.*, 2013). Increased GPS statistics i.e. greater high intensity running/number of sprints correlates with the player scoring higher on the RPE scale (Casamichana *et al.*, 2013; Malone *et al.*, 2015). This suggests that player’s perceptions of the intensity of a session is usually in line with the physical demands of the session. RPE can be used then as a quick, cheap and none-invasive measuring tool of exercise intensity (Lovell *et al.*, 2013; Gomes *et al.*, 2015), although some research has contradicted these studies claiming that athletes can over estimate the intensity that the coach had aimed for and can lead to maladaptation if not reviewed (Rodríguez-Marroyo and Antoñan, 2015). This research paper has found that there were no significant differences between RPE and GPS (both distance and high intensity distance). This backs up papers by (Lovell *et al.*, 2013; Gomes *et al.*, 2015) in supporting the use of RPE as a none-invase measuring tool.

Some HRV indices are not suitable as a replacement of GPS measures. Using HRV indices SD1 which measures the beat to beat validity, as been found to not be suitable to measure training load in football when used in a 2-week training camp (Buchheit *et al.*, 2013). As mentioned earlier, rMSSD and SDNN are more widely used in research due to there lesser variability than other measures. Buccheit's research further justifys not using certain HRV indices such as SD1 as it does not correlate with other external measures such as GPS. This previous literature supports not using SD1 in this current study.

A recent study has shown the internal changes and there link to external factors. It has been found that when training intensity is high I.e the training load data collected from the GPS is high, then resting heart rate increases and rMSSD decreases (Stanley, D'Auria and Buchheit, 2015). This further supports the trend of a decrease in HRV parameter values when training load/intensity is large, this would suggest that rMSSD is sensitive to increases in training load. In this current study, MeanRR (heart rate) had a positive correlation with distance covered and high intensity distance covered (figures 5-8). This contradicts Stanley's findings as increasing training load appears to have a positive effect on resting heart rate i.e. a lower resting heart rate. As mentioned earlier, results in this paper support the previous literature that suggests that increased training load results in lower resting heart rate (Aubert, Seps and Beckers, 2003; Sandercock, Bromley and Brodie, 2005). The findings from this study do not support the decrease in rMSSD when training load is high, this may be due to as already mentioned, limitations with this study, potentially being underpowered in terms of participants, the study not being longitudianal and the high training status of the participants before the study took place. Stanley also found that there was a correlation when performance increased i.e. GPS statistics were higher and a decrease in resting heart rate along with an increase in rMSSD. This further answers the aims behind this study, that a increase in rMSSD i.e. the increased tone of the parasympathetic nervous system then the less fatigue players have and therefore can increase performance. Performance was not significantly correlated with rMSSD however, there was a positive between an increase in distance and rMSSD along with a positive trend between an increase in high intensity distance and rMSSD.

4.5 (3) $VO_2$max & Time to Exhaustion

There was no significant difference between groups from pre to post study $VO_2$max tests. There was no difference for both the key outcome measures from the $VO_2$max of $VO_2$ l.min/kg and time to exhaustion (TTE).

There was an 8.8% increase in TTE for the intervention group compared to a 3.2% increase in TTE for the control group. This difference between groups suggests a potential performance improvement for the intervention group, however, as stated earlier this was not a significant difference (>0.05). This difference may not have been significant due to the number of participants in the study being too low to elicit a real change between groups. Power analysis calculates how many participants would be needed in order to have enough “power” to find any changes between groups. When calculated at 80% power the participants needed for TTE was 25 participants, 7 more than in the current study, showing that it is slightly underpowered and may be a reason for no significant changes between groups.

Training interventions using aerobic steady state protocol have shown a significant improvement in $VO_2$ max where participants completed tri-weekly sessions for 8 weeks totalling 24 intervention sessions. The study also found that aerobic base training was as effective in increasing $VO_2$ max as high-intensity interval training (HIIT) training. Both types of training made significant increases in $VO_2$ max but there were no significant differences between groups (Foster *et al.*, 2015).

## 4.6. Conclusion

In conclusion, tri-weekly aerobic base training with elite youth football players did not elicit any changes in HRV when compared to a typical training regime, consisting of field based football training 4 days a week with a proportion of the work being at high intensity.

A positive linear trend was seen in MeanRR and distance along with high intensity distance covered, suggesting that the higher the training load the lower the resting heart rate which backs up previous literature (Aubert, Seps and Beckers, 2003; Sandercock, Bromley and Brodie, 2005).There were improvements in TTE for the intervention group, although they were not significant. The increase (8.8%) does suggest that the use of aerobic base training as an extra training session may have a positive effect on performance (effect size >1.0). As mentioned the increase was not significant however, power analysis suggests that the study was underpowered and this may be why only trends were found rather than significant changes.

Recent research has shown the importance of tracking acute and chronic workloads. Acute workload is the short-term load the athlete is subjected to i.e. the current week whereas chronic workload is the long-term load that has been placed on the athlete i.e. 4 weeks. Players who are exposed to high loads can be positive or negative. Players with a high chronic load are more resistant to injury with moderate-low through moderate-high acute:chronic ratio (0.85-1.35), whereas they are less resistant to injury when subjected to ‘spikes’ in acute load and therefore are very high in terms of acute:chronic load (>1.5) (Hulin *et al.*, 2016). Appropriately prescribing high training loads can improve players' fitness and may protect against injury ultimately leading too greater physical performance and resilience in competition along with a greater squad availability (Gabbett, 2016). In this current study the use of the additional aerobic base training sessions did not have a negative impact on participants in terms of performance outputs in training and in competition along with the internal impact on participants not being significantly different to the control group. This suggests that the use of extra sessions at a low-moderate intensity could be a safe and controlled way of increasing training load but without risk of fatigue or decreased performance.

Future research could look in to the effect of additional training and how both acute and chronic load can be increased safely without increasing the injury risk of players. Players with a low chronic load may increase their training, causing a 'spike' in their acute load. Introducing aerobic base training sessions may be a way to increase acute load slightly and therefore over time increase chronic load. Future research could investigate the most effective way to increase short term load in order to increase chronic load but without any detriment to the player in terms of injury risk and fatigue.

This study has in the main contradicted previous research suggesting that HRV could be manipulated and by changing the sympathetic and parasympathetic tone in the ANS. Positive trends in performance measures were seen although they were not significant. In terms of the aims of this study. It has been found that HRV is variable when used in a field setting, when using HRV in a practical setting the high variability of the results should be considered. It cannot be said that aerobic base training can aid recovery and increase HRV however, it aerobic base training can be added as additional training without having a negative effect on HRV.

Future research in this area should consider a larger sample size due to the highly variable nature of HRV especially when it is used in an applied environment. Additional research in to potential performance gains from the use of low intensity exercise sessions could be explored.

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