A comparison of force-, velocity- and balanced training approach on force-velocity mechanical outputs and vertical jump height

– of national level athletes during a competitive season

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ACKNOWLEDGMENTS

We are truly grateful for the subjects' willingness to participate in the study and to the University of Agder (UiA) and Olympiatoppen for making this project come true. It has been a challenging and rewarding journey being able to contribute to the planning, preparation, and administration of the present study. In addition, we wish to acknowledge the substantial contribution of our supervisors, PhD student Thomas Bjørnsen and Professor Sveinung Berntsen, whose leadership made this research possible. We would also like to thank Martin Thorsen Frank and MSc Kolbjørn Lindberg, for all your involvement throughout this project — it has been a true pleasure working alongside you.

It has been two memorable years at the University of Agder. Thank you!

Kristiansand, Norway

May 2019

Gøran Abusdal & Tommy Larsen

CONTENTS

ABBREVATIONS

F-v	Force-velocity
FV_{imb}	Force-velocity imbalance
Sfv	Slope of the linear force-velocity relationship
Sfv_{opt}	Optimal force-velocity relationship
F_{max}	Maximal isometric force
V_{max}	Maximal velocity of shortening
P_{max}	Maximal power output
F_0	Theoretical maximum force
V_0	Theoretical maximum velocity
SJ	Squat jump
CMJ	Countermovement jump
1RM	One repetition maximum
SSC	Stretch-shortening cycle
MVC	Maximal voluntary contraction
MTU	Muscle-tendon unit
RFD	Rate of force development
CSA	Cross-sectional area
EMG	Electromyography
PA	Pennation angle
SD	Standard deviation
CI	Confidence interval

ABSTRACT

INTRODUCTION. Optimizing muscular power output is considered crucial to performance across different sports, but the exact training approach to optimize muscular power is not clear. Therefore, the aim of the present study was to compare the effect of a force- vs. velocity-dominated vs. balanced power training approach on force-velocity mechanical outputs (F_0, V_0 & P_{max}) and vertical jump height.

METHODS. Thirty-five elite male athletes were recruited and divided with stratified randomization based on force-velocity profile slope into a force-, velocity-dominated or balanced power training group, and performed a 10-week training intervention. Thirty subjects (age = 20.0 ± 4.8) completed the intervention and underwent pre- and post-tests with a test-protocol consisting of: body composition with DXA, muscle thickness and architecture with ultrasonography, force-velocity mechanical outputs (F_0, V_0 & P_{max}) during squat- and countermovement-jumps (SJ & CMJ), Keiser leg press and leg extensions, as well as one repetition maximum in back-squat, and 30m sprint.

RESULTS. There were no group differences in force-velocity mechanical outputs (F_0, V_0 & P_{max}) in SJ, CMJ, Keiser leg press or leg extension. The Balanced group increased SJ-height by 6% (95% CI, 0.4, 11.5, p=0.036) and 9.8% (1.5, 18.2, p=0.023) more than Force group at 40 and 60 kg, respectively. The Velocity group increased SJ-height 7.8% (1.1, 14.4, p=0.023) more than Balanced group at 0.1 kg, and CMJ-height by 6% (-12.0, -0.1, p=0.048) more than the Force group at 20 kg.

CONLCUSION. A velocity-dominated or balanced training approach may be more beneficial to increase force-velocity mechanical outputs and vertical jump height for national level athletes during a competitive season, compared to a force-dominated power training approach.

KEYWORDS. Power training, force-velocity profile, muscular power, jump performance

SAMMENDRAG

INTRODUKSJON. Optimalisering av muskulær power-produksjon har blitt vurdert til å være en essensiell del av prestasjon i ulike idretter, men det foreligger lite litteratur på utøvere på nasjonalt nivå. På bakgrunn av dette, er målet med studien å sammenlikne hvilket treningsprogram (kraftdominert, hastighetsdominert eller balansert) som er mest gunstig for å øke kraft-hastighetsparametre (F_0, V_0 & P_{max}) og vertikal hopphøyde.

METODE. Trettifem mannlige elite-utøvere ble rekruttert og delt med stratifisert randomisering ut ifra deres kraft-hastighetsprofil inn i tre ulike treningsgrupper (kraftdominert, hastighetsdominert og balansert), og gjennomførte en ti ukers treningsintervensjon. Tretti forsøkspersoner (alder = 20.0 ± 4.8) fullførte treningsintervensjonen og ble testet ved fire måletidspunkter i følgende testbatteri: kroppssammensetning med DXA, muskeltykkelse og muskelarkitektur med ultralyd, kraft-hastighetsparametre (F_0, V_0 & P_{max}) fra knebøyhopp og svikthopp (SJ & CMJ), Keiser benpress og kne-ekstensjon, i tillegg til én repetisjon maksimum i knebøy og 30 meter sprint.

RESULTATER. Det var ingen gruppeforskjeller i kraft-hastighetsparametre (F_0, V_0 & P_{max}) i knebøyhopp, svikthopp, Keiser benpress eller kne-ekstensjon. Den balanserte gruppen (balansert program) økte hopphøyde i knebøy med 6% (95% CI, 0.4, 11.5, p=0.036) og 9.8% (1.5, 18.2, p=0.023) mer enn kraftgruppen, henholdsvis ved 40 og 60 kg motstand. Hastighetsgruppen økte hopphøyde i knebøyhopp med 7.8% (1.1, 14.4, p=0.023) mer enn den balanserte gruppen ved 0.1 kg motstand, og hopphøyde i svikthopp med 6% (-12.0, -0.1, p=0.048) mer enn kraftgruppen ved 20 kg motstand.

KONKLUSJON. En hastighetsdominert eller balansert powertrening tilnærming er muligens mer fordelaktig til å øke kraft-hastighetsparametre og hopphøyde for utøvere på nasjonalt nivå i sesong, sammenliknet med kraftdominert tilnærming.

NØKKELORD. Powertrening, kraft-hastighetsprofil, muskulær power, hopp-prestasjon

STRUCTURE OF THESIS AND AUTHORS’ CONTRIBUTIONS

The thesis is divided into two parts. Part 1 presents a theoretical framework of the studied topic, a methodological chapter of how the present study is conducted, followed by a chapter of methodological discussion. Part 2 presents a research paper regarding the present experimental study, and is written according to the standards of the journal: Medicine & Science in Sports & Exercise (MSSE).

Due to the word-limitation of the master thesis, results, discussion, and conclusion of the present experimental study are only included in part 2.

The authors’ have contributed equally to the preparation and completion of the study.

PART 1

THEORETICAL BACKGROUND AND METHODS

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TABLE OF CONTENTS

1.0 Introduction

Sport science is characterized by finding new and better methods for optimizing performance — and is a field undergoing constant change. The evolution in physical demands of competition in sports such as handball, ice hockey, or athletics, alongside with advancements in strength and conditioning methodologies have led to increased relevance of high-intensity, ballistic actions. High levels of force, velocity and power are physical factors that determine the performance of ballistic movements such as jumps, changes of direction, or sprint (Cormie, McGuigan & Newton, 2010; Cronin & Sleivert, 2005).

