Effects of In-Season Subjective vs. Objective Autoregulation on Sprint-, Jump- and Power Performance in Professional Soccer Players

Chris Jakob Homman

SUPERVISORS

Thomas Bjørnsen, Fredrik Tonstad Vårvik, Kolbjørn Lindberg

University of Agder, [2021-2022]
Faculty of Health and Sport Science
Department of Sport Science and Physical Education

Structure of the present thesis

The present thesis is presented in two parts, followed by part 3: appendices. Part 1 presents the theoretical framework, along with methods of the present study and a methodical discussion. Part 2 entails the research paper, written according to the guidelines of "Scandinavian Journal of Science and Medicine in Sports".

ACKNOWLEDGEMENTS

Firstly, I would like to thank my supervisors, Thomas Bjørnsen, Fredrik Tonstad Vårvik and Kolbjørn Lindberg for their guidance during the writing of this Master's Thesis. Your help has been greatly appreciated. Secondly, I would like to thank all of you who sat in the second floor of Spicheren, you have made this master's program one (two) hell of a year! A special shout out needs to go to Andreas Mathingsdal Pedersen for providing us with free coffee throughout the year. Lastly, a big, big thanks to my family for supporting me and providing much needed breaks.

Best regards,
Chris Jakob Homman

Abbreviations

CSA	Muscle cross-sectional area
RFD	Rate of Force Development
MVC	Maximal Voluntary Contraction
SSC	Stretch Shortening Cycle
TP	Traditional Periodization
BP	Block Periodization
EMG	Electromyographic Activity
1RM	Maximal Strength
VBT	Velocity-based Training
PBT	Percentage-based Training
Pmax	Maximal Power
CMJ	Countermovement Jump
RPE	Rating of Perceived Exertion
RIR	Repetitions in Reserve
SS	Self-selection of training/volume
OA	Objective Autoregulation
GPS	Global Positioning System
IMU	Inertial Movement Unit

ABSTRACT

Purpose: The study aimed to compare the effects of subjective and objective autoregulation of strength training on sprint time, jump height and power in-season in professional soccer players.

Methods: Sixteen players (24.6±3.5 years) from second highest national level in Norway completed a 10-week training period focusing on lower-limb exercises. They were randomized to a group that self-selected (SS) volume based on how they felt immediately before the strength training sessions, or an objectively autoregulated group (OA) that adjusted volume based on distance covered ≥5.5m/s (>420m,420-687m,>687m) during soccer matches preceding strength training. Pre- and post-measurements were sprint split times (0-30m), countermovement jump height (CMJ), and power (P_{max}) in a pneumatic leg press device.

Results: An independent samples t-test revealed no significant differences between groups in neither changes of leg press power (SS: 0.1±4.1% vs. OA: -0.9±6.3%, p=0.87), CMJ (SS: 4.3±8.9% vs. OA: 2.6±8.9%, p=0.70) or 0-30m sprint split times (SS: -2.2±4.8 to -0.62±2.05%, vs. OA: -2.46±3.51 to -0.86±1.86%, p>0.91-0.83). A paired samples t-test revealed no within-group changes from baseline. All participants pooled showed improvement tendencies in 0-5m sprint time (-2.3±4.2%, p=0.052), 15- and 20m sprint times (-1.1%, p=0.09 and -1.0 %, p=0.10, respectively), from baseline.

Conclusion: Neither subjective SS nor OA of volume based on locomotive data from soccer matches improved any power-related measure, but one weekly strength training session seemed to be sufficient to maintain in-season power performance in professional soccer players. More research is warranted, with a larger sample size and training volume than in the present study.

KEYWORDS

autonomy, global positioning system, competitive, neuromuscular, speed threshold.

SAMMENDRAG

Hensikt: Denne studien ville undersøke effekten av subjektiv mot objektiv autoregulering på spurt, hopp og power i profesjonelle fotballspillere innad i sesong.

Metode: Seksten spillere (24.6±3.5 år) fra en fotballklubb i OBOS-ligaen gjennomførte en 10 ukers treningsintervensjon med fokus på underekstremitetene. Subjektene ble randomisert inn i to grupper, hvor den ene valgte treningsvolum basert på hvordan de følte seg (SS). Den andre fikk treningsvolumet justert objektivt (OA), basert på hvor langt de løp med en hastighet ≥5.5m/s (>420m, 420-687m, >687m) i trening og kamp. Før- og etter-tester var deltider for spurt (0-30m), svikthopp-høyde (CMJ) og power (P_{max}) i et pneumatisk beinpress-apparat.

Resultater: En uavhengig t-test observerte ingen forskjeller i de avhengige målene mellom gruppene. En paret t-test viste ingen forskjeller innad i gruppene fra start. Når gruppene ble paret var det tendenser til statistisk signifikante forbedringer i 5m-spurt (-2.3%, p = 0.052) og 15- og 20m spurt-tider (henholdsvis -1.1%, p=0.08 og -1.0 %, p=0.09)

Konklusjon: Verken SS-justering eller OA-justering av volum førte til forskjell mellom gruppene i spurt, svikthopp eller power. Det kan se ut til at en økt i uken var nok til å vedlikeholde power-ferdigheter i profesjonelle fotballspiller i sesong. Mer forskning kreves for å fastslå effektene av subjektiv og objektiv autoregulering i fotballspillere, med et større utvalg og treningsvolum enn i denne studien.

Part 1:

INTRODUCTION AND THEORETICAL BACKGROUND OF THE THESIS

1.0 Introduction

The purpose of monitoring training Load TL is to make evidence-based decisions on loading schemes to minimize the risk of injuries, as well as facilitate positive team performance (Akenhead & Nassis, 2016). TL can be divided into external (ETL) and internal (ITL) training load ITL accounts for the physiological responses to training (e.g., muscular fatigue or stress) while ETL is essentially the work the athlete is doing, e.g., number of sprints, acceleration, or total distance (TD) covered(Akenhead & Nassis, 2016; Malone et al., 2015). However, these measures alone do not consider an athletes' daily fluctuations in fitness, fatigue and readiness, nor individual training capacity or response to ETL. Another common form of TL is strength training. Strength training is regularly used to improve maximal strength, and the importance of high maximal strength for athletes is well documented in the literature (Chelly et al., 2009; Rønnestad et al., 2011; Silva et al., 2015; Støren et al., 2008; Suchomel et al., 2016; Vikmoen et al., 2017).

When aiming to enhance strength and power abilities, a one-repetition maximum (1RM) is traditionally used as a main reference to determine the relative load to be used during training (Banyard et al., 2019). As with the TL-measures, the use of a fixed resistance over a longer period can neglect daily fluctuations in neuromuscular performance and athlete readiness. Factors such as diet, sleep quantity and quality, stress and life events affect the capacity of recovery, which in turn affects the amount of external load that gives the best response to training. For example, if the load (%1RM) does not reflect the athletes true 1RM in a particular training session, this could lead to an inappropriate training stimulus over time (Banyard et al., 2019).

Therefore, to prescribe an appropriate training program to each individual athlete, one could use autoregulatory training (Larsen et al., 2021). There are two broad autoregulation methods, which can be divided into subjective and objective autoregulation (OA) methods. Subjective measures include questionnaires such as Borg's Rating of Perceived Exertion (RPE), or the RPE-based scale repetitions in reserve (RIR) and subjective self-selection (SS) of exercise order or volume, and it has been reported that SS of exercise or volume improved maximal strength in trained and untrained populations (Colquhoun et al., 2017; Larsen et al., 2021; McNamara & Stearne, 2010). On the other hand, OA methods include velocity-based training (VBT) where the barbell speed is used as an estimate of acute fatigue within a muscle and has been established as an effective method of improving maximal strength in athletes. (Hickmott et al., 2022; Pareja-Blanco et al., 2017). Maximal strength is a basic quality of power performance, as high levels of neuromuscular strength influences power performance and an improvement in maximal strength will improve power capabilities (Cormie et al., 2011; Stolen et al., 2005).

Power is in essence the ability to produce the most force in the shortest amount of time, in other words the product of strength and speed (Stolen et al., 2005). Further, maximal power (Pmax) is the highest level of power in a muscular contraction where the goal is to produce maximal velocity at take-off, release, or impact (Cormie et al., 2011). Pmax is again dependent on rate of force development (RFD), which is the rate of contractile force at the start of contraction and early phase of muscular force production (Cormie et al., 2011; Suchomel et al., 2018; Aagaard et al., 2002). Power is essential in sports that place high demands of high intermittent intensity (Suchomel et al., 2016). In soccer, powerful actions such as accelerations, jumps and sprints are crucial determinants of performance. However, strength training to improve these abilities during the competitive season may be challenging, and reductions or maintenance in maximal strength and power has been observed with insufficient strength training frequency or volume in professional soccer players (Rønnestad et al., 2011).

The use of autoregulation during the competitive season may allow for frequent adjustments of strength training. To the authors knowledge, only one study has directly compared subjective and OA and reported increases in maximal strength and countermovement jump (CMJ) height in amateur rugby players (Shattock & Tee, 2020). However, they autoregulated strength training by VBT, RPE and RIR, and the intervention was conducted in pre-season. Subjective SS has been suggested as a practical method of strength training adjustment for athletes with a tight competitive schedule (McNamara & Stearne, 2010). On the other hand, OA methods such as VBT may not accurately reflect the ETL of competitive soccer, where the strength training stress comes in addition to training- and match-induced load (Hader et al., 2019; Silva, 2019; Wilson et al., 2012).

It has been proposed that locomotive data from global positioning system (GPS) is reliable for TL monitoring in soccer. Specifically, distance covered $\geq 5.5 m/s^{-1}$ during match-play was reported to strongly correlate with measures of neuromuscular and biochemical fatigue (Hader et al., 2019). Running at speeds ≥5.5m/s^{-1} can be classified as very high-intensity running (VHIR) (Hader et al., 2019).

Further, to the authors knowledge, no one has investigated the use of different autoregulation methods in soccer players during the competitive season. It may be that the use of SS or objectively autoregulated strength training based on locomotive data from GPS-units improve sprint- jump and power-performance in soccer players during the in-season.

1.1 Overall aim and objective of the present study

The study aimed to compare the effects of subjective and objective autoregulation of strength training on sprint split times (0-30m), jump height (CMJ) and power (P_{max}) in-season in professional soccer players. The intervention period lasted 10 weeks, and initiated during the latter stages of the competitive season

Primary outcome:

The main objective of this thesis is to investigate whether subjective self-selected or objectively autoregulated strength training volume based on locomotive data from competitive matches will induce different performance-enhancing effects in sprint split times (0-30m), CMJ-height or leg press power.

2.0 THEORETICAL BACKGROUND OF THE THESIS

2.1 Physical Work Demands of Soccer

The activity pattern of a soccer match is mainly aerobic, with players covering 9-14 km during a match (Stolen et al., 2005). However, intense match periods with maximal or close to maximal exercise depend on anaerobic mechanisms, with high metabolic and mechanical stress (Helgerud et al., 2011; Silva et al., 2015). Further, game-decisive moments in soccer are dependent on powerful actions of maximal neuromuscular activity, including sprints and jumps (Helgerud et al., 2011; Stolen et al., 2005), especially at higher levels (Barnes et al., 2014). Ability to perform more powerful actions than the opponent can be advantageous (Chelly et al., 2009). According to the findings of Faude et al., (2012), 83% of goals scored in the German Bundesliga was preceded by one or more actions of maximal or near maximal neuromuscular activity for either the assister or scorer. Tenga et al., (2010) reported that in the Norwegian Premier league, chances of

scoring were higher during counter attacks, which typically involve maximal sprint efforts.
Sprints have been reported to be performed approximately every 90 seconds, constituting up to 11% of total distance covered during a match (Stolen et al., 2005). From 2006-2012, the number of powerful neuromuscular actions such as high intensity running and sprints increased significantly per match in the Premier League, while total distance covered remained unchanged (Barnes et al., 2014). Also, accelerations and decelerations are powerful neuromuscular actions that are frequent in soccer. Maximal acceleration can be defined as the rate of change in velocity to reach peak velocity in the shortest amount of time, however, there are different acceleration rates, and even slow acceleration can have high metabolic loads (Beato & Drust, 2021; Little & Williams, 2003; Osgnach et al., 2010). The frequency of acceleration was 91 ± 21 per match in the Norwegian Premier League, with lower frequencies in second halves, and decreased as the season progressed (Ingebritsen et al., 2015). Dalen et al., (2019) reported similar findings, suggesting that accelerations are a sensitive measure of physical performance in soccer.

Furthermore, research has indicated that jumping ability is associated with team success (Arnason et al., 2004). Soccer players have been reported to perform headers or arial duels 2.2-18.5 times per game, and these numbers vary by playing position and national league (Sarajärvi et al., 2020). The countermovement jump (CMJ) height in elite Croatian footballers ranged from 41.4 to 50.1cm depending on playing position (Sporis et al., 2009). In the Norwegian Premier League, headers were performed ~113 times per match (Sandmo et al., 2020). Further, jumping ability can be decisive in determining the outcome of competition (Suchomel et al., 2018), as 19-22% of goals scored in the World Cup in 2014, Euros 2016 and World Cup 2018 came from headers (Sarajärvi et al., 2020). Further, starting soccer players are reported to have higher levels of strength and power, compared to non-starters (Silva et al., 2015), therefore, starting players are likely to have better sprinting- vertical jumping and other power-related abilities.