Ballistic movements, such as jumping, may be defined as the ability to accelerate body mass as fast as possible in the shortest duration of time during a push-off phase (Samozino, Rejc, Di Prampero, Belli & Morin, 2012). Neuromuscular power has been highlighted in numerous studies as one of the primary variables related to ballistic performance (Cormie, McGuigan & Newton, 2011a; De Luca & Hostage, 2010; Harwood, Dalton, Power & Rice, 2013). Yet, this is only a partial representation of the true maximal mechanical capabilities of the athletes (Cronin & Sleivert, 2005).

In recent times, a method based on optimal force-velocity (F-v) profiling, has shown promising results across different sports for optimizing individual test results (Jiménez-Reyes et al., 2018; Jiménez-Reyes, Samozino, Brughelli & Morin, 2017; Marcote-Pequeño et al., 2018; McMaster, Gill, Cronin & McGuigan, 2016; Slimani, Paravlic & Granacher, 2018). The potential of this method could be of substantial value for future research for improving performance across the science of sports.

Although maximal power output (P_{max}) that the lower limbs can generate, is a significant determinant for ballistic performance (Yamauchi & Ishii, 2007), it is also influenced by the individual combination of the individuals' force-velocity profile (*Sfv*) (Samozino et al., 2012; 2014). P_{max} is a widely accepted muscular determinant for jump- and sprint performance, which is determined by both force and velocity production capabilities (Samozino et al., 2012, 2016). The performance is therefore mainly dependent on the ability of neuromuscular systems to (a) generate high levels of force, (b) ensure the effective application of this force onto the environment (i.e., supporting ground) and (c) produce this effective force at high contraction velocities (Jiménez-Reyes et al., 2018; Morin & Samozino, 2016). Thus, the inclusion of *Sfv* may provide a more accurate representation of the athletes' maximal force and velocity capabilities (Morin & Samozino, 2016; Samozino et al., 2012).

1.1 Overall aim and hypothesis

The present study aimed to compare the effect of a Force- vs. Velocity-dominated vs. Balanced power training approach on force-velocity mechanical outputs (F_0, V_0 & P_{max}) and vertical jump height. We hypothesize that the Balanced power training approach would increase force-velocity mechanical outputs and vertical jump height more than a Force- and Velocity-dominated approach.

1.2 Delimitation of the thesis

Due to the word limitation, following factors affecting the development of neuromuscular power were not covered: time available to develop force, storage and utilization of elastic energy, interaction- and potentiation of contractile and elastic filaments, stretch reflexes, effect of training on stretch-shortening cycle function, tendon properties and muscle environment.

2.0 Theoretical framework

2.1 Application of training programs

Development of training programs aiming to improve maximal power production in dynamic movements is a topic of interest for many scientists and coaches (Cormie, Mcguigan & Newton, 2011b; Haff & Nimphius, 2012). An existing fundamental relationship between strength and power dictates that an individual cannot generate high levels of muscular power without first being relatively strong. Power is greatly dependent on the ability to generate the highest possible force (i.e., maximum strength) (Stone et al., 2003) and can be evidenced by the high and positive correlation between peak power and maximum strength (r=0.77–0.94) (Asci & Acikada, 2007) in both the upper-body (Baker, 2001; Baker, Nance & Moore, 2001, Baker & Newton, 2006) and lower-body (Baker, 2001; Baker & Newton, 2008; Nuzzo, McBride, Cormie & McCaulley, 2008; Peterson, Alvar & Rhea, 2006). For example, Nuzzo et al. (2008) observed significant correlations between one repetition maximum (1RM) squat relative to body mass, countermovement jump (CMJ) peak power, CMJ peak velocity, and CMJ height. This is further supported by Peterson et al. (2006) who found significant linear relationships between 1RM squat, vertical jump peak power and all explosive performance tests (vertical jump, broad jump, agility t-test, sprint acceleration). Therefore, enhancement and maintenance of maximal strength are essential when considering the long-term development of power (Cormie et al., 2011b; Haff & Nimphius, 2012).

Further, consideration of movement pattern, load and velocity specificity is essential when designing power training programs. A program containing ballistic, plyometric and/or weightlifting exercises can be used effectively as primary exercises towards maximal power enhancement (Baker, 2001; Baker & Newton, 2008; Cormie, McGuigan & Newton, 2007; Dæhlin, Krosshaug & Chiu, 2017; Fatouros et al., 2000; Harris, Stone, O'Bryant, Proulx & Johnson, 2000; Markovic, 2007; Nuzzo et al., 2008; Peterson et al., 2006). The external loads in these exercises will depend on the specific requirements of each sport and the type of movement being trained (Cormie et al., 2011b). Strength training prescription is not only governed by intensity (% of 1RM), but also the combination of several other factors, including: type of exercises used, volume (sets × repetitions), exercise sequence within a strength training session, repetition velocity, training frequency, and rest interval length between sets (Cormie et al., 2011b; Kraemer & Ratamess, 2004; Sarabia, 2017).

It has been reported that loads of 80–100% of 1RM, for the enhancement of the force component of the power equation, whereas loads of 0–60% of 1RM, for the enhancement of the rate of force development (RFD), are recommended when resistance exercises are used for power training of the lower body (Bird, Tarpenning & Marino, 2005; Maffiueletti et al., 2016; Ratamess et al., 2009). Lastly, there is a consensus within the literature that training programs for maximal power should involve an intention to move explosively (Behm & Sale, 1993; Cormie et al., 2011b; Turner, 2009). This intention is specified on all exercises within the training programs in the present study *(Appendix II–IV)* and was closely followed up on workouts during intervention.

Heavy strength training. Heavy strength training is a common training approach to enhance the muscles' ability to produce maximum force at any given velocity (Cormie et al., 2007). Increasing maximal strength through such training has been shown to significantly improve power output (Bird et al., 2005; Maffiueletti et al., 2016); Ratamess et al., 2009) and jump height (Jiménez-Reyes et al., 2017; Wisløff, Castagna, Helgerud, Jones & Hoff, 2004). Power production is a consequence of efficient neuromuscular processes and as such, quality should be in focus, and each repetition should have the intention to move as fast as possible. It has been hypothesized that each repetition should achieve ≥80% of maximum power output or velocity. This is best achieved with the use of three repetitions per set, at least three minutes' rest between sets (Baker & Newton, 2005; Fleck & Kraemer, 2013), and a maximum of five sets (Fleck & Kraemer, 2013).

Power training. The theory of velocity specificity in resistance training suggests that adaptations following training are maximized at or near the velocity of movement used during training (Cormie et al., 2011b). However, another theory suggests that training adaptations are influenced by the intention to move explosively, regardless of the actual movement velocity (Behm & Sale, 1993). To individualize the training stimulus, a load that maximizes mechanical power output in a specific exercise for each individual should be used for power enhancement (Cronin & Sleivert, 2005). A variety of movements have been prescribed for improving maximal power output, such as plyometrics, traditional resistance training and ballistic exercises (Cormie et al., 2011b). Ballistic exercises can be described as explosive movements (i.e., rapid acceleration against resistance), whereby the body or object is rapidly subjected to full acceleration. Essentially, such exercises target the velocity (and acceleration) component of the movement by manipulating the resistance. It is theorized that ballistic training generates a higher rate of force development (RFD), and may therefore provide sufficient stimulus for enhancement of intra- and intermuscular coordination during dynamic movements (Harris et al., 2000).

Using ballistic exercises with external loads ranging from 0–50% of 1RM and/or weightlifting exercises performed with loads ranging from 50–90% of 1RM appears to be the most effective loading stimulus for improving maximal power in complex movements (Cormie et al., 2011b; Winchester, McBride, Maher & McGuigan, 2008). Moreover, plyometric exercises should contain sport specific movements and involve little to no external resistance (Turner, 2009).

These loading conditions allow superior transfer to performance due to the similar movement velocities encountered in the specific sport (Cormie et al., 2011b).

Further, it is generally advised to perform power-training in a non-fatigued state, whereby neural adaptations can be enhanced via a more optimal training stimulus. However, in many high-power sports, motor skills are required to be executed under fatigued conditions, thus power-training while fatigued may hold some sport specificity (Turner, 2009).

Balanced power training. Different training methods, such as traditional strength training and plyometrics or a combination of both, have been reported effective for development of muscular power (Cormie, McCaulley, Triplett & McBride, 2007; Dæhlin et al., 2017; Fatouros et al., 2000; Harris et al., 2000; Markovic, 2007; Nuzzo et al., 2008). It has been hypothesized that a combination of heavy strength and power training is more effective given significant improvements in both maximal force and maximal velocity, in comparison to maximal velocity alone (Turner, 2009). Similarly, Cormie et al. (2007), Harris et al. (2000) and Nuzzo et al. (2008) concluded that when considering the improvement of a wide variety of performance variables requiring strength, power, and speed, combination-training produces superior results. The premise of this approach is thought to result from the additive improvements in both maximum force (through strength training) and maximum velocity (through power training), thus leading to greater enhancements in power output across the entire F-v curve (Turner, 2009).

Fundamental mechanisms. Maintenance and enhancement of maximal strength are essential to the long-term development of power as the ability to generate maximal muscular power is influenced by the individual’s strength level (Cormie et al., 2011b; Haff & Nimphius, 2012). Traditional heavy load strength training is therefore an important component of a variety of athletes’ training program (Cormie et al., 2011b). Following strength training, the magnitude of improvements in strength and the different mechanisms driving those adaptions differ as the athletes’ strength level improves (Cormie et al., 2010; Folland & Williams, 2007). While neurological adaptions impact strength improvements primarily during the early stages of a training program, morphological factors become more critical as further increases in strength are progressively harder to achieve (Cormie et al., 2010; Folland & Williams, 2007).

2.2 Morphological factors

The contractile capacity of muscle is primarily influenced by architectural features and its fiber type compositions. The contractile capacity highly dictates the ability of the involved muscles to generate maximal power during movements. Additionally, the function of the contractile components within the «muscle-tendon unit» (MTU) is influenced by the tendon properties and, therefore impact maximal power production (Cormie et al., 2011a).

Cross-sectional area. Several studies conclude that muscle CSA is a major predictor of force-production (Fukunaga et al., 2001; Jones, Bishop, Woods & Green, 2008; Suchomel, Nimphius, Bellon & Stone, 2018). In a study involving comparisons of single muscle fibers between sedentary- and resistance-trained men (7.6 ± 1.6 years of regular training), the resistance-trained had significantly greater CSA, F_{max} and P_{max} for type I and II fibers compared with sedentary (Shoepe, Stelzer, Garner & Widrick, 2003). However, when normalizing F_{max} to CSA and P_{max} to fiber volume, there were no longer distinct differences — which accounts for differences in both fiber CSA and length (Shoepe, Stelzer, Garner & Widrick, 2003). Increments in fiber CSA are obtained through increments in the size (hypertrophy) and number (hyperplasia) of myofibrils inside the muscle fiber (Jones et al., 2008).

Vast research has established that heavy strength training is an effective stimulus for hypertrophic responses to be evoked within a muscle (Aagaard et al., 2001; Blazevich, Gill, Bronks & Newton, 2003; Folland & Williams, 2007; Widrick, Stelzer, Shoepe & Garner, 2002). Training-induced changes to F_{max} of single muscle fibers are proportional to changes in fiber CSA (Shoepe et al., 2003; Trappe et al., 2000), where increments of F_{max} or CSA generally is accompanied by improvements in P_{max} (MacIntosh & Holash, 2000; Malisoux, Francaux, Nielens & Theisen, 2006; Widrick et al., 2002). It is important to note that relatively untrained subjects with low to moderate levels of strength are involved in the majority of this research, and their improvements in muscle function are easily invoked (Folland & Williams, 2007). Heavy strength training of stronger and well-trained individuals is expected to have a smaller increase in CSA, and require a longer time (Suchomel et al., 2018).

Furthermore, muscle growth is strongly dependent on the type of training and the specific program variables (i.e., intensity, volume, frequency) (Wernbom, Augustsson & Thomee, 2007). Increases in maximal muscular power brought about by improved CSA are mainly achieved through heavy strength training (Cormie et al., 2011b). The relatively light loads in ballistic power training are typically too small to affect the necessary mechanical stimulus required for significant muscle growth response (Kyröläinen, Avela & Komi 2005; Wernbom et al., 2007).

2.2.1 Muscle architecture

Fascicle length. Assuming there is a constant level of activation, the V_{max} of a muscle fiber is proportional to its length, even though differences in the V_{max} of various fiber types differ quite significantly (MacIntosh & Holash, 2000). For example, assuming the shortening speed of a sarcomere is two fiber lengths per second, a fiber containing ten sarcomeres in series would have a greater V_{max} than a fiber containing five (Lieber & Ward, 2011). Since power is heavily influenced by V_{max}, a longer muscle fiber can, therefore, generate higher P_{max} (MacIntosh & Holash, 2000).

Correlation studies have revealed significant relationships between 100m sprint time and fascicle length (FL) of *m. vastus lateralis* and *m. gastrocnemius lateralis* in both men and women (r=-0.43 to -0.57) (Abe, Fukashiro, Harada & Kawamoto, 2001; Kumagai et al., 2000). Furthermore, a study reported significantly longer fascicle lengths of *m. vastus lateralis*, *m. gastrocnemius medialis* and *m. gastrocnemius lateralis* in sprinters compared with long-distance runners and untrained controls (Abe, Kumagai & Brechue, 2000). However, whether these observations are a result of adaptions in FL to training commonly used by sprinters (i.e., high-intensity sprint/strength/power training) or a result of genetic predisposition remains unclear.