Put together, these findings may indicate a shift in the physical demands of soccer, where the focus is more turned to powerful neuromuscular ability and anaerobic capacity, compared to aerobic endurance alone. In the following sections, the morphological and neural factors of muscular strength and power will be reviewed, along with strength training methods and prescriptions for soccer players.

2.2 Morphological factors

2.2.1 Muscle Cross-Sectional Area & Muscle Fiber Type

A muscle fibers capability to produce maximal force is proportional to its cross-sectional area (CSA) (Cormie et al., 2011). When CSA is increased, there is also an increase in the amount of interaction between actin and myosin filaments. This leads to an increase in cross-bridge cycles, which is responsible for muscular contraction (Suchomel et al., 2018). Muscle fibers are generally distinguished from one another based on the contractile apparatus, contractile characteristics and metabolic profile (Ørtenblad et al., 2018) Increased CSA leads to more and larger myofibrils in both type I and type II muscle fibers (Cormie et al., 2011), and research has shown maximal force production to increase largely following an increase in CSA, although in untrained individuals (Suchomel et al., 2018).

Shoepe et al., (2003) compared single muscle fibers of sedentary and resistance trained men. Results showed that resistance trained men had a significantly greater CSA, maximal force (Fmax) and maximal power (Pmax) in type I and II fibers, however these differences were less distinct when Fmax and Pmax was normalized to CSA and muscle fiber volume respectively. In untrained populations, these changes are easily invoked, and well-trained athletes take longer time to increase CSA (Suchomel et al., 2018). Type II muscle fibers generally increase more than type I fibers in response to heavy strength training (Abernethy et al., 1994; Fry, 2004; Ogborn & Schoenfeld, 2014; Aagaard et al., 2002). Further, type II fibers can produce 3-4 times more power than type I fibers (Cormie et al., 2011). As such, type II fibers are paramount to power development. In fact, it has been observed that the world's best sprinters have higher levels have higher concentrations of type II fibers (Trappe et al., 2015). Therefore, hypertrophy in CSA, especially in type II fibers can lead to higher power production, because hypertrophy leads to an increase of sarcomeres in series.

2.2.2 Pennation Angle

The pennation angle is the angle between the muscle fascicles and the line of action (Cormie et al., 2011), in essence where the external force is directed onto the muscle fiber. A greater pennation angle makes it possible for more sarcomeres to line up in parallel (Cormie et al., 2011). As more sarcomeres are lined up in parallel, it allows more contractile tissue to connect to a tendon following increased pennation angle, which can make muscle fibers to have less shortening distance in a contraction. Therefore, muscle fibers could theoretically work closer to an optimal length, thus increasing the amount of force generated by the muscle (Cormie et al., 2011) On the other hand, with a lower pennation angle, the fascicle length increases. The increase in length of contractile elements will also increase velocity of contraction, and the force that can be produced at high velocities (Earp et al., 2010). If there is a constant level of activation, the fascicle length of a muscle is proportional to the maximal contraction velocity of the muscle (Cormie et al., 2011), and the maximal velocity of a muscle fiber heavily influences power production. Therefore, the speed of shortening at two fiber lengths per second would be faster in a fiber with 10 sarcomeres in a series compared to a fiber containing 5 sarcomeres in series (Cormie et al., 2011).

There has been reported significant relationships between fascicle lengths in vastus lateralis and gastrocnemius in sprinters versus untrained controls, though it is unclear whether this is down to genetic factors or sprint training modalities (Cormie et al., 2011). Interestingly, fascicle length in vastus lateralis has been shown to increase following heavy strength training in untrained individuals (Seynnes et al., 2007; Trezise & Blazevich, 2019). Fascicle length has been indicated to increase following heavy eccentric strength training in trained individuals as well (Blazevich et al., 2007), such as with the Nordic Hamstring exercise (Seymore et al., 2017). Eccentric strength training is thought to be effective for increase in muscle fiber length (sarcomerogenesis) because of increased shortening speed (Blazevich et al., 2007). However, the most effective method for increasing fiber length is not yet understood (Cormie et al., 2011).

Architectural and mechanical factors like tendon properties and the force-velocity relationship are other factors that play a part in maximal power production, but are outside the scope of this article, and therefore will not be discussed further throughout this paper.

2.3 Neural Factors

2.3.1 Recruitment of Motor Units

Motor unit recruitment is fundamental to the force production of a muscle. It is established in the literature that motor units are recruited in a systematic order, from smaller motor units of type I fibers, to bigger motor units with type II fibers (Cormie et al., 2011; Suchomel et al., 2018). Type I fibers are innervated by the smaller alpha-motoneurons, which are recruited at slow, graded dynamic and isometric contractions (Suchomel et al., 2018). Type II fibers, on the other hand, are innervated by larger alpha-motoneurons and recruited in more explosive or heavy loaded contractions (Cormie et al., 2011). Therefore, the maximal power production of a muscle is dependent on recruitment of high threshold motor units that consist of type II fibers, because of their explosive characteristics w and to train the fastest motor units, one can work against a load of 85-95% 1RM (D. Behm & Sale, 1993; Hoff & Helgerud, 2004). Further, exercises with a low % of 1RM such as plyometric exercises or exercises with maximal intentional velocity has been shown to recruit the fastest motor units (Maffiuletti et al., 2016).

2.3.2 Firing Frequency

Firing frequency impacts muscle fibers force production in two ways: 1) increased firing frequency enhances the amount of force during voluntary contraction, 2) increased firing frequency leads to improved RFD (Cormie et al., 2011). Therefore, firing frequency is important for developing maximal muscular power. Herda et al., (2015) noted that firing frequency in trained individuals during a maximal voluntary contraction (MVC) was larger in comparison with untrained controls. Further, research states that motor units have high frequency of firing during ballistic contractions (Cormie et al., 2011). Ballistic muscular actions are contractions that are performed with maximal intentional velocity (MIV) and acceleration (Behm, 1995; Zehr & Sale, 1994). This has been linked to an increase in motor unit doublet charges. Motor unit doublet charges are in essence a pair of action potentials with short interspike intervals (below 10ms) (Mrówczyński et al., 2015). Motor unit doublet charges affects RFD, (Cormie et al., 2011; Mrówczyński et al., 2015). Therefore, an increase in firing frequency is theorized to be a mechanism for neuromuscular performance improvements (Cormie et al., 2011).

2.3.3 Type of muscle action

The type of muscle action influences maximal power production (i.e., concentric, eccentric, or a combination of the two) (Cormie et al., 2011). The combination of eccentric and concentric action is termed "stretch-shortening cycle" (SSC) and is the most common muscle action. In an SSC-action the muscle fiber is activated, stretched, and immediately contracted. This type of action generates superior power in the concentric phase compared with an exclusively concentric contraction, because there is a mechanical deformation of the muscle spindles that activate stretch reflexes of alpha-moto neurons, which in turn increases muscle stimulation. The increase in muscle stimulation leads to increased contraction force and power output (Cormie et al., 2011).

2.4 Strength Training Periodization

Periodization can be defined as manipulating training variables to increase specific performance goals (Stone et al., 1999). Periodization aims to reduce the risk of overtraining, to maintain form throughout a season, or reach peak form in important competitions. This is done by manipulation the volume and intensity of exercises or training sessions. Periodization is split into time schemes, macro- meso- and microcycles (Stone et al., 1999). Further, periodization can be split into traditional (TP) and block (BP) periodized programs (Bartolomei et al., 2014). In the TP model, the macro- and mesocycle starts with high volume/low intensity workloads, progressing into a low volume/high intensity workload (Stone et al., 1999; Bartolomei et al., 2014). In these cycles, there are 4 phases: preparatory, competition and transition phases (Stone et al., 1999). On the other hand, BP has several mesocycles, each with specific training goals. There are 3 phases in BP: the accumulation phase, focusing on hypertrophy, transformation phase, focusing on maximal strength, and the realization phase that focuses on power. The progression of these blocks is performed in a logical order where the performance gains of one block is meant to contribute to the next (Bartolomei et al., 2014).

However, these methods are not without limitations. In these methods, intensity is usually described as relative load (% 1RM). Not only is determining the relative load time consuming and impractical for large groups, but an athlete's neuromuscular performance fluctuates on a day-to-day basis because of fatigue, diet and sleep (Banyard et al., 2019). Therefore, the load in a particular training session may not represent the true 1RM of the athlete.

2.5 Autoregulation

Therefore, researchers have turned to an alternative periodization concept called autoregulation. This is a method that aims to adjust intensity and volume on an individual basis (Larsen et al., 2021). To accomplish this, there are subjective and objective methods. Subjective autoregulation methods include methods such as Autoregulatory Progressive Resistance exercise (APRE), Borg's Rating of Perceived Exertion (RPE) and the RPE-variant Repetitions in Reserve (RIR). The RPE scale is used to rate perceived intensity of a session in between sets, and the scale ranges from 6 (very light) to 20 (extremely hard) (Larsen et al., 2021). The RIR-scale ranges from 1-10, with 0 indicating rest, and 10 indicating maximal effort. Using this scale, one can measure how close an individual is to momentary muscular failure (Larsen et al., 2021; Steele et al., 2017). Graham & Cleather (2021) investigated the effect of repetitions in reserve compared to fixed loading. The autoregulation group showed greater improvements in front- and back squat compared to the fixed linear group. Further, Colquhoun et al., (2017) carried out an intervention with a program consisting of 3 sessions: hypertrophy, strength, and power. Subjects were divided in two groups: one with a fixed training session schedule, and one self-selected group, where they could select the order of the workouts. Volume and intensity were equal for the two groups, and performance gains were similar across the two groups. Mann et al., (2010) studied the effect of APRE compared to linear periodization in collegiate athletes. The autoregulated group self-selected the load in their final set based on their third set performance, and results showed that autoregulation was more effective compared to linear periodization. Practically, these subjective methods are often widespread in sports settings. (Greig et al., 2020).

However, these subjective methods are not without limitations. For instance, RPE-based measurements have shown to be unreliable in subjects with little to no strength training experience (Larsen et al., 2021). Further, RIR has been shown to be unreliable if subjects perform many repetitions within a set, but more reliable in low-repetition sets (Zourdos et al., 2016; Helms et al., 2017).

2.5.1 Objective Autoregulation

Objective autoregulation (OA) includes forms such as velocity loss and velocity-based strength training (VBT), which uses accelerometers, high speed cameras position- or velocity transducers to track the movement velocity of an exercise (Larsen et al., 2021). Dorrell et al., (2020) compared VBT and traditional percentage-based loading methods on maximal strength and power adaptations in trained men. They were tested in CMJ, along with 1RM in back squat, bench press, overhead press and deadlift. Results showed that the VBT group achieved favorable adaptations in 1RM and CMJ-height despite lower total training volume.
Shattock & Tee., (2020) studied the effect of VBT and RPE intensity prescriptions. Subjects were tested in CMJ, 1RM back squat, bench-press, and sprint (10-40m) and split in one objective and one subjective autoregulation group. They found that both groups most likely improved all performance measures, apart from CMJ performance, and suggested that OA measures were more effective for improvement in CMJ and squat performance. As with subjective autoregulation methods, objective methods also have limitations. Firstly, velocity-based training is dependent on the use of linear encoders, and some studies have shown linear encoders to have fluctuating reliability (Greig et al., 2020). Further, the external training load (ETL) in soccer is comprised of both physical conditioning (strength and power training) outside of competition, and ETL accumulated throughout matches. Soccer has traditionally used data from global positioning system units to monitor and analyze ETL, to prescribe an appropriate training stimulus and adequate recovery (Ehrmann et al., 2016).

2.5.2 Global Positioning Systems in Sports

Global Positioning Systems (GPS) use satellite-based navigation (Cummins et al., 2013). GPS allows for three-dimensional tracking of movement in different environments (Cummins et al., 2013). GPS has been used in sports for several years but has in the last decade increased in use in team sports such as Australian Football, rugby and soccer. This increase is due to the development of GPS systems in the last decade, and these developments allow backroom staff comprehensive real time data on the individual, both in training and competition (Cummins et al., 2013). GPS data generally entail variables include acceleration, deceleration, movement speed and total distance covered (Cummins et al., 2013).

Previously, these variables have been somewhat unreliable due to low sampling rate. Varley et al., (2012) compared validity and reliability of instantaneous velocity during acceleration, deceleration and constant motion in sub-elite team sport athletes using 5Hz and 10Hz GPS units. They reported that the 10Hz unit had three times higher validity and six times higher reliability in all measures. The reason for this may be that 10Hz GPS units record with precision down to a hundredth of a second, however a 5Hz unit can record precision down to two hundredths of a second (Nikolaidis et al., 2018). However, research has failed to prove the advantage of a higher sampling frequency than 10Hz (Varley et al., 2012). Recently, there has been insertion of an accelerometer, gyroscope and magnetometer in GPS units, making it possible to identify short accelerations and decelerations (Akenhead & Nassis, 2016; Bourdon et al., 2017).