These observations indicate the impact of longer fascicle lengths on rapid force-generation- and maximal power production abilities during dynamic movements, despite the origin of the architectural difference (Cormie et al., 2011a). Studies have reported an increase in fascicle length in response to heavy strength training (Blazevich, Cannavan, Coleman & Horne, 2007; Blazevich et al., 2003; Seynnes, de Boer & Narici, 2007), light strength training (Alegre, Jiménez, Gonzalo-Orden, Martín-Acero & Aquado, 2006), as well as ballistic jump- and sprint training (Blazevich et al., 2003). On the contrary, no effects on FL were observed in a lower body heavy strength training program (Blazevich et al., 2007). Even though some of these changes were associated with performance improvements, exactly how the changes in FL affected V_{max} or P_{max} is unknown, as the adaptive response of fiber length following training is not well understood (Cormie et al., 2011a). Elucidating the most effective training stimulus for growth in fiber length still requires more research.

Pennation angle. The pennation angle (PA) of a muscle, defined as the angle between a fascicle's orientation and the attached tendon axis, has significant physiological effects on the determination of a fascicle's force-contribution to the skeletal system (Lee, de Boef Miara, Arnold, Biewener & Wakening, 2013). The PA has great effects on P_{max}, and thus the *Sfv* (Cormie et al., 2011a). The force production of a muscle may be greater with an increased PA, as the architectural changes allow for more sarcomeres to be arranged in parallel, as well as allowing greater attachment of muscle mass to a given area of a tendon (Blazevich et al., 2003; Lee et al., 2013). Additionally, muscle fibers are then allowed to shorten less during contraction for a given tendon displacement, due to the rotation of pennate muscle fibers (Cormie et al., 2011a). Under such conditions, and based on the length-tension relationship (further described in *section 2.2.1*), it is possible that fibers operate closer to their optimum length, and could in return generate more force (Blazevich et al., 2003). These factors contribute to increased F_{max} and, therefore, the P_{max} generated by a muscle is influenced by the PA (Cormie et al., 2011a).

However, a greater PA may negatively impact V_{max} due to the association with slower contraction velocities as the PA increases (MacIntosh & Holash, 2000). Despite this, F_{max} is theorized to have a greater effect on P_{max} than V_{max} brought about by an increase in PA (MacIntosh & Holash, 2000). Heavy strength training is generally thought to increase the PA of a muscle fiber, while sprint training is thought to decrease the PA (Cormie et al., 2011a). Observations of population differences displayed that highly trained sprinters possessed smaller PA than both less trained sprinters (Kumagai et al., 2000), and untrained controls (Abe et al., 2001). In addition, bodybuilders displayed greater PA and CSA than untrained subjects (Aagaard et al., 2001). Furthermore, it is unknown whether ballistic power training and other training approaches elicit changes in PA or if the training status of the subject influences these changes.

2.3 Muscle mechanics

2.3.1 Length-tension relationships

The length-tension relationship describes the relationship between the maximum, active, steady-state isometric force of a muscle and its lengths, were lengths may be represented by the entire MTU, a fascicle/fiber, or even a single sarcomere (Moo, Fortuna, Sibole, Abusara & Herzog 2016). The skeletal muscles' force generating abilities are critically reliant on sarcomere length, and force production on activation of the cross-bridge has its greatest potential when the sarcomere length provides for the optimal overlap between the actin and myosin filaments (described as the «optimal length») (Cormie et al., 2011a). When sarcomere lengths shorten below the optimal length, force production is impeded due to the overlap of the actin filaments from opposite ends of the sarcomere (Moo et al., 2016).

On the contrary, a sarcomere stretched beyond the optimal length, also has reduced force production capacity, due to less overlap between actin and myosin filaments (Moo et al., 2016). While the *Sfv* defines muscular power, the length-tension relationship affects the ability of force development in muscle fibers, and therefore, plays an important role in maximal muscular power production (Cormie et al., 2011a).

2.3.2 Type of muscle activation

Muscles' ability to generate maximal power is depended on the movement involved: eccentric, concentric, isometric or a combination of these contractions (Turner & Jeffreys, 2010). The combination of eccentric and concentric actions establishes the most common type of muscle function and is termed the «stretch-shortening cycle» (SSC) (Turner & Jeffreys, 2010). When a muscle fiber is activated, stretched, then immediately shortened, the power generated during the concentric action are greater than a concentric-only contraction *(Figure 1)* (Fukutani, Misaki & Isaka, 2016; Pierrynowski, 2007). Therefore, movements involving an SSC (e.g., CMJ) is thought to maximize muscular power production (Fukutani et al., 2016). Moreover, there is an issue of debate among researchers regarding the underlying mechanisms responsible for performance during SSC movements (Cormie et al., 2011; Fukutani et al., 2016).

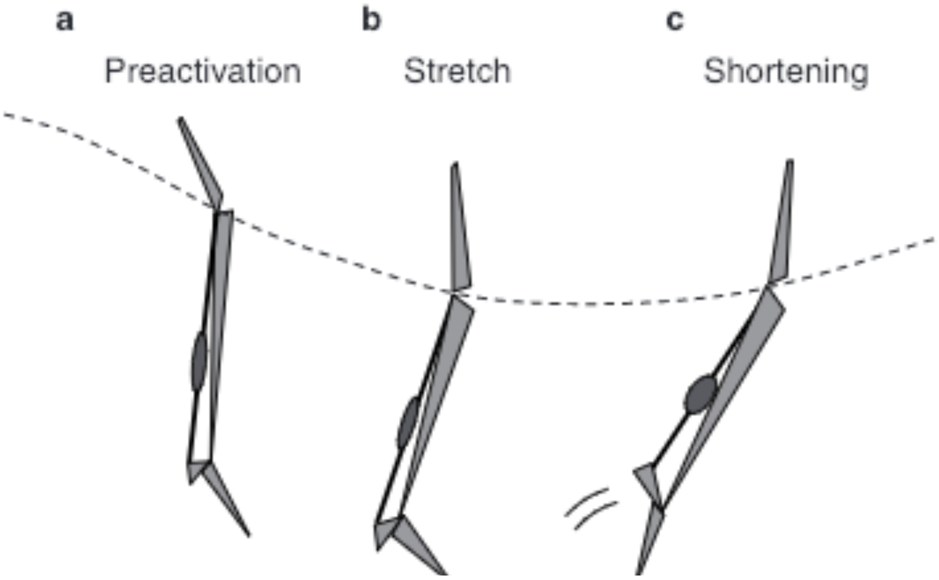

Figure 1. The stretch-shortening cycle (SSC). In human walking, jumping and running, considerable impact loads occur when contact takes place with the ground. This requires pre-activation from the lower-limb extensor muscles before the ground contact to make them ready to resist the impact (a) and the active braking phase. The stretch phase (b) is followed by a shortening (concentric) action (c) (Pierrynowski, 2007).