2.5.3 GPS in soccer

Powerful locomotive actions are generally divided into speed thresholds. However, there are no standardized speed thresholds, which makes comparisons between research difficult (Rago et al., 2019). In soccer, speed thresholds are generally reported as high speed running (HSR): 4,2-5.5m/s, very high speed running (VSHR): 5.5-7.0m/s, and sprinting (>7m/s) (Rago et al., 2019). While the GPS is used to monitor ETL-variables like those mentioned previously, research investigating the use of GPS measures to adjust volume of strength training is sparse in the literature. In a meta-analysis conducted by

Hader et al., (2019), they found that distance covered ≥5.5m/s^{-1} was a sensitive measure of fatigue. Considering that the locomotive variables measured by GPS mentioned is related to power performance, and maximal strength is a basic quality for power performance, it could theoretically be used to adjust intensity and volume of strength training in soccer.

2.5.4 Strength Training in Soccer

Ronnestad et al., (2008) investigated the effect of strength -and plyometric training on sprint and jump performance in professional soccer players in pre-season. Subjects were split into a strength training group, a strength and plyometrics group and a control group. The strength group performed 2 heavy sessions per week, the strength and plyometric group performed an additional plyometric session. The control group performed soccer specific training only. Results showed that when the strength and the strength/plyometric groups were pooled together, there were significant improvements in 1RM back half squat (215 ± 4kg), CMJ height, squat jump height, peak power, along with slight improvements in sprint times from 10-40m.

Wisloff et al., (2004) investigated the correlation between squat 1RM, sprint performance and vertical jump capability in elite soccer players, who performed a 1RM test in the back half squat. Results showed that 1RM in the back half squat had strong correlation with 10m sprint times ($r = 0,94$; $p<0,94$), 30m sprint time ($r=0,74$; $p<0,01$), and jump height ($r = 0,78$; $p<0,02$) Further, vertical jump heigh correlated significantly with 10- and 30m sprint times (($r = 0,72$; $p<0,001$) & ($r = 0,6$; $p<0,02$)).

While these findings, and others, highlight the importance of 1RM and power for soccer performance (Rønnestad et al., 2008; Silva et al., 2015; Stolen et al., 2005; Wisløff et al., 2004), it is challenging to implement in-season strength training interventions. Some reasons for this might be preparation and recovery from congested fixture schedules with 1-3 matches per week, technical and tactical training, and high training loads over a long season. Further, highly trained players will likely need a high training stress to maintain or improve strength and power related qualities (Rønnestad et al., 2011), which would theoretically only add to internal and external load. However, there is some literature investigating in-season strength training in soccer, which will be the topic of the following paragraphs.

Rønnestad et al., (2011) reported that one strength training session per week in-season was enough to maintain strength gains from a pre-season training program. The intervention consisted of 2 strength training sessions per week in pre-season. In-season, Group 2+1 performed 1 strength training per week, Group 2+0 performed 1 session every 2 weeks. The training program consisted of the back half squat only. For pre-season conditioning, 4-10RM was used. Intensity was increased to 4RM in-season for both groups. The following pre-season results included a 19 ± 5% improvement in back half squat 1RM ($p<0{,}01$), 1,8% in 40m sprint time, a 3,3 ± 1,2% improvement in squat jump ($p<0{,}05$) and a trend towards improvement in CMJ. During in-season, there was a 10 ± 4% decrease in strength, along with a decrement in 40m sprint performance for group two. In group 2+1, strength levels and sprint performance from pre-season was maintained. No reductions were noted in vertical jump ability for any group, and strength gains were maintained in the group with one session per week.

Styles et al., (2016) implemented a 6-week in-season strength training program in professional soccer players. The training program consisted of back squat, Romanian deadlift and Nordic Hamstrings, with an intensity of 85-90% of 1RM. The high volume consisted of 4 repetitions and 5 sets for high volume, and 3 reps/3 sets for the low volume. Sessions were performed twice a week, and high/low volume was performed depending on fixture schedule. Sprint tests and 1RM back squats were tested pre- and post-intervention. Results showed that there were improvements in absolute and relative strength (19% and 16% respectively, $p<0.001$), and small improvements in sprint performance over 5- (~5%), 10- (~3%) and 20m (~1%) ($p<0.001$). Further, changes in 1RM squat strength was associated with the post-test times in 5- ($r = 0.62$), 10- ($r = 0.78$) and 20m sprint ($r = 0.6$).

Chelly et al., (2009) studied the effect of a back half squat program on leg power, jump and sprint performance in youth soccer players during competition (February-March). The intervention included a resistance-training group and a control group. The training program consisted of 2 sessions per week for 10 weeks. Subjects performed back half squats with loads progressing from 70 – 90% of 1RM. 1RM was reassessed after 4 weeks. The strength training group improved in all test parameters, with no changes in muscle volume or CSA.

The comparative effects of contrast strength versus plyometric training on leg peak power and electromyographic (EMG) activity in adolescent soccer players has also been studied. Contrast strength training uses high and low loads within the same training session (Hammami et al., 2019). In the study of Hammami et al., (2019), subjects were split into a contrast training group (CSG) and a plyometric training group (PT) and a control group (CG). Both training groups improved in 5- ($p = 0.001$) and 40m ($p = 0.05$) sprint times relative to CG. Further, the CSG group improved more in squat jump ($p = 0.05$). Both training groups improved in CMJ height relative to CG.

Further, de Hoyo et al., (2016) investigated comparative effects of in-season full back-squat, resisted sprint training and plyometric training in U-19 elite soccer players. In this study, the subjects were split into a strength training group, and a plyometric group. The specific strength training was performed 2 times per week. The full back-squat program consisted of 4-8 repetitions with 2-3 sets, and 3 minutes of rest between each set. The plyometric exercises were performed with maximal effort and increased the volume in the last three weeks. Results showed that there were improvements in CMJ (effect size [ES]: 0.50-0.57), 30-50m sprint (ES: 0.45-0.84). The squat group likely to very likely improved in 10-20m sprint (ES: 0.61) the plyometric and squat groups looked to have substantial improvements in 0-50m sprint (ES: 0.46-0.60). Further, the squat group seemed to improve more in 10-20m (ES: 0.49) compared to the plyometric group.

Faude et al., (2013) analyzed the effects of combined strength and power training on physical fitness in-season in high level amateur soccer players. Subjects were divided into a strength group and a control group. The strength group performed the training program on 2 days. On day 1, unilateral loaded half squats at 90% of 1RM and single leg hurdle jumps were performed. On day 2, intensity was reduced to 50-60% 1RM, and the exercises included half squats, calf raises, step ups, and various jump exercises such as drop jumps, and headers. Additionally, they performed sprints. The control group performed technical and tactical training. Their findings indicated significant time-group interactions for increases in 1RM, CMJ, DJ reactivity for the strength training group (18%) compared to the control group (11%).

3.0 Methods

The present study used a randomized experimental trial design (RET), where subjects were randomly assigned to either a subjective autoregulated (SS) group, where session volume was self-selected based on perceived recovery and readiness, or an objectively autoregulated (OA) group, where volume was regulated using external training load measures from worn GPS units. The present study is part of a research project conducted by the University of Agder, specifically the "Faculty of Health- and Sports Science".

3.1.1 Subjects

The subjects in the present study were professional soccer players from the second highest national level in Norway. The total number of participants were n = 16. For subject characteristics and the assigned groups, see table 4.1. Subjects were recruited in 2020 and 2021. The intervention started on 06.09.21 and ended on 15.11.21.

Table 3.1. Group and subject characteristics.

	Self-Selected Group	**Objectively Autoregulated Group**	**Total**
N	9	7	16
Age (yrs)	23.7 ± 3.9	24.1 ± 4.7	23.9 ± 4.1
Height (cm)	185.0 ± 6.9	181.4 ± 5.0	183.4 ± 6.2
Weight (kg)	77.4 ± 8.4	76.6 ± 7.0	77.0 ± 7.6
Position			
Defenders	6	3	9
Midfielders	2	3	5
Forwards	1	1	2

Age: years; height: mean; ±: standard deviation; weight: kg; Position: number of defenders, midfielders and forwards per group; Total: Group means and total players per position.

3.1.2 Sprint test

Subjects performed a light jogging warm up for 10 minutes at the start of testing procedure. The sprint test was performed on an indoor elastic surface at Olympiatoppen Sør. Subjects were instructed to do 2-3 sub-maximal warm up runs, increasing speed throughout. There was a break of 4 minutes between the last sub-maximal warm up run and each sprint attempt to ensure adequate recovery. Photocells and reflectors (Musclelab, Ergotest, Porsgrunn) were placed at 5m intervals (0, 5, 15, 20, 25 & 30) along the 30m track to include split times. An additional system was placed at 0m, 15m and 30m to validate sprint time (Brower Timing Systems, Draper, USA). Three instructors were placed at entry/exit points along the track to prevent potential accidents. Players were instructed to keep their front foot on the starting line. The sprint started from a stand-still position, with the feet staggered. The preferred foot was placed on the starting line, with the other further back. The distance between feet was self-selected for each subject. They were allowed to perform one counter movement at the start of the attempt as long as both feet were in contact with the ground. Verbal encouragement was given throughout the sprints to ensure maximal effort. An instructor kept track of sprint times on a tablet and wrote split times manually on a sheet. Each subject performed 3 sprinting attempts. If sprint times improved following the third attempt, another attempt was performed.

3.1.3 Countermovement Jump Test

Subjects performed a counter movement jump (CMJ) test using an AMTI force platform (Advanced Mechanical Technology, Inc Waltham Street, Watertown, USA). Sampling rate of the force platform was 1000Hz. The test was performed from a standing position, with feet shoulder-width apart. Hands were placed on the hips during each trial. An instructor told subjects to jump as high as possible. Subjects dropped to a self-selected depth into an immediate maximal vertical jump. Subjects performed 2 sets of 3 repetitions, with a 30 second break between each repetition. There was a break of 2 minutes between each set. If the vertical jump was performed wrongly, the jump was repeated. If they improved on the third repetition in the second set, another 3 minutes of rest were given, before a third and final set was conducted.

3.1.4 Leg Press Power Test

A pneumatic leg press device was used to measure maximal power in the lower limbs (Keiser A3000, Keiser, Fresno; USA). The Keiser A3000 uses compressed air to regulate resistance. The lower muscles are activated through the entire range of motion (90-180°).

A 10-step test was conducted to determine 1RM in both legs for each subject. Subjects had a repetition range of ~10-15 repetitions. Firstly, any new signings were added to the database of Olympiatoppen. Subjects were weighed on a scale before starting the test. Subjects were then told to sit in the device. An instructor ensured a 90-degree angle between the femur and tibia. Then, verbal instructions about the test itself, and instructions to push as hard and fast as possible throughout the concentric phase was given. Each subject started with standard theoretical 1RM of 250kg. Before the test started, two very light warm up repetitions were performed. Following warm up repetitions, the initial load started at 41kg. Loads increased by ~20-30kg per repetition, and rest periods increased with each repetition, up to ~1 minute at the heavier loads. As subjects started to struggle, they were allowed to stand up and shake their legs. Pre- and post-test 1RM was established when loads did not increase. Test result files were located, translated and stored in the databases of Olympiatoppen Sør.

3.1.5 Training Load Monitoring

Subjects wore GPS units (Catapult Vector S7, Catapult Sports, Melbourne, Australia) during soccer-specific conditioning and competitive matches. The GPS units had a sampling rate of 10Hz (Catapult Sports, 2021). Subjects ETL data was analyzed from Catapult Sport database OpenField. Each subject wore the same GPS unit each time, to avoid interunit-variability.

3.1.6 Strength training Program

The intervention had three training programs: one activation program, one micro-dose program and one full program. The training programs mainly targeted muscles in the lower limbs that are important for sprint and CMJ performance, such as the quadriceps muscles, gluteus musculature and hamstrings (Howard et al., 2018; Morin et al., 2015). Both groups performed the activation program before fixtures. The micro-dose program was performed on days where there was a congested fixture schedule (≤3 days between matches, table 2.1). The full Normal program was used when time for recovery was sufficient (≥4 days between matches, table 3.2). The SS group chose session volume and program (number of sets, micro- or standard-dose) based on how they felt overall. The

OA group was objectively autoregulated depending on how many meters they accumulated at high intensity running (>19.8km/h). For OA, three threshold values were used to regulate session volume: <420m, 420 – 687m, and >687m.

Table 3.2: strength training programs.

ACTIVATION						
Exercise	**Sets**	**Reps**	**RIR**	**Load (%/1RM)**	**Rest (min)**	**Comment**
Squats	3	3		80-90	2-3	Drop to 45° w/barbell
Squat jumps	3	2-3		30-40	2-3	W/dumbbells
Bench press	3	3-4		80-90	2-3	W/barbell
MICRO-DOSE						
Squats	1-2		1-2		2-3	Deep w/barbell
Assisted band jumps	1-2		1-2		2-3	Reset. Pause 2 seconds at bottom of jump
Glute bridge	1-2		1-2		2-3	
Depth jump	1-2		1-2		2-3	As high as possible
STANDARD-DOSE						
Squats	1-3	6	1-2		2-3	Deep w/barbell
Glute bridge	1-3	6	1-2		2-3	
Bulgarian split squat	1-3	6	1-2		2-3	Sets x reps/side
Seated calf raises	1-3	6	1-2		2-3	
Side-plank	1-3	8	1-2		2-3	Lay sideways w/knee-kicks, sets x reps/side
Pallof-press	1-3	8	1-2		2-3	Standing in cable machine. Sets x reps/side

Reps = repetitions; RIR = Repetitions in Reserve; min = minutes; Rest = rest period between sets; w/ = with reps/side = repetitions per side.

When subjects ran under 420m, the sets in the easy program did not increase, in respect to risk of overload in a congested fixture schedule.

3.1.7 Statistical Analysis

Statistical analysis of study data was conducted in IBM SPSS Statistics 25. Data was visually inspected for normal distribution and deemed to be normally distributed. Independent samples t-tests were conducted to investigate differences between groups in sprint, CMJ and power variables. Paired sample t-tests were conducted to investigate within-group differences from baseline. Additionally, a paired samples t-test was conducted to investigate training changes of the intervention groups pooled. Significant p-value was set to an a-level of 0.05, and data was presented as mean ± standard deviation, and percentage change (%) unless stated otherwise.
An independent samples t-test was conducted to see if there were any differences between groups at baseline, which there were not.

4.0 METHODOLOGICAL DISCUSSION

This chapter will discuss and describe the methodological perspectives and challenges of the present research project.

4.1 Study design

We aimed to compare differences between groups using self-selected and (SS) objective autoregulation (OA). In the present study, a randomized experimental trial was used. Randomization is an optimal method to eliminate potential biases (Concato et al., 2000). However, a randomized controlled trial (RCT) has been described as the gold standard for investigating treatment outcomes (Bhide et al., 2018). In an RCT, there is often a treatment group that is controlled against another group. This other group could have no treatment at all, or the treatment group can be compared against former practices. The present study compared two practices against each other, and was conducted on professional soccer players, but did not have a control group to investigate the effect of strength and power training *per se*. There has been observed reductions in maximal strength and power during the competitive season when no strength training was conducted female volleyball players, or with a low strength training frequency in professional soccer players (Häkkinen, 1993; Rønnestad et al., 2011).

Therefore, having an additional group that performed no prescribed training may have clarified if the autoregulation practices successfully maintained sprint, CMJ-height and P_{max}. Further, if the present study had one group that performed linear periodization, it could better clarify the effects of the autoregulation compared to traditional strength training prescriptions. However, carrying out an intervention that can potentially enhance performance for one group of players as opposed to others within the same team may not be wanted. Secondly, due to practical reasons, the low number of subjects would make it challenging to include a control group with an appropriate sample size, meaning decreased statistical power (Thomas et al., 2013).

4.2 Study subjects

In total, 16 subjects (first-team, n=15; B-team, n=1) were included in the study. For the final analysis, 1 subject was excluded from sprint test analysis due to missing data on the post-test but were included for the power and CMJ-height tests. Therefore, 15-16 subjects were included in the final analysis (Power, n=16; CMJ, n=16 & sprint, n=15). Sample size is extremely important for statistical power, as power increases with a larger n (Thomas et al., 2015). Initially, the present study had recruited the B-team as well, meaning more than double the current sample size. This would have increased the statistical power of the present study. For instance, with a lower n, the probability of finding a real difference is much lower compared to a larger n (Thomas et al., 2015). Furthermore, because of the Covid-19 situation and restrictions, we could only continue with the first team due to risk of infectious outbreaks. Therefore, the present study may not have been able to unveil the true effects of subjective SS and OA. While larger sample sizes increase statistical power, large sample sizes are unrealistic in within-team studies in soccer, as squads consist of 25-30 players, and interventions generally include ~14-30 subjects (Rønnestad et al., 2011; Chelly et al., 2009; de Hoyo et al., 2016).

The subjects in the present study were professional soccer players, playing at the second highest national level in Norway. physical capacity of subjects in the present study might differ from players in elite European teams. It is reasonable to assume that elite European teams have more resources and specialists in all aspects of the physical conditioning compared to the level of the present subjects. Therefore, generalization of subjects in the present study compared to those in other leagues or elite teams may be difficult. However, they were deemed to be representative for other professionals from the second highest level in Norway.

4.3 Testing Procedure

The present study consisted of 2 test days for all subjects. Pre- and post-tests were conducted during the international breaks. Initially, the intervention was supposed to include a mid-test. With a mid-test, the present study would have an additional measurement point. This could have revealed potential acute effects of the autoregulation methods and allowed for adjustments of training if the volume in the first part of the intervention was deemed insufficient. Prior to test days, subjects had the weekend off. Recovery from a normal training session has been reported to be 48 hours, thus, subjects came fully rested (Parra et al., 2000). Fully rested, the neuromuscular capacity for performing explosive actions is better compared to testing ≤24 hours post-match or training *per se* (Hader et al., 2019).

All tests were performed in the same order: sprint, then CMJ, then Keiser 1RM. Firstly, performing the Keiser-test before either the sprint or CMJ-test could potentially lead to increased fatigue in the lower limbs, which may negatively affect sprint times or CMJ-height. Secondly, it could be speculated that tests should be performed in the same order, to ensure reliability. Some subjects consumed caffeine or food prior to testing, although they were instructed not to consume any caffeine and/or food. For instance, caffeine has been reported to have potentially performance enhancing effects in anaerobic exercise performance, and therefore it can be speculated that inferred test-results may have occurred (Stuart et al., 2005).

Recovery time between tests were not standardized, as subjects were sent to the next performance test immediately after completion. It seems that rest periods of ~2-3 minutes is sufficient for most of the neuromuscular recovery (Martorelli et al., 2015). Thus, some subjects may have had more rest in-between tests, but since there was no standardized recovery time this is difficult to conclude with. Subjects were intended to test in the same order every time. This was the case for most of our subjects. However, some subjects appeared before or after their intended times on the second test day. Furthermore, test days started at 08:00 hours and ended around 14-16:00 hours. Therefore, it is possible that test times on pre and post days could have been an advantage for some, as there have been reported fluctuations in physiological parameters and neuromuscular performance throughout the day (Guette et al., 2005; Mirizio et al., 2020). Thus, one can argue that the present study should have controlled testing order and times even more strictly.

4.4 Test protocol

Sprint distances can reach 30m depending on playing position; however, it has been reported that sprints rarely exceed 10m (Andrzejewski et al., 2013; Salvo et al., 2007; Stolen et al., 2005). In the present study, we tested sprint times from 0-30m, with split times every 5m of the track. Considering previous sprint lengths, this was deemed a representative range of sprint distances for soccer players in the second highest national level in Norway. Fully-automatic timing systems such as silent gun or photo-finish cameras have been considered the gold standard (Haugen et al., 2014; Haugen & Buchheit, 2016) For instance, photo-finish cameras can estimate time with less than 0.0005 s resolution (Haugen & Bucheit, 2016) In the present study, we used dual-beamed photocells, which is considered a valid and reliable instrument for measuring short sprint differences and are considered more reliable than single beam systems (Haugen & Bucheit, 2016; Haugen et al., 2014) For instance, Cronin & Templeton (2008) report than inappropriate height adjustment of single-cell beams increase timing error. With dual-beam photocells, photocells are broken at hip and chest-height. There has been reported a 0.02 Standard Error Mean and ~1% coefficient variance for 20m sprint times with dual-beam photocells (Haugen & Bucheit, 2016).

Further, our photocells were set at hip height, which is in line with recommendations of Haugen & Bucheit, (2016). The sprint started from a standstill position. Research has shown that starting position is important for the sprint test. For instance, Cronin et al., (2007) compared parallel stand-still, staggered and false starts. In a false start, the preferred leg to a staggered stance when the movement is initiated (Cronin et al., 2007). and found that the staggered and false starts were faster compared to the parallel stand still. Further, Johnson et al., (2010) compared four different stances in volleyball players and suggested that staggered stance produced the fastest sprinting velocities over the first ~5m. Thus, the use of a staggered start in the present study could be justified. However, ~75% of sprints in soccer are performed from a flying start (Haugen & Buchheit, 2016). Therefore, the use of a flying start would possibly yield larger ecological validity, and the combination of stand-still and flying starts in soccer players has been proposed (Haugen & Buchheit, 2016).

4.5 Countermovement Jump Test

To test the countermovement jump, methods such as the Sargent vertical jump test and contact mats with flight time calculation are often used (Markovic et al., 2004; Toft Nielsen et al., 2019). Further, there are many ways to calculate vertical jump height. Flight time has been defined as the time between the instants of takeoff and landing (Toft Nielsen et al., 2019). However, flight time calculation requires the assumption that takeoff and landing postures are identical. Also, the flight time method assumes that there is a constant push-off distance across different loads and trials (Lindberg et al., 2021a). Another method is calculating the ratio between flight-time and landing, which yields the flight-time:contract-time (FT:CT) ratio. This ratio is often used in team sports. However, if there are errors in the identification of contract time or flight time, it can have negative consequences for the FT:CT-ratio (McMahon et al., 2018). Further, calculation can be done by the impulse-method (Street et al., 2001). Here, the overall force acting on the jumper before take-off is integrated to estimate take-off (Street et al., 2001).

The use of force plates to measure countermovement jump is the presumed gold standard (García-Ramos et al., 2019). In the present study, the countermovement jump test was performed on an AMTI force platform (Advanced Mechanical Technology, Inc Waltham

Street, Watertown, USA). This platform had a sampling rate of 1000Hz, which seems to be preferred (McMahon et al., 2018). Hands were kept on the hips throughout each trial. While performing CMJ with an arm swing may improve ecological validity, placing the hands on the hips isolates force production in the lower limbs and eliminates potential effects of the arm-swing. Therefore, hands on hips may be more accurate for detecting acute changes in neuromuscular fatigue and athlete readiness (Heishman et al., 2020).

4.6 Leg Press Power Test

The Keiser Air-300 horizontal pneumatic leg press device, with A420 software, was used to establish Pmax in the lower limbs. This device utilizes air pressure as a means of resistance, through compression forces of the piston in air cylinder (Lindberg et al., 2021b). The reliability of the Keiser Air-300 on elite soccer players has been reported by Redden et al., (2018). The validity of the Keiser Air-300 on force-velocity profiling was investigated by Lindberg et al., (2021b), and found that it was valid over a wide range of forces and velocities, although power measures were underestimated at single repetitions with low loads. The software has a 5% cut-off in range of motion for the average values, which can lead to differences in the absolute power between tall and short athletes. Therefore, average power-values for taller players could be relatively smaller compared to the shorter ones. Further. average power can be somewhat affected by inertia; however this bias is small (Lindberg et al., 2021b). Thus, the Keiser Air-300 seems a good instrument for the present study.

The test itself was a 10-step test, with increasing resistance in block increments depending on the pre-determined maximum resistance. Redden et al., (2018) argued that a limitation with this method was that if the maximum resistance was set to 300kg, the following repetition would increase by ~9%, which may mask a little bit of the athletes' strength. However, as they tested elite soccer players from the English Premier League, this was deemed insignificant. In the present study, a theoretical 1RM of 250kg was set. Hence, since load increases by 23.2kg following the 10th repetition, for all subsequent reps, there is a ~9% increase for our subjects as well. However, there were multiple subjects that completed >10 repetitions, with the best repetition range being 16. Therefore, the increase in resistance was not a problem for our subjects.

4.7 Training intervention

The present study aimed to perform 2 strength training sessions per week. However, due to a tight fixture schedule and the unpredictable Covid-19 situation, our subjects were only able to complete ~1 session per week during the 10-week intervention. This might have influenced our results, as Rønnestad et al., (2011) showed that 1 strength training session per week during the in-season was enough to maintain strength gains from pre-season, whereas others have reported in-season strength gains with 2 sessions per week, or larger volume (Chelly et al., 2009). In regard to the training programs, both micro-dose and standard-dose programs had a total of 4 lower-limb exercises. The difference in repetition ranges between these two programs were trivial (Normal: 24 reps; Easy: 20 reps). For instance, the volume in Chelly et al., (2009) were 32 repetitions in the back half-squat per week.

Therefore, one can argue that our intervention should have had a higher frequency and/or volume of strength training to induce increases in strength and power in the lower-limbs during the in-season training period. Furthermore, there were only 1-2 sets difference between cut offs for the objectively autoregulated group. Therefore, the actual difference in training volume between those that were prescribed a lower volume compared a greater volume was rather small. Volume is a crucial determinator of strength training adaptations in already trained individuals (Häkkinen, 1989; Suchomel et al., 2018). This suggests that the difference in volume should have been greater, as the difference in fatigue markers between the cut-offs were large.

4.8 Statistical Analysis

An independent samples t-test was conducted to investigate differences between the self-selected group and the objectively autoregulation group at baseline, and after the training intervention. Independent samples t-tests are used when comparing two samples, to see if the means differ from each other (O'Donoghue, 2012; Thomas et al., 2015). The nullhypothesis of an independent t-test is that there is no difference between groups (O'Donoghue, 2012). The main assumptions of an independent samples t-test are 1) the independent variables are measured on an interval/ratio scale, 2) group sizes are approximately equal and 3) the assumption of normality (O'Donoghue, 2012; Thomas et al., 2015). Firstly, sprint times (s), CMJ-height (cm) and Pmax (N) were all measured on an interval scale. Secondly, group sizes were approximately equal (SS=9; OA=7).