2.4 Neural factors

The ability to generate maximal power during a movement is regulated by the morphology and mechanics of the muscle, along with the ability of the nervous system to appropriately activate the muscles involved (Cormie et al., 2011a). A voluntary contraction is controlled by the nervous system primarily through the rate of motor unit recruitment and firing frequency (Enoka & Duchateau, 2017), synchronization and inter-muscular coordination (Hug & Tucker, 2017). Following subchapters will elucidate some of the neural factors that are considered important for developing muscular power.

2.4.1 Motor unit recruitment

The number and type of motor units recruited is related to the muscles' ability to generate force (Pucci, Griffin & Carafelli, 2005). Progressive motor unit recruitment related to motor neuron size is a main neuromuscular factor responsible for roughly linear gradations in force in a variety of human muscles (Harwood et al., 2013). Relatively small α-motoneurons that innervate type I fibers are initially activated at low force levels while progressively larger α-motoneurons that activate type IIa and IIx fibers are typically activated after the slow-twitch motor units at higher thresholds of force (Mantilla, Seven & Sieck, 2014). The maximum force-capability of a motor unit has been estimated to vary by up to 50 times (Enoka, 1995). Hence, the force capable of being generated during a movement is highly affected by the motor units recruited (Cormie et al., 2011a). Contractions required for maximal power production requires recruitment of high-threshold motor units, as they innervate a relatively large number of force-producing muscle fibers (Enoka, 2001).

Therefore, recruitment of high-threshold motor units is thought to be highly beneficial for the development of maximal power production. There are three prevailing theories on adaptation in motor unit recruitment as a response to training. It is hypothesized that increased motor unit recruitment, preferentially recruitment of high-threshold motor units and/or lowering the thresholds of the motor unit recruitment, would lead to increased tension development by the muscle and consequently improved power output. Moreover, observations of increased «electromyography» (EMG) amplitude following training suggests that an increase in the level of motor unit recruitment may develop a possible adaption with enhanced muscular power (De Luca & Hostage, 2010). Moreover, voluntary activation during maximal dynamic contractions were significantly lower (88.0 ± 1.9%, $p < 0.05$) than voluntary activation during maximal isometric contraction (95.2 ± 1.2%, $p < 0.01$) (Babault, Pousson, Ballay & Von Hoecke, 2001). Therefore, training is likely to result in improved voluntary activation during dynamic movements and especially in more complex, multi-joint sport-specific movements (e.g., CMJ). If future research were to demonstrate this, increased motor unit recruitment (or firing frequency) may contribute to training-induced improvements in maximal muscular power (Cormie et al., 2011a).

2.4.2 Firing frequency

The firing frequency of a motor unit represents the rate of neural impulses transmitted from the α-motoneuron to the muscle fibers. Moreover. firing frequency may impact the muscle fibers' ability to generate force in two ways: (a) by increasing the firing frequency it enhances the magnitude of the force generated during a contraction, and (b) impact the RFD of muscle contraction (Cormie et al., 2010). It has been reported that during ballistic movements motor units begin to fire at very high frequencies followed by a rapid decline (Crago, Makowski &

Cole, 2014). The high initial firing frequency, which is associated with an increase in the number of doublet discharges, results in increased RFD, even if only maintained for a very short period of time (Pedersen, Nielsen & Overgaard, 2013). Therefore, motor unit firing frequency plays an important role in the development of maximal muscular power by influencing the force and RFD of muscle contraction (Cormie et al., 2011a). Enhancement of maximum motor unit firing frequency in response to training has been proposed as a probable mechanism for inherent improvements in neuromuscular performance (Duchateau, Semmler & Enoka, 2006). A comparative study reported that trained individuals displayed greater maximum motor unit firing frequency during an MVC compared to untrained controls (Herda, Siedlik, Trevino, Cooper & Weir, 2015). Thus, indicating that the maximal firing frequency may increase in response to training.

2.4.3 Motor unit synchronization

Motor unit synchronization occurs when two or more motor units are activated concurrently (Kamen & Knight, 2004). Although it is yet to be adequately demonstrated, synchronization has commonly been hypothesized to enhance force production and positively influence RFD (Semmler & Enoka, 2000). Further, synchronization is theorized to be an adaptation of the nervous system that assists with the coactivation of numerous different muscles to enhance RFD (Mellor & Hodges, 2005; Semmler, 2002). The way synchronization may influence force or RFD is not clear (Cormie et al., 2011a). However, synchronization may be one of the strategies for inter-muscular coordination, and therefore could impact force and/or RFD during complex, multi-joint movements (e.g., CMJ) in contrast to isolated, single-joint movements where synchronization appears to have no significant impact (e.g., leg extension) (Cormie et al., 2011a).

2.4.4 Inter-muscular coordination

Inter-muscular coordination of synergistic and antagonistic muscles can be regarded as the basis for explaining the generation of voluntary and targeted-oriented movement (Giroux, Rabita, Chollet & Guilhem, 2014). Biomechanics and muscular features contributing to human movement patterns are thereby combined to control inter-muscular coordination and preferentially recruit responsible muscles (Giroux et al., 2014). Through precise timing and level of activation and relaxation of the agonists, synergists and antagonists, the kinetic chain will be optimized. This would result in a maximized impulse on the ground, that leads to better velocity performance in the takeoff-phase of the jump (Cormie et al., 2011a).

2.5 Force-velocity relationship

F-v profiling is in its essence a simple and inexpensive way to access an athlete's force and velocity production capabilities during ballistic tasks (e.g., vertical jumps and horizontal sprints). Ballistic performances are determined by both the maximal lower limb power output (P_{max}) and their individual F-v mechanical profile (Sfv), especially the FV_{imb} — the difference between the athlete's actual and optimal F-v profile (Sfv_{opt}) (Jiménez-Reyes et al., 2017). As shown theoretically (Samozino et al., 2012; Samozino, Morin, Hintzy & Belli, 2008) and proven experimentally (Samozino et al., 2014), there is, for any given individual, an Sfv_{opt} that maximizes the ballistic performance and represents the optimal balance between force and velocity qualities (Samozino et al., 2012, 2014). The relative difference between actual and optimal profile for a given individual represents the unfavorable balance between force and velocity qualities (i.e., FV_{imb} in %), which makes the individual determination of force or velocity deficit (Jiménez-Reyes et al., 2017).

The individuals' Sfv and P_{max} can be obtained from a series of loaded vertical jumps (Giroux et al., 2014; Jiménez-Reyes et al., 2014, 2017, 2018; Samozino et al., 2008, 2014;), while the Sfv_{opt} can be computed using previously proposed equations based on a biomechanical model (Samozino et al., 2012, 2014). Quantifying F-v mechanical profile and FV_{imb} on an individual basis could, therefore, help enhance the effectiveness of the training method by tailoring it to the needs of each individual athlete. In theory, this would contribute to improved ballistic performance through an effective adjustment in the individuals' actual Sfv toward the Sfv_{opt}, and/or an increase in P_{max} (Samozino et al., 2014).