However, 1 subject in OA was excluded from sprint-tests because of missing data on the post-test, but this did not affect the normality of the data. Thirdly, data was deemed to be normally distributed because of histogram shapes, mean and median similarity, and low skewness and kurtosis values. Furthermore, intervention groups were pooled using a paired samples t-test. Paired samples t-tests are used to compare means of two samples from the same group of participants (O'Donoghue, 2012). In this case, the means of the two samples were soccer-players from the same team. Since subjects were pooled, this increased the n, and therefore the overall statistical power of the analysis.

4.9 Training Load Monitoring

Traditionally, total distance (TD) covered is the most common parameter for ETL in soccer (Akenhead & Nassis, 2016). Other variables such as high intensity running (>4m/s^{-1}) and PlayerLoad^{TM}, which analyses changes in movement-patterns in a three-dimensional plane have also been used to monitor ETL, however they are not necessarily the best markers for muscle damage or internal fatigue (Hader et al., 2019). It has been reported strong correlations between distance covered ≥5.5m/s^{-1} and markers of neuromuscular and biochemical fatigue, and this is suggested to be a more sensitive measure compared to TD covered, high intensity running or PlayerLoad^{TM}. In the present study, the distance covered ≥5.5m/s^{-1} was used to adjust strength training volume in OA. This was based on the notion that for every 100m covered ≥5.5m/s^{-1}, neuromuscular processes such as creatine kinase-activity increased by 30%, and peak power output in CMJ decreased by 0.5% (Hader et al., 2019). Therefore, could argue that the use of locomotive GPS-data from matches may better represent the external training load imposed on soccer-players in season, compared to other OA-methods such as VBT. The use of VBT is well-established in the literature, and is reported to provide accurate estimates of internal mechanical fatigue in a muscle (Pareja-Blanco et al., 2017). However, VBT solely considers acute fatigue within a strength training repetition, exercise, or set, and does not account for the additional external load from competitive match-play. Furthermore, the initial plan was to conduct a pilot test preceding the intervention, to identify potential markers of fatigue. These markers of fatigue would have been tested against individual performance makers of isometric strength, CMJ, and 30m sprint times, to investigate whether they were reflected in isometric force production, power output in CMJ or differing 30m sprint times.

However, due to the Covid-19 situation and national restrictions, the pilot test did not go ahead. It could be speculated that the cut-offs used to adjust strength training would be even more precise on an individual level if these potential markers of fatigue were identified. Since these were not found, however, the cut-offs used to objectively autoregulate subjects in the present study were distance covered <420m, 420-687m and >687m. These were calculated based the present team's locomotive data from the 2020/21-season. Here, 1/3 of the players fell within each of the cut-offs, respectively. Therefore, although they may not be as optimal as fatigue-markers from a pilot study, they were directly related to the locomotive patterns of the present subjects.

4.9.1 Self-selected training

In regard to subjective methods in professional soccer, RPE is often used to determine the players' response to training, and subjective measures of fatigue, sleep and muscle soreness has been noted to closely reflect acute changes in training and match-load in professional soccer players (Akenhead & Nassis, 2016; Thorpe et al., 2017). Further, the RPE-based RIR-scale is used to regulate strength training by estimating how many repetitions one can perform within a strength training set. However, similar to VBT, these methods only consider perceived fatigue within exercises or training sessions, but do not account for the athletes' overall perception of fatigue or "readiness". The SS of exercise volume has emerged as an alternative, where athletes can SS training based on how they feel overall (Larsen et al., 2021). Previous studies have demonstrated that SS of volume and intensity can be effective to improve strength-related performance in both trained or untrained men and women (McNamara & Stearne, 2010; Coulquhoun et al., 2017).

Subjects in the SS-group self-selected training how they felt prior to training sessions. Furthermore, when athletes are allowed to SS training, research suggest they experience more motivation to perform, well-being and are more likely to follow the training program as prescribed (Halperin et al., 2018; Watson et al., 2020). It is interesting to consider on what grounds the subjects in the present study made good choices when self-selecting strength training volume. In the present study, SS of strength training was solely based on how subjects felt overall. In retrospect, one can argue that this approach was somewhat vague. It could be that some subjects self-selected based on how much they enjoy strength training on a whole, or that some selected a higher strength training volume than they should have to impress teammates. However, all strength training sessions were supervised by the teams physical coach, and mature athletes are suggested to be less affected by competitive pressure (Halperin et al., 2018).

Further, it can be speculated that the different aspects of how they felt overall should have been emphasized in the SS process. For example, it may be that subjects' SS choices would differ if they were aware of selecting the standard-dose or micro-dose programs based on additional aspects such as perceived quality of sleep, fatigue, hunger or muscular soreness. If so, it could be important to distinguish between emphasizing and controllingly instructing the selection based on the different aspects. Instructions that provide subjects with a sense of choice has been shown to improve performance in bowling players (Halperin, 2018). Further, force-production in boxing punches have been reported to be harder when delivered in a preferred order compared to a pre-determined order (Halperin et al., 2018). Therefore, the different aspects of how subjects felt overall could be emphasized as "you may want to" consider more closely how hungry, tired or sore you are, before selecting the exercise volume (Halperin, 2018).

4.9.2 Strengths and limitations

The main strengths of the present study were a) the athlete's physical level, b) the test protocol, with valid and reliable tests for performance measures and c) the high adherence in pre- and post-tests. Given that the intervention was conducted in-season, some limitations arise. Firstly, the time available to conduct strength training volume seems to be insufficient, the low number of strength training sessions (~1/week) performed during the 10-week intervention did not elicit any differences between or within the subjective or objectively autoregulated group. Secondly, the present study was underpowered and had a relatively small N, our aim was to include the junior team and double the number of participants compared the number that is included in the present study. Thirdly, this study had no control group. Therefore, it is difficult to conclude whether the training could elicit any differences between groups, or if the training was sufficient to maintain sprint, CMJ and P_{max}.

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Part 2:

Research Paper

Effects of In-Season Subjective vs. Objective Autoregulation on Sprint-, Jump- and Power Performance in Professional Soccer Players

The following paper is written in according to the standards of the following journal:

Scandinavian Journal of Medicine & Science in Sport

Chris Jakob Homman
University of Agder
May, 2022

Effects of In-Season Subjective vs. Objective Autoregulation on Sprint-, Jump- and Power Performance in Professional Soccer Players

Chris Jakob Homman

Department of Sport Science and Physical Education, Faculty of Health and Sport Sciences, University of Agder, Kristiansand, Norway

Corresponding author:
Chris Jakob Homman
University of Agder, Faculty of Health and Sport Science
Postboks 442, 4604 Kristiansand, Norway
e-mail: chrisjh@student.uia.no

Telephone: +47 918 24 257

ABSTRACT

Purpose: The study aimed to compare the effects of subjective and objective autoregulation of strength training on sprint time, jump height and power in-season in professional soccer players.

Methods: Sixteen players (24.6±3.5 years) from second highest national level in Norway completed a 10-week training period focusing on lower-limb exercises. They were randomized to a group that self-selected (SS) volume based on how they felt immediately before the strength training sessions, or an objectively autoregulated group (OA) that adjusted volume based on distance covered ≥5.5m/s^{-1} (>420m,420-687m,>687m) during soccer matches preceding strength training. Pre- and post-measurements were sprint split times (0-30m), countermovement jump height (CMJ), and power (Pmax) in a pneumatic leg press device.

Results: An independent samples t-test revealed no significant differences between groups in neither changes of leg press power (SS: 0.1±4.1% vs. OA: -0.9±6.3%, p=0.87), CMJ (SS: 4.3±8.9% vs. OA: 2.6±8.9%, p=0.70) or 0-30m sprint split times (SS: -2.2±4.8 to -0.62±2.05%, vs. OA: -2.46±3.51 to -0.86±1.86%, p>0.91-0.83). A paired samples t-test revealed no within-group changes from baseline. All participants pooled showed improvement tendencies in 0-5m sprint time (-2.3±4.2%, p=0.052), 15- and 20m sprint times (-1.1%, p=0.09 and -1.0 %, p=0.10, respectively), from baseline.

Conclusion: Neither subjective SS nor OA of volume based on locomotive data from soccer matches improved any power-related measure, but one weekly strength training session seemed to be sufficient to maintain in-season power performance in professional soccer players. More research is warranted, with a larger sample size and training volume than in the present study.

KEYWORDS

autonomy, global positioning system, competitive, neuromuscular, speed threshold.

1 INTRODUCTION

Soccer players cover roughly 9-14km during a competitive match, interspersed with intense match periods.[1] These intense match periods are characterized by maximal or close to maximal anaerobic mechanisms, making players subject to high metabolic and mechanical stress.[1,2] Actions of maximal neuromuscular activity, such as sprints, jumps and accelerations are key determinants of match outcomes, as 83% of goals scored in the German Bundesliga was preceded by ≥ 1 action of near maximal or maximal neuromuscular action.[3] It has been reported that sprints constitute up to 11% of the total distance covered in a match, and the number of powerful neuromuscular actions have increased significantly over a 6-year period in the English Premier League.[1,4] Further, players perform 2.2-18.5 headers per game, subject to playing position and level.[5,6] These findings may indicate a slight shift in work demands in soccer, with more focus on powerful neuromuscular actions. The capacity to perform these actions are dependent on maximal strength (1RM) and power.[2,7,8]

Methods to improve 1RM and power in soccer is traditionally done through percentage-based periodization plans (PBT).[7,9,10] However, this does not consider daily fluctuations in neuromuscular performance, which can be affected by stress, nutrition and sleep [11]. Therefore, it may not reflect an athlete's true 1RM for a given session and can lead to inadequate loads and training stimulus over time.[12] Autoregulation accounts for an athlete's daily fluctuations in perceived readiness and daily physical form.[11] There are two main groups of autoregulation methods, which can be characterized as subjective[13–15], and objective autoregulation methods.[16,17] Objective autoregulation (OA) often includes the use of velocity-based training (VBT), such as barbell speed or velocity loss.[11,18] During in-season soccer however, the total training stress from competitive matches is arguably greater than the stress from strength training alone. It has been reported that utilizing global positioning system (GPS) variables such as distance covered at speeds >5.5m/s^{-1} strongly correlate with different markers of fatigue, compared to the traditionally used total distance (TD) covered.[19] Thus, distance covered at speeds >5.5m/s^{-1} could be a potential variable to use as an objective measure of external load during a competitive season for soccer players. To the authors knowledge, no one has investigated autoregulation based on external load during soccer matches.

Further, there are several subjective autoregulation methods. Some of these include rating of perceived exertion (RPE), repetitions in reserve (RIR) and flexible daily undulating periodization [11,14,15]. In professional soccer, RPE is often used to determine the players' response to training, and subjective measures of fatigue, sleep and muscle soreness has been noted to closely reflect acute changes in training and match-load in professional soccer players [20,21]. However, RPE may not accurately reflect load induced by strength training.[11] It is believed that self-selection (SS) provides a good overall image of factors that affect daily neuromuscular fluctuations [11,15].

Further, self-selected volume has been shown to increase strength and power-related measures in trained and untrained populations [15,22]. However, SS of exercise and volume may not reflect the external training- and match-induced load on its own. On the other hand, while objective measures of can provide detailed information about match-induced muscle damage and neuromuscular fatigue, it does not account for an athlete's subjective perception of overall feeling. Very few have directly compared SS to different methods of OA, and no one has attempted to use of locomotive data from GPS to adjust volume of strength training in professional soccer players. Therefore, the aim of the present study was to compare the effects of subjective self-selected versus objective GPS locomotive data adjusted autoregulation of strength training on sprint time, jump height and power in-season in professional soccer-players.

2 METHODS

The present study used a randomized trial design (RET). Subjects were randomly assigned to either a self-selected (SS), where session volume was self-selected based on perceived recovery and readiness, or an objectively autoregulated (OA) group, where volume was regulated using external training load measures of distance covered at speeds >5.5m/s^{-1} from worn GPS units. The intervention period was 10 weeks. Subjects provided written consent, and the study was approved by the local ethics committee FEK.

2.1 Subjects

The subjects in the present study were professional soccer players from the second highest national level in Norway. The total number of participants were n=16. Initially, the B-team was recruited to participate in the present study. However, due to the Covid-19 situation and national restrictions, we could only continue with one team, thus the first team was chosen for participation. For subject characteristics and assigned groups, see table 2.1. Subjects were recruited in 2020 and 2021. The intervention started on 06.09.21 and ended on 15.11.21.

Table 2.1. Group and subject characteristics.

	Self-Selected Group	**Objectively Autoregulated Group**	**Total**
N	9	7	16
Age (yrs)	23.7 ± 3.9	24.1 ± 4.7	23.9 ± 4.1
Height (cm)	185.0 ± 6.9	181.4 ± 5.0	183.4 ± 6.2
Weight	77.4 ± 8.4	76.6 ± 7.0	77.0 ± 7.6
Position			
Defenders	6	3	9
Midfielders	2	3	5
Forwards	1	1	2

Age: years; height: mean; ±: standard deviation; weight: kg; Position: defenders, midfielders and forwards per group; Total: Group means and total players per position.