Through F-v profiling, a coach can identify whether an athlete is force- or velocity-deficient during any given movement (e.g., vertical jump or horizontal sprints), independent of their power capability. Targeted resistance training can then be implemented to reduce the deficiency of the athlete's force or velocity, and in return improve their performance on that given task (e.g., vertical jump or horizontal sprint). As a result, F-v profiling allows the strength and conditioning coach to tailor their athletes' programs more specifically by using detailed, objective information (Dobbs, 2017). The ability to produce high levels of muscular power is considered a vital an essential component during many athletic and sporting activities (Cronin & Sleivert, 2005; Suchomel, Nimphius & Stone, 2016). Given that power is the product of force multiplied by velocity (Power = Force x Velocity), it is conceived that these two components underpin the ability to be influential.

The *Sfv* represents a characteristic property of muscle that dictates its power production capacities (Cormie et al., 2011a). Hill and colleagues developed a characteristic hyperbola back in 1938 that describes the inverse relationship between the force and velocity during concentric muscle contraction *(Figure 2)*. As the concentric muscle action velocity is increased, less force is capable of being generated during that contraction (Fenwick, 2017). This phenomenon is true for a given muscle or muscle group activated at a constant level, due to actin-myosin cross-bridge cycling (Cormie et al., 2011a; Fenwick, 2017). Specifically, due to the amount of time it takes for the cross-bridges to attach and detach, the total number of attached cross-bridges decreases with increasing velocity of muscle shortening (Cormie et al., 2011a; Fenwick, 2017). Since the amount of force generated by a muscle is dependent upon the number of attached cross-bridges, force-production decreases as the velocity of the contraction increases. This leads to muscular power being maximized at a combination of submaximal force and velocity values (Fenwick, 2017).

Furthermore, P_{max} is determined by the mechanical outputs of the *Sfv*: maximal isometric force (F_{max}), maximal velocity of shortening (V_{max}) and the degree of curvature that is the slope. Improvements in P_{max} of a muscle can be achieved through either increasing F_{max} or V_{max} and/or decreasing the degree of curvature (Cormie et al., 2011a). Having that in mind, while two athletes may display similar power outputs, their force- and velocity capabilities might be remarkably different *(Figure 3)*. In theory, athletes are biased towards either strength (force) or speed (velocity) (Jiménez-Reyes et al., 2017; Morin & Samozino, 2016).

Therefore, measuring force and velocity, independent from power output, is useful for identifying whether an athlete is force- or velocity-deficient. Based on the test results, the given data provides information on what type of training the athlete should train to improve the *Sfv*.

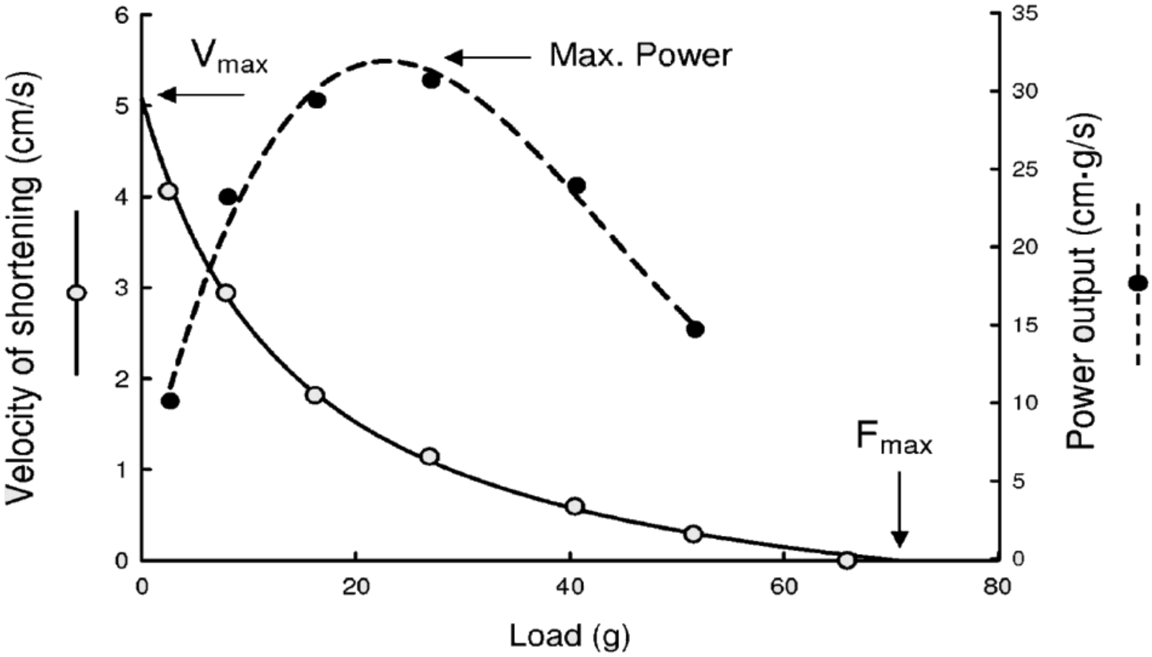

Figure 2. Force-velocity relationship. Velocity (solid line and open circles) and power (dashed line and closed circles) as functions of a load in an isotonic contraction. The figure is modified by Seow (2019) from Hill et al. (1938) with permission from Proceedings of the Royal Society B: Biological Sciences (Seow, 2019).

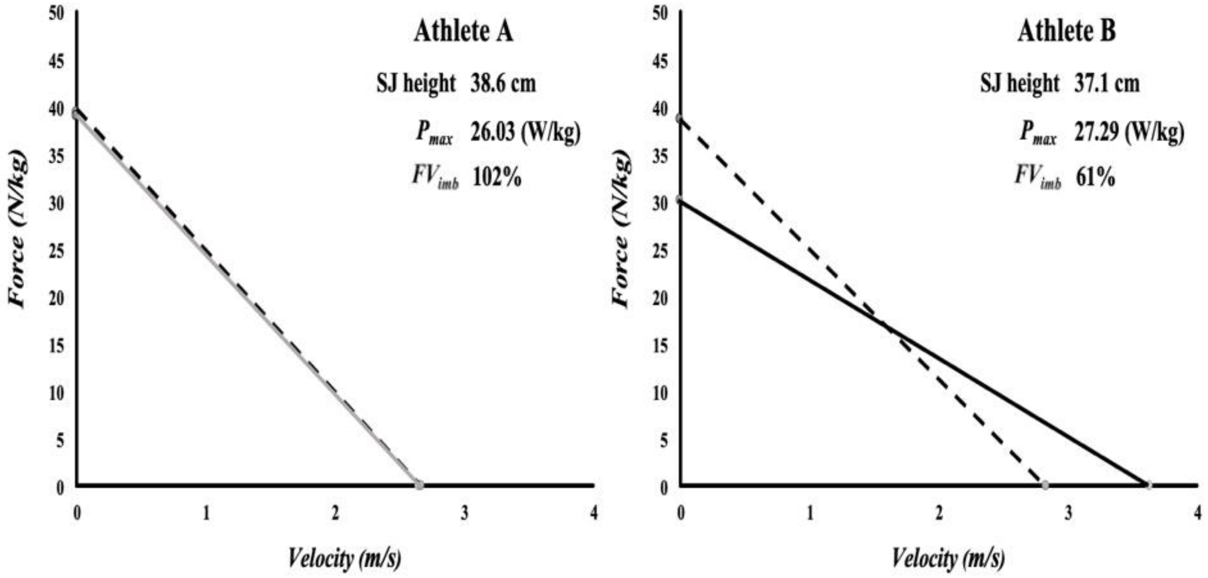

Figure 3. Vertical F-v profiles of two subjects in the present study obtained from maximal squat jumps against additional loads of 0.1, 20, 40, 60 and 80 kg. Note that Athlete A’s profile is almost optimal, and therefore the actual and optimal relationships are confounded in the left panel (gray line and black dashed line).