2.2 Sprint test

Subjects performed a light jogging warm up for 10 minutes at the start of testing procedure. The sprint test was performed on an indoor elastic surface. Subjects were instructed to do 2-3 sub-maximal warm up runs, increasing speed throughout. There was a break of 4 minutes between the last sub-maximal warm up run and each sprint attempt to ensure adequate recovery. Photocells and reflectors (Musclelab, Ergotest, Porsgrunn) were placed at 5m intervals (0-5-15-20-25 & 30) along the 30m track to include split times. An additional system was used (0-15 & 30m) to validate sprint time (Brower Timing Systems, Draper, USA).

Three instructors were placed at entry/exit points along the track to prevent potential accidents. Players were instructed to keep their preferred front foot on the starting line with the other further back. The sprint started from a stand-still staggered position. Distance between feet was self-selected for each subject. They were allowed to perform one counter movement at the start of the attempt as long as both feet were in contact with the ground. Verbal encouragement was given throughout the sprint to ensure maximal effort. An instructor kept track of sprint times on a tablet and wrote split times manually on a sheet. Each subject performed 3 attempts. If sprint times improved following the third attempt, another attempt was performed.

2.3 Countermovement Jump Test

Subjects performed a counter movement jump (CMJ) test using an AMTI force platform (Advanced Mechanical Technology, Inc Waltham Street, Watertown, USA). Sampling rate of the force platform was 1000Hz. The test was performed from a standing position, with feet shoulder-width apart. Hands were placed on the hips during each trial. An instructor told subjects to jump as high as possible. Subjects dropped to a self-selected depth into an immediate maximal vertical jump. Subjects performed 2 sets of 3 repetitions, with a 30 second break between each trial. There was a break of 2 minutes between each set. If the vertical jump was performed wrongly, the jump was repeated. If they improved on the third repetition in the second set, another 3 minutes of rest were given, before a third and final set was conducted.

2.4 Leg Press Power Test

A pneumatic leg press device was used to estimate maximal power in the lower limbs with A420 software (Keiser Air-300, Keiser, Fresno; USA). A 10-step test was conducted to determine 1RM in both legs for each subject. Subjects had a repetition range of ~10-16 repetitions. Firstly, any new signings were added to the database of Olympiatoppen. Subjects were weighed on a scale before starting the test. Subjects were then told to sit in the device. An instructor ensured a 90-degree angle between the femur and tibia. Then, verbal instructions about the test, and instructions to push as hard and fast as possible throughout the concentric phase was given.

Each subject started with standard theoretical 1RM of 250kg. Warm-up repetitions and the initial load started at 41kg. Loads increased by 23kg per repetition, and rest periods increased with each repetition, up to 1 minute at the heavier loads. As subjects started to struggle, they were allowed to stand up and shake their legs. Pre- and post-test 1RM was established when loads did not increase. Test result files were located, translated and stored in the databases of Olympiatoppen Sør.

2.5 Training Load Monitoring

Subjects wore GPS units (Catapult Vector S7, Catapult Sports, Melbourne, Australia) during soccer-specific conditioning and competitive matches. The GPS units had a sampling rate of 10Hz (Catapult Sports, 2021). Subjects ETL data was analyzed from Catapult Sport database OpenField. Each subject wore the same GPS unit each time, to ensure interunit reliability.

2.6 Strength training Program

The intervention had three training programs: an activation program, a micro-dose program and a standard-dose program (table 2.2). Both groups performed the activation program before fixtures, The micro-dose program was performed when there was ≤3 days between matches, and the standard-dose program was performed when there was ≥5 days between matches.

The OA-group was objectively autoregulated depending on how many meters they covered at very high intensity running (≥5.5m/s^{-1}), and three threshold values were used to regulate session volume: <420m, 420 – 687m, and >687m. Subjects in SS chose session volume and program based on how they felt overall, immediately prior to the strength training sessions.

Table 2.2: Activation, Micro-dose and Standard-dose strength training programs

			ACTIVATION			
Exercise	**Sets**	**Reps**	**RIR**	**Load (%/1RM)**	**Rest (min)**	**Comment**
Squats	3	3		80-90	2-3	Drop to 45° w/barbell
Squat jumps	3	2-3		30-40	2-3	W/dumbbells
Bench press	3	3-4		80-90	2-3	W/barbell
			MICRO-DOSE			
Squats	1-2	6	1-2		2-3	Deep w/barbell
Assisted band jumps	1-2	4	1-2		2-3	Reset. Pause for 2 seconds at bottom of the jump
Glute bridge	1-2	6	1-2		2-3	
Depth jump	1-2	4	1-2		2-3	As high as possible
			STANDARD-DOSE			
Squats	1-3	6	1-2		2-3	Deep w/barbell
Glute bridge	1-3	6	1-2		2-3	
Bulgarian split squat	1-3	6	1-2		2-3	Sets x reps/side
Seated calf raises	1-3	6	1-2		2-3	

Side-plank	1-3	8	1-2		2-3	Lay sideways w/knee-kicks, sets x reps/side
Pallof-press	1-3	8	1-2		2-3	Standing in cable machine. Sets x reps/side

Reps = repetitions; RIR = Repetitions in Reserve; Load = percentage load of maximal strength; min = minutes; Rest = rest period between sets; BW = bodyweight; w/ = with reps/side = repetitions per side.

2.7 Statistical Analysis

Statistical analysis of study data was conducted in IBM SPSS Statistics 25. Data was visually inspected and deemed to be normally distributed. Independent samples t-tests were conducted to investigate differences between groups in sprint, CMJ and power variables, both at baseline and pre-post. Paired sample t-tests were conducted to investigate within-group differences. Additionally, a paired sampled t-test was conducted to investigate training changes on a whole. Significant p-value was set to an a-level of 0.05, and data was presented as mean ± standard deviation, and percentage change (%) unless stated otherwise.

3 RESULTS

Overall, 16 subjects completed the study (table 2.1). However, 1 subject in the OA group only had one measurement on the 30m sprint split time on the posttest and was therefore excluded from sprint analysis. Sprint, power and CMJ performance in the two groups were similar at baseline (table 4.2). Data from all participants pooled is presented in table 4.3. Accumulated strength training volume is presented in table 4.4

Sprint Performance

No significant differences were found when comparing the changes in sprint performance between the SS-group and the OA-group: 5m (0.26% difference, $p = 0.91$), 10m (0.61%, $p = 0.68$), 15m (0.46%, $p = 0.73$), 20m (0.07%, $p = 0.96$), 25m (0.16%, $p = 0.82$) or 30m (0.23%, $p = 0.83$) sprint split times (Figure 4.1 A-F).

Paired samples t-tests revealed no within group changes for SS-group for 5m (-2.20% $p = 0.20$), 10m (-0.78%, $p = 0.98$) 15m (-0.94%, $p = 0.24$), 20m sprint time (-1.02%, $p = 0.24$), 25m (-0.81%, $p = 0.28$) or 30m sprint time (-0.62%, $p = 0.38$). No within-group changes were found in the OA-group either on 5m (0.02% p=0.15) 10, 20, 25 or 30m sprint times (~0.03% p, 0.25-0.34).

Table 4.2: Independent t-test results for changes from baseline.

Variables & groups	n	Pre Mean ± SD	Post Mean ± SD	Between Group Differences at baseline Mean ± SD	95% CI	p
5m sprint (s)						
SS	9	0.821 ± 0.039	0.802 ± 0.047			
OA	6	0.819 ± 0.029	0.796 ± 0.019	0.004 ± 0.02	[-0.037, 0.046]	0.83
10m sprint (s)						
SS	9	1.530 ± 0.070	1.517 ± 0.062			
OA	6	1.517 ± 0.047	1.491 ± 0.027	0.0016 ± 0.03	[-0.056, 0.089]	0.63
15m sprint (s)						
SS	9	2.183 ± 0.093	2.161 ± 0.080			
OA	6	2.164 ± 0.080	2.129 ± 0.043	0.002 ± 0.04	[-0.073, 0.118]	0.62
20m sprint (s)						
SS	9	2.791 ± 0.120	2.761 ± 0.110			
OA	6	2.765 ± 0.078	2.730 ± 0.056	0.03 ± 0.05	[-0.094, 0.152]	0.62
25m sprint (s)						
SS	9	3.376 ± 0.143	3.348 ± 0.130			
OA	6	3.342 ± 0.089	3.306 ± 0.070	0.003 ± 0.07	[-0.109, 0.182]	0.56
30m sprint (s)						
SS	9	3.949 ± 0.171	3.923 ± 0.155			
OA	6	3.906 ± 0.109	3.884 ± 0.096	0.05 ± 0.08	[-0.127, 0.222]	0.84
P_{max} (N)						
SS	9	1486.88 ± 308.66	1488.22 ± 361.90	-180 ± 177	[-561.7, 201.5]	0.33
OA	7	1667.00 ± 404.7	1649.71 ± 430.51			
CMJ (cm)						
SS	9	39.3 ± 6.2	40.9 ± 7.0	-3.03 ± 2.7	[-8.7, 2.7]	0.27
OA	7	42.3 ± 3.6	43.5 ± 6.1			

Abbreviations: Pre: Pre-test mean; Post: Post-test mean; SD: Standard deviation; 95% CI: confidence interval; SSG: Self-Selected Group; OAG: Objectively Autoregulated Group; (s): seconds; Pmax: Maximal power; (N): Newton; CMJ: Countermovement Jump Height

CMJ Performance

There was no significant difference between SS and OA groups in CMJ changes (1.70%, p = 0.70) (figure 4.3). Further, no significant differences from baseline were found within the SS-group (4.35%, p = 0.20) or the OA-group (0.78%, p = 0.46).

Power Performance

No significant changes were seen between groups in leg press P_{max} (0.84%, p = 0.87) (Figure 4.2). Furthermore, a paired samples t-test revealed no significant differences from baseline within the SS (-0.25%, p = 0.98) or OA (2.64%, p = 0.70) groups.

Table 4.3: paired sample t-test for pooled intervention group.

Variables	n	Mean ± SD	CI (95%)	p
5m sprint (s)	15	0.02 ± 0.04	[-0.00002, 0,038954]	0.052
10msprint (s)	15	0.016 ± 0.04	[0.00704, 0.039976]	0.15
15m sprint (s)	15	0.025 ± 0.05	[-0.00378, 0.5472]	0.08
20m sprint (s)	15	0.030 ± 0.07	[0.00652, 0.0671]	0.09
25m sprint (s)	15	0.03 ± 0.07	[-0.00938, 0.0708]	0.12
30m sprint (s)	16	0.02 ± 0.08	[-0.01663, 0.06525]	0.22
Pmax (N)	16	8.813 ± 158.44	[-77.615, 91.240]	0.13
CMJ (cm)	16	-1.46 ± 3.63	[-3.39, 0.480]	0.86

Abbreviations: Mean: variable mean; SD: standard deviaton; CI: confidence interval; p: alpha-value; (s): seconds; (N): Newton

Because of the small sample size included in the present study, the two intervention groups were also pooled to investigate if there were any changes from baseline on a whole. When the two training groups were pooled (table 4.3), a paired samples t-test revealed tendencies to improvement in 5m sprint time (-2.3%, p = 0.052). Furthermore, there were tendencies towards significant difference in both 15m (-1.1%) and 20m (-1.0%) sprint times, see table 3. However, no significant changes were observed for 10m (-1.0%), 25m (-0.9%) and 30m sprint times (-0.7%), along with Pmax (-0.45%) and CMJ (3%).

Table 4.4: Accumulated strength training volume in the intervention groups.

Groups	n	Total sessions/week	Total Standard-Dose sessions/week	Total Standard-Dose reps/week	Total Micro-Dose sessions/week	Total Micro-Dose reps/week (legs/week)	Total volume reps/week (legs/week)
SS	9	1	0.5	48 (28.8)	0.5	22.9 (22.9)	35.5 (25.9)
OA	7	1	0.5	41.1 (24.7)	0.6	20 (20)	30.5 (22.4)

Abbriviations: /week = per week; (legs/week) = amount of repetitions for lower limbs per week

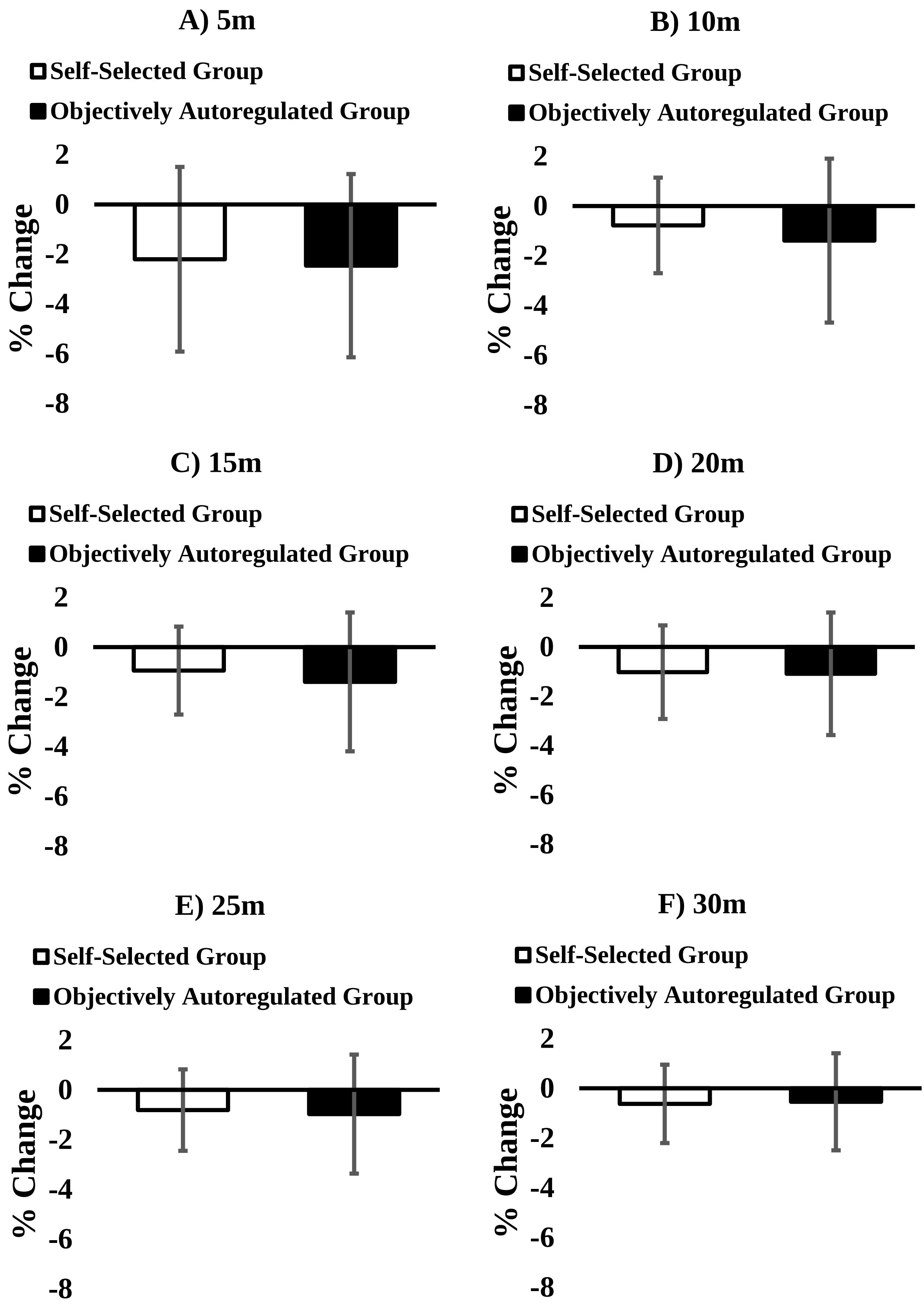

Figure 4.1 A-F: Percentage change in 5 – 30m split times. % Change: average percentage change from pre to post test (in seconds); Error bars: Confidence Interval (95%).

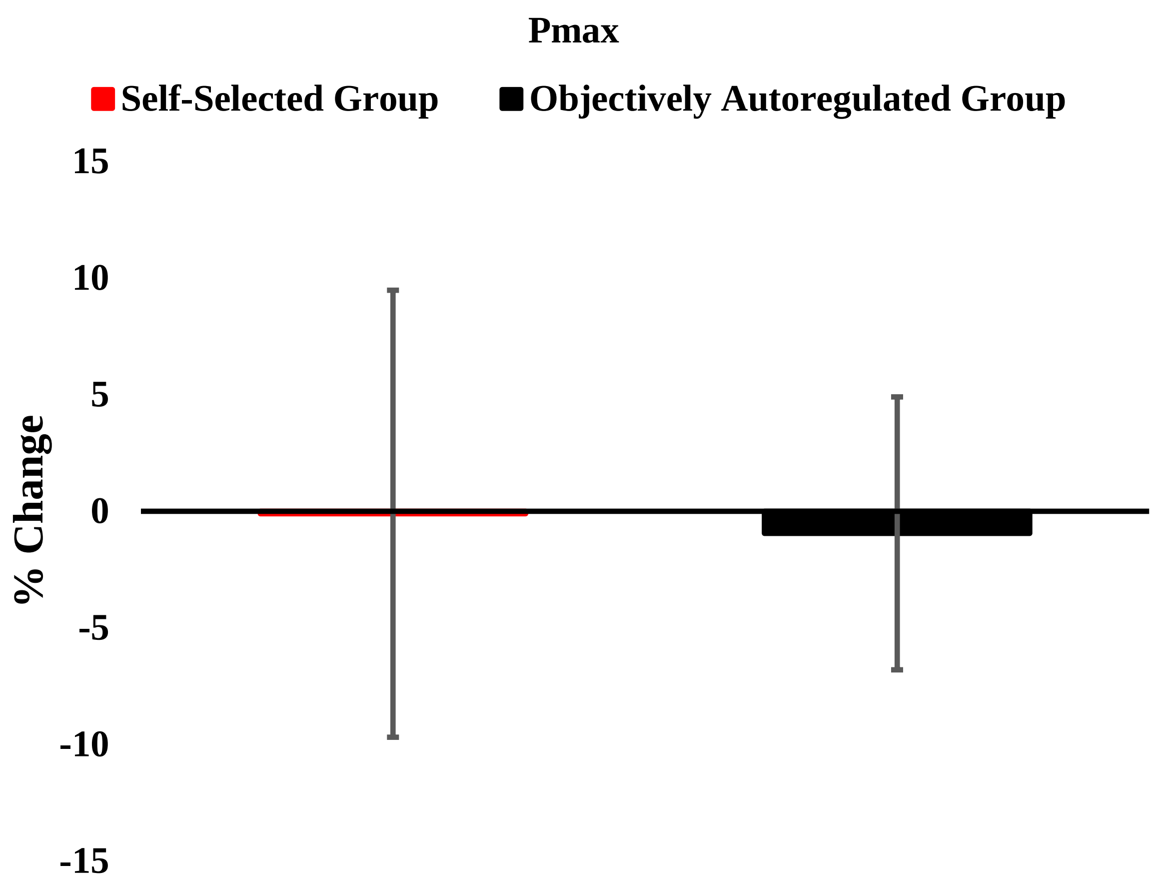

Figure 4.2: Percentage change in Pmax in SS and OA. % Change: average percentage change from pre to post test (in Newton); Pmax: Maximal power; Error bars: Confidence Interval (95%).

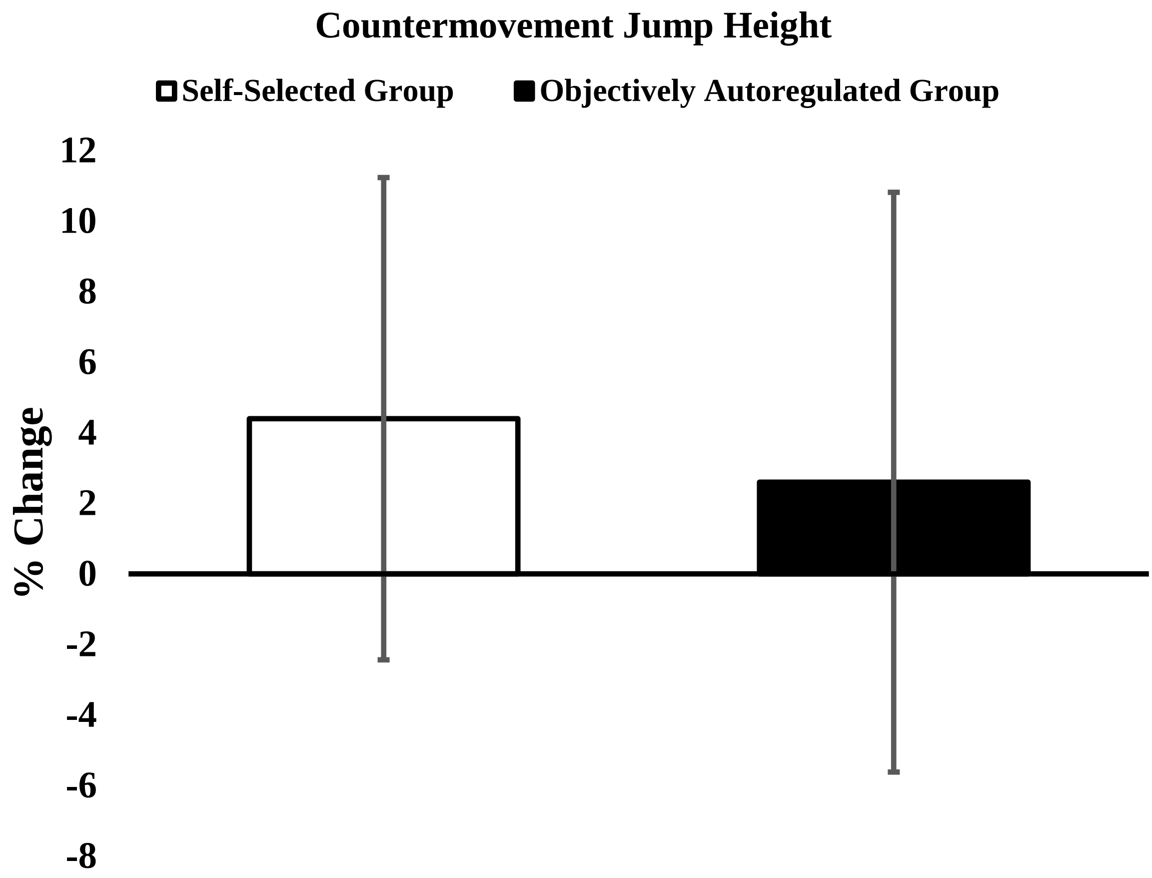

Figure 4.3: Percentage change in CMJ height for the Self-Selected Group and Objectively Autoregulated Group from pre to post test. % Change: Percentage change from pre to post test (in cm); Error Bars: Confidence Interval (95%).

4 DISCUSSION

The study aimed to compare the effects of subjective (SS) and objective autoregulation (OA) of strength training on sprint time, jump height and leg press power in-season in professional soccer players. The findings revealed no significant group differences between SS and OA any sprint split times, CMJ-height, or leg press power output. Notably, neither of the groups increased leg press power, sprint- or CMJ-performance from baseline, however, when the intervention groups were pooled, there were tendencies toward statistically significant effects on 5m- (p = 0.052), 15m- and 20m sprint times (p=0.08, 0.09, respectively).

To the best of the authors knowledge, no one has compared different autoregulation methods in professional soccer players. Nevertheless, it seems that autoregulation is advantageous compared to traditional percentage-based strength training alone [23]. Despite this, direct comparisons of subjective and OA methods in the literature are sparce. To the authors knowledge, only one study has directly compared the effects of subjective and OA. In their study, Shattock & Tee [17] compared 12 weeks of VBT and repetitions in reserve in amateur rugby players. They found that both objective (8.2±1.1%) and subjective autoregulation (3.8±0.9%) improved CMJ-height, and the effect size represented the significant difference between groups [ES: 1.78].

Changes in 10-, 20- and 40m sprint performance were likely trivial in both the objective (-0.4±0.2-0.4%) and subjective group (0.5±0.3±; -0.1±0.2-0.3%), and there was a difference between groups [ES: 0.82, 0.49, 0.76]. In the present study, no improvements in the objectively autoregulated group, in contrast to Shattock & Tee [17]. A reason for this can be that they implemented 1) a training period focusing on maximal strength and 2) had a specific "speed-strength" training block for the objectively autoregulated group. Furthermore, they had a randomized cross over design where the groups changed the autoregulation methods from the first to second training blocks. The present study used a RET-design, with each group having the same autoregulation method throughout the entire intervention period.

OBJECTIVE AND SUBJECTIVE AUTOREGULATION ON SPRINT PERFORMANCE

It has been reported by Orange et al., [24] that effects of VBT and PBT on 5-30m sprint times between were unclear, with the 10m sprint possibly favoring PBT. Similarly, Jiménez-Reyes et al.,[25] found that 10-, 10-20- and 20m sprint speed improved from pre- to post-testing in VBT (-1.2±0.0%; -0.59±0.0%; -0.95±0.01%, respectively; ES: 0.5, 0,5, 0.37), but the PBT-group had the greatest improvements (-2.26±0.0%; -1.6±0.0% & -1.99±0.1%, ES: 0.53; 0.63 & 0.60, respectively). In the present study, there was no significant improvements in sprint performance in either group, although the average volume for the OA-group was similar to that in Jiménez-Reyes et al.,[25] (28.3 repetitions vs. 22.4 repetitions per week, respectively). However, the decreases in sprint split times reported by Jiménez-Reyes et al.,[25] are similar to the present findings.

Volume may not explain the contradicting findings, as Pareja-Blanco et al.,[26] investigated the effect of 15- (VL15) and 30% (VL30) VBT by velocity-loss in professional soccer players and reported no improvements in 30m-sprint performance (ES: 0.1 and 0.06, respectively) despite a larger volume (VL15: 41.8 and VL30: 69.2 repetitions per week, respectively) compared to Jiménez-Reyes et al.,[25] and Orange et al.,[24] (40 back-squat repetitions per week).