2.6 The science of handball and ice hockey

Handball players' performance is determined by many different factors, such as technical, tactical, psychosocial, and physical characteristics (Michalsik, Madsen & Aagaard, 2014). To fully exploit the technical and tactical qualities, there is a need for superior physical conditioning. Time-motion analysis shows that handball players spend a short period of time in running velocities defined as sprinting (Sibila, Vuleta & Pori, 2004). This may be due to the small active playing area in handball, which does not allow players to achieve maximum speed (Wagner, Finkenzeller, Würth, & von Duvillard, 2014). Despite this, there seems to be no doubt that handball requires high-intensity actions and sprinting efforts (Sibilia et al., 2004; Wagner et al., 2013). Consequently, the acceleration phase of a sprint is likely to have greater importance than maximal speed for performance in handball (Sibilia et al., 2004).

Knowledge of the working demands in sports is essential for many reasons. First, understanding the physical demands of a sport is a precondition for the planning and execution of optimal training (Luteberget & Spencer, 2017). Second, it is relevant to examine differences in physical demands imposed by various playing positions. In case of such differences, physical training should be organized in a more individualized manner rather than providing a uniform type of training for all players regardless of the playing position (Karcher & Buchheit, 2014). That is, indeed, where F-v profiling can be of high relevance.

Ice hockey is a team sport characterized by high-intensity intermittent skating and physical contact that is highly dependent on both aerobic and anaerobic energy systems (Flik, Lyman & Marx, 2005; Roczniok et al., 2016). Prominent features of this sport include three 20-minute periods with a 15-minute rest period in between and six men on the ice per team (including the goaltender). On-ice player shifts typically range from 30–85 seconds, seldom exceeding 90 seconds (Quinney et al. 2008), with breaks in play to accommodate penalties and injuries. At highly-competitive levels, hockey players typically possess high levels of muscular strength, lean body mass, speed, and endurance to facilitate maximal performance (Flik et al., 2005). Due to the sports' physical demands, it is believed individualized training can be of great value for hockey players' performance.

3.0 Methods

3.1 Design

The present study was a randomized control trial (RCT), where the subjects were randomized to one of three groups (Force-, Velocity- or Balanced group) *(Table 1)* to improve force-velocity mechanical outputs (F_0, V_0 & P_{max}) and vertical jump height. Our inclusion criteria were; (a) 16–35 years of age, (b) national level athletes, (c) regularly participates in strength training, (d) no significant injuries, diseases or medical use, and (e) non-smoker *(Appendix I)*.

In the present study, the subjects were divided with stratified randomization into one of three groups (Force-, Velocity- or Balanced group) and then assigned a group-specific training program *(Appendix II–IV)* of 10-weeks with focus on training their group characteristic to optimize their force-velocity mechanical outputs and vertical jump height. The subjects were ranged based on FV_{imb} from squat jump, and then divided into sections of three. To divide FV_{imb} equally, each subject of the sections was randomized into one of the three groups.

Table 1. *Training intervention groupings.*

Force	**Velocity**	**Balanced**
Subjects' focus is on improving their force characteristics	Subjects' focus is on improving their velocity characteristics	Subjects' focus is improving both characteristics, force and velocity

3.2 Study sample

Thirty-five (n=35) elite male athletes gave their written informed consent to participate in the present study, which was approved by the local ethical committee (FEK) of the University of Agder (UiA) in agreement with the Declaration of Helsinki *(Appendix VIII)*. All subjects were national level handball or ice hockey players. All athletes were familiar with strength training.

Table 2. *Descriptive data of participants.*

Group	N	Age (years)	Height (cm)	Weight (kg)	Workouts (n)
All groups	30	20.0 ± 4.8	180.0 ± 9.4	78.2 ± 15.8	13.4 ± 2.9
Force	8	17.9 ± 1.7	179.4 ± 8.1	74.8 ± 11.6	13.3 ± 3.9
Velocity	11	21.3 ± 5.9	186.5 ± 8.8	82.3 ± 21.3	12.7 ± 2.9
Balanced	11	20.8 ± 5.0	184.7 ± 10.7	76.9 ± 13.8	14.2 ± 1.9

Workouts, number of workouts during the training intervention. No significant changes between groups. All values are presented as mean ± SD.

3.3 Testing procedures

The subjects arrived fasted at the local facilities for body composition analyses with Dual-energy X-ray absorptiometry (DXA). Ultrasonographic measurements of muscle thickness, pennation angle and fascicle length were conducted by a trained researcher. Further, the subjects had a brief 10-minutes warm-up, consisting of jogging with different knee-raisings, before they were tested in vertical jumps (SJ & CMJ). After the jump-tests, the subjects had a few test-runs before being tested in 30m horizontal sprints. After initial sprints, they were tested in one repetition maximum (1RM) back-squats, Keiser leg-press and finished off with leg extensions.

The subjects underwent an anthropometric assessment before the mean mechanical outputs were calculated using Samozino's method (Samozino et al., 2008). Using this method, it is possible to establish mean force, velocity, and power, calculated by using three equations considering only simple input values: body mass, jump height and push-off distance. The latter corresponds to the extension range of lower limbs from the starting position to take-off (Samozino et al., 2008), and was previously measured for each subject by the difference between the extended lower limb length (iliac crest to toes with plantarflexed ankle) and the height in the individual standardized starting position (vertical distance of iliac crest to the ground).

To determine the individual F-v mechanical profile, each subject performed maximal vertical squat jumps without loads and against five additional loads ranging from 0.1 to 80 kg (0.1, 20, 40, 60, 80 kg, respectively). The F-v profile was determined using the best trials of each loading condition and least squares linear regressions. F-v curves were extrapolated to obtain F_0 (then normalized to body mass) and V_0, which respectively correspond to the intercepts of the F-v curve with the force and velocity axis. The F-v profile, that is the slope of the force-velocity linear relationship, was then computed from F_0 and V_0 using the method of Samozino et al. (2012). Values of P_{max} (normalized to body mass) were determined as: $P_{max} = F_0 \text{ x } V_0 / 4$ (Samozino et al., 2012; 2014). From P_{max} and h_{po} values, there is an individual theoretical optimal F-v profile (normalized to body mass, in N.s.kg^{-1}.m^{-1}) maximizing vertical jumping performance, that was computed for each subject using equations proposed by Samozino et al. (2012). The force-velocity imbalance (FV_{imb} in %), was then individually computed as recently proposed by Samozino et al. (2014):

$$Fv_{imb} = 100. \left|1 - \frac{S_{Fv}}{S_{Fv}\ opt}\right|$$

An FV_{imb} value around 0% indicates an F-v profile equal to 100% of the optimal profile (perfect balance between force and velocity qualities), where an F-v profile value higher or lower than the optimal indicates profile too orientated toward force or velocity capabilities, respectively.