Therefore, subject characteristics could be a possible explanation. Subjects in the present study were professional soccer players, while subjects in Orange et al.,[24] and Jiménez-Reyes et al.,[25] were academy league-rugby players and sport-science students, respectively. However, improvements in sprint 5 and 10m-sprint times performance has been reported following VBT in strength-trained men (-6.5& vs. -3.8%, ES: 1.17 vs 0.93, respectively), where subjects performed ~75 repetitions per week.[12] Therefore, it seems that OA can be effective to improve sprint performance, but may be ineffective to improve sprint performance in professional soccer players.

In comparison, subjective autoregulation methods have shown to have effects on short sprint performance in populations with no additional competitive demands. For instance, Silva et al.,[27] compared SS of session order and daily non-linear periodization (DNLP) on 100m sprint speed in untrained army recruits. Their findings indicated that both DNLP and SS improved 5m sprint speed (-5.45% & 9.5%; ES: 1.2, 0.9, respectively). On the other hand, Westblad et al.,[28] investigated set-RPE on flywheel (FRT) and traditional strength training (TST) on sprint performance in youth athletes, with findings suggesting that autoregulation had minimal influence on sprint performance, despite a tendency for improvement in 0-10m sprint time in both groups (FRT: -1.34%; TST: -2.8%). The present study revealed no improvements in sprint times in the SS-group (-2.2%, p=0.20).

In Silva et al.,[27] subjects had a larger average weekly volume for the lower limbs in both FNLP and DNLP, with greater volume training frequency (106.2 repetitions, 4 sessions per week) compared to the present study (SS:25.9, OA: 22.4 repetitions, 1 session per week), which may explain the contrasting results. However, Shattock & Tee[17] reported no improvements in sprint performance following subjective autoregulation, despite a similar training frequency as Silva et al.[27] but lower average lower-limb volume (60 repetitions per week). Therefore, the differing results may be down to strength training experience, as subjects in Shattock & Tee[17] and the present study were amateur and professional athletes, respectively, compared to Silva et al.,[27] who investigated on subjects with no previous strength training experience.

In summary, taking the findings of studies conducting subjective and OA together, one can argue that autoregulation of strength training is ineffective to improve sprint performance in already trained soccer players. It may be that the competitive demands during the in-season is an explanation for the trivial findings on sprint performance in the present and former studies. The intervention period in the present study was during the latter stages of the competitive season, and neuromuscular capacity has been shown to decrease in elite soccer players and in-season Australian Football-players.[29,30]. This may explain why the present study found no improvements in sprint split times, considering that the intervention was conducted in the latter stages of the competitive season and the players neuromuscular capacities might have been reduced. Nevertheless, sprint performance did not decrease in the present study. Therefore, the autoregulation may be sufficient to maintain sprint performance in in-season professional soccer players.

OBJECTIVE AND SUBJECTIVE AUTOREGULATION ON CMJ

OA has been reported to improve CMJ-height. For instance, Shattock & Tee[17] reported improvements in CMJ (8.2±1.1%) following VBT, while Jiménez-Reyes et al.,[25] and Dorrell et al.,[18] reported improvements of 7.9±0.06% (ES: 0.82) and 5%, ($p=0.018$), respectively. Further, Orange et al.,[24] reported that improvements in CMJ favored VBT compared to PBT, although the effect estimate was small (SMD: 0.28±0.61), making the difference between groups unclear. As for subjective autoregulation, the reported effects on CMJ-height varies. For instance, Shattock & Tee[17] reported an improvement of 3.8±0.9% in amateur rugby players.

On the other hand, Silva et al.,[27] found decrements in CMJ-performance following 12 weeks of FNLP and DNLP (0.13% and 2.44%, respectively). Further, Westblad et al.,[28] noted no improvements in CMJ-height following subjective autoregulation (FRT: 2.7%; TST: 0.12%). Thus, the improvements in SS in the present study (~4%), although not significant, are in line with the findings of Shattock & Tee[17], but differ from the findings in Silva et al.,[27] and Westblad et al.,[28]. It can be speculated that the small decrements in CMJ-performance reported by Silva et al.,[27] may be down to fatigue, as they performed 4 sessions per week during a 12 week intervention with large volumes for in untrained individuals.

In summary, autoregulation seems to improve CMJ-height compared to no autoregulation, but positive effects on CMJ-height tends to be greater with OA[17,18] compared to subjective autoregulation[17,18,27], which is in contrast to this study where SS had the greatest improvement. Further, there was no decrements or significant improvements in CMJ-height in either group, thus the findings indicate that the autoregulation methods used in the present study maintained CMJ-height in the subjects.

OBJECTIVE AND SUBJECTIVE AUTOREGULATION ON MAXIMAL STRENGTH AND POWER

Both objective and subjective autoregulation has been shown to increase maximal strength in trained and untrained populations. For instance, Orange et al.,[24] reported that both VBT and PBT improved maximal strength, however effect estimates between groups were likely trivial (SMD: -0.08±0.18). VBT had likely to very likely improvements in maximal strength at 60% of 1RM (SMD: 0.5±0.66), which authors argued represented an improvement in explosive strength. Furter, Dorrell et al.,[18] noted a 9% increase in maximal strength following VBT, while Shattock & Tee[17] and Jiménez-Reyes et al.,[25] reported strength gains of 7.5±1.5% and 12.7±0.06 respectively. Similarly, strength gains have also been reported following subjective autoregulation. For instance, McNamara & Stearne[15] investigated the use of SS workouts on leg press among other measures. The SS improved leg press strength by ~43%, which was significantly different to the DNLP-group (~11%).

However, in contrast to our study, their subjects were weight training beginners, and their training protocol consisted of 10, 15- and 20RM sets. Further, they had 2 strength training sessions per week, compared to our ~1 session. The subjects in the present study were highly trained professional soccer players, and the present training protocol consisted of high-intensity strength training (4-6 reps per set). Colquhoun et al.,[22] investigated SS-workout volume and SS-workout program order in resistance trained men. Their results indicated that both methods induced similar lower-limb strength training adaptations (FNLP: 11.8%, ES: 0.46; DUP: 12.2%, ES: 0.64). Therefore, it seems that both autoregulation methods can be implemented effectively both in trained and untrained populations to improve maximal strength.

Further, since maximal strength is a basic quality for power performance, it should, in theory, be able to improve leg press power. Still, the findings of the present study found no improvements in Pmax. To the authors knowledge, no studies have investigated autoregulation effects leg press power *per se*. It seems that measures of muscular power in autoregulation studies include power/force production in CMJ and mean or mean propulsive velocity in the squat exercise.[31] It can be speculated that the use of different test-instruments can explain why no improvements in power was observed. In the present study, a pneumatic leg press device was used to test Pmax. However, the Keiser leg press has been reported to have a lower coefficient of variance (CV) and higher interclass correlation (ICC) compared to P_{max} measured in a CMJ on a force plate (CV: 4.2±1.6 vs. 8.8±3.1; ICC: 0.97±0.03 vs. 0.77±0.19, respectively).[32]

On the other hand, it should be noted that subjects in these autoregulation studies were either amateur or semi-professional athletes[17,24], strength trained males[18,22] or subjects with no previous resistance training experience.[15,27] Research has shown that untrained individuals can experience huge gains in neural adaptation, muscle hypertrophy and power following short term interventions compared with trained individuals.[33] This study implemented autoregulated strength training in already trained soccer players, which could explain why we found no increases in P_{max}. Furthermore, subjects in McNamara & Stearne[15] and Colquhoun et al.,[22] had no additional aerobic or anaerobic training. Research has shown that concurrent training, in essence endurance exercise and strength training, may be limiting for strength and power adaptions.[8] Therefore, this could be a potential explanatory factor as to why others have found effects, in contrast to the present study .

EVALUATING THE AUTOREGULATION METHODS IN THE PRESENT STUDY

Objective methods compared to traditional strength training prescriptions are well-researched in the literature[12,18,24,25,31]. While such methods can be effective for improving sprint times and CMJ, they usually only consider acute fatigue withing a strength training repetition, set or session, but may not consider internal fatigue induced by soccer training- and match-play. The present study investigated autoregulation through comparison of a novel GPS-based method and SS of exercise volume. One could argue that locomotive GPS-data may better represent external training load of a soccer player in-season, as Hader et al.,[19] reported strong correlations between distance covered ≥5.5m/s^{-1} and fatigue-related markers, compared to the traditionally used TD covered. Therefore, the use of GPS-data could in theory lead to more “precise” adjustment of strength training in soccer-players in-season. This method of adjusting strength training accordingly may reduce the amount of fatigue and lead players to be closer to their optimal neuromuscular capacity in a tight competitive schedule. However, since the present study is the first to investigate OA of strength training based on GPS-data, this hypothesis should be considered with caution. Furthermore, the use of GPS-data alone may not reflect the total training load, as it solely concerns external training- and match-induced load.

Therefore, the use of subjective methods may be used to provide information about the internal load imposed on the players. Subjective methods such as RPE is often used in soccer to determine the players’ response to training- and non-training stressors, and has been noted to closely reflect acute changes in training and match-load in professional soccer players [20,21]. However, SS has been proposed to better adjust strength training, as RPE determines strength training variables based on subjective fatigue scores within repetitions and/or sets, whereas SS determines strength training variables based on the athletes’ overall preference prior to the strength training session.[11] In line with this, subjects in the present study self-selected strength training *volume* solely based on how they felt overall. One could argue that the different aspects of how they felt overall, in essence the degree of fatigue, perceived sleep quality, hunger or muscular soreness should have been emphasized in the selection process, as research has shown instructions that give athletes a sense of choice can have performance-enhancing effects.[34] In essence, the SS process should perhaps have been emphasized trough telling subjects that “they may want to” select exercise volume based on how they slept the preceding night, how hungry they felt or how sore they were.

However, the findings in the present study indicate that there was no difference between SS and OA. However, this may be due to the low training frequency and volume. However, as high frequencies of strength training during in-season soccer may be challenging, it is possible that a higher strength training volume could reveal greater differences between the methods and groups [10]. Therefore, future research should investigate OA based on locomotive GPS-data and subjective SS with a higher volume, and if possible, a higher training frequency.

PERSPECTIVE

The present study found no differences between subjective SS and OA for sprint, CMJ or leg press power in professional soccer players in-season. However, the observations indicate that ~1 session of subjective or OA per week was sufficient for in-season soccer players to maintain leg press power, sprint and CMJ-height performance. Considering a tight competitive schedule for professional soccer players, it may be that the use of autoregulation during the competitive season is more practical for maintenance of power performance, compared to traditional methods such as VBT. Future research should investigate self-selected vs GPS-regulated autoregulation in in-season soccer players, with a larger sample size and strength training volume to clarify the effects of the present methods.

ACKNOWLEDGEMENTS

Supervisors: TB, FTV, KL. Thank you to all the athletes that participated in the present study. No financial support was provided in the completion of the present study.

CONFLICTS OF INTEREST

The author declares no conflicts of interest concerning the results of the present study.

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Part 3:

Appendices

Per Thomas
Byrkjedal

Besøksadresse:
Universitetsveien 25
Kristiansand

Ref: [object Object]
Tidspunkt for godkjenning: 28/02/2020

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

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

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

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

UNIVERSITETET I AGDER
POSTBOKS 422 4604 KRISTIANSAND
TELEFON 38 14 10 00
ORG. NR 970 546 200 MVA - post@uia.no -
www.uia.no

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NSD NORSK SENTER FOR FORSKNINGSDATA

NSD sin vurdering

Prosjekttittel

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

Referansenummer

464080

Registrert

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

Behandlingsansvarlig institusjon

Universitetet I Agder / Fakultetet for helse- og idrettsvitenskap / Institutt for folkehelse, idrett og ernæring

Prosjektansvarlig (vitenskapelig ansatt/veileder eller stipendiat)

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

Type prosjekt

Forskerprosjekt

Prosjektperiode

15.02.2020 – 31.12.2023

Status

31.05.2021 – Vurdert

Vurdering (2)

31.05.2021 – Vurdert

NSD har vurdert endringen registrert 21.05.2021. Dato for prosjektslutt er endret til 31.12.2021. Data med personopplysninger oppbevares da også lengre, nemlig til 31.12.2028 grunnet dokumentasjonshensyn. De registrerte informeres om endringene.

Det er vår vurdering at behandlingen av personopplysninger i prosjektet vil være i samsvar med personvernlovgivningen så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet med vedlegg den 31.05.2021. Behandlingen kan fortsette.

OPPFØLGING AV PROSJEKTET

NSD vil følge opp ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.

Lykke til med prosjektet!

Tlf. Personverntjenester: 55 58 21 17 (tast 1)

17.02.2020 – Vurdert

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

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

TYPE OPPLYSNINGER OG VARIGHET
Prosjektet vil behandle særlige kategorier av personopplysninger om helseopplysninger og alminnelige kategorier av personopplysninger frem til 31.12.2021. Data med personopplysninger oppbevares deretter internt ved behandlingsansvarlig institusjon frem til 31.12.2026, dette til forskningsformål.

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

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

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

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

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

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

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

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

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

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

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

Lykke til med prosjektet!

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