3.4 Training intervention

After initial testing of their individual F-v properties, participants were randomized by stratified randomization into one of three groups: (a) Force group (n = 8; body mass, 74.8 ± 11.6 kg; stature, 180.0 ± 9.4 cm), (b) Velocity group (n = 11; body mass, 82.3 ± 21.3 kg; stature, 186.5 ± 8.8 cm), and (c) Balanced group (n = 11; body mass, 76.9 ± 13.8 kg; stature, 184.7 ± 10.7 cm) *(Table 2)*. All training programs involved two sessions per week, separated by at least 48 hours of recovery. Registration of completed workouts was carried out during the intervention. Subjects refrained from any additional lower body resistance training outside the experimental training in the present study. Competitive activities and sport-specific training were maintained throughout the intervention. During the 10-weeks of training, the Force group performed mainly force-orientated (very high loads) training *(Appendix II)*, while the Velocity group performed velocity-orientated (ballistic, very high velocity of limbs extension) training *(Appendix III)*. The Balanced group followed a training program covering the entire F-v spectrum in equal proportions: heavy loads, power, and ballistic training *(Appendix IV)*.

The training intervention for all groups was organized following recommendations from the literature: more than three sets/session (Rhea et al., 2002) and a frequency of 2–3 sessions/week for strength (Peterson et al., 2004; Rhea et al., 2003), including plyometrics (Markovic, 2007). Due to the subjects being in season competing, their coach only permitted two strength-sessions per week. The training dose required to develop strength is generally described as high frequency (3–5 weekly sessions per muscle group), moderate volume (3–6 sets x 2–6 repetitions x load mass), and high intensity (85–100% 1RM) and a non-ballistic nature of strength training exercises; while power mainly differs in the intensity (20–70% 1RM) and high movement velocity (i.e., explosive-ballistic) (Fleck & Kraemer, 2013; Raastad, Refsnes, Rønnestad & Wisnes, 2010). For example, «strength»-exercises used heavy loads moved at a low velocity such as >80% of 1RM back-squat to target the force components, whereas «speed»-exercises used the force of body mass moved at very high velocity or reduced the internal resistance with elastic bands (i.e., assisted jumps) to further increase the velocity aspects of the F-v curve. The Balanced group followed a training program covering the entire F-v spectrum in equal proportions: heavy loads, power, and ballistic training.

3.5 Measurements

Vertical jump tests (SJ & CMJ). To determine the individual F-v mechanical profile, each subject performed maximal vertical squat jumps without loads and against five additional loads ranging from 0.1 to 80 kg (0.1, 20, 40, 60, 80 kg, respectively). The tests were performed on a modified squat rack, measured by an infrared optical contact grid (Musclelab, Ergotest innovation AS, Langesund, Norway) with a linear position transducer (Musclelab Force sensor, Ergotest innovation AS, Langesund, Norway) attached to the bar, to quantify jump height and force-velocity mechanical outputs, respectively. Moreover, a force plate (Musclelab, Force plate 2000 kg, ML6FPL01, Ergotest innovation AS, Langesund, Norway) was used for visual feedback of the jumps. In addition, countermovement was controlled carefully on a monitor showing motion impulse facing the test leaders and subjects. Before each SJ condition, participants were instructed to stand straight and still on the center of the force plate, as well as to keep their hands on their hips during each condition. Furthermore, the subjects were instructed to maintain their starting position (90º knee angle) for about two seconds — and then apply force as fast as possible and jump for maximum height. If the requirements were not met, the trial was repeated. Two valid trials were performed with each load, with two minutes of recovery between trials, and 4–5 minutes between loads condition.

Leg press. The leg press was performed using an Air300 leg press machine (Keiser, Fre1lsno, CA, USA) that allows the muscles to remain active and engaged throughout the entire range of motion and velocities, with reduced shock loading to the muscles, connective tissues and joints. The Keiser leg press is connected to a computer programmed with Musclelab software that can make individual F-v profiles from the obtained data. The subjects performed leg presses (6-step 1RM & 10-step test at baseline 1 and 2, respectively) against force cells with maximal velocity on each load, with a full range of motion (0–90°). The loads increased until 1RM was obtained at baseline 1. Based on this data, force-velocity mechanical outputs for each participant was acquired.

Leg extension. The leg extension was performed in a versatile device for the knee extension (G- and F200 Knee Extension, David health solutions LTD, Helsinki, Finland). To measure force and velocity, an encoder (Musclelab, Encoder, SKU 1320, Ergotest innovation AS, Langesund, Norway) was attached to the weights of the machine. The subjects had two bilateral lifts at each load, ranging from 40 to 80 kg (40, 50, 60, 70, 80 kg, respectively). The obtained data provided F-v mechanical outputs on each leg, separately. The recovery time was set to 10–20 seconds between each attempt, and 2–minutes between each load.

1RM back-squat. One repetition maximum (1RM) was assessed with the back-squat exercise. Prior to the test, participants completed a brief warm-up consisting of submaximal squats with 2–4 repetitions at 50% and 60% of 1RM, and one repetition at 80%, 90% and 95% of 1RM (self-estimated at the first time-point). Squat depth was standardized to parallel (thighs parallel to the ground) for each participant individually, using a box and additional weight plates to obtain a parallel between the thighs and ground for all subjects. Participants had 2–3 trials at 1RM with an inter-repetition rest of three minutes. After successful 1RM attempts, the loads increased with a minimum of 2.5 kg until no further weights could be lifted. The largest load successfully lifted to the standardized depth was recorded as the participant's 1RM.

30m sprint. The 30-meter sprint test was measured horizontally by infrared optical contact grid and wireless timing gates placed with intervals of 5-meter (Musclelab, Ergotest innovation AS, Langesund, Norway). Further, a contact grid was used as a starting position. The sprint trial started as soon as the subjects' foot left the sensors. Participants performed 2–3 test-runs before data was obtained. Each participant completed 2–4 runs and the data obtained provided F-v parameters for each participant. Recovery time was five minutes between each run, as explosive movements require long restitution to achieve maximum power.

Ultrasonography & body composition. The ultrasound (LogicScan 128 CEXT-1Z kit, Telemed, Vilnius, Lithuania) was used to measure the subjects' fascicle length (FL), muscle thickness (MT), and pennation angle (PA) of *m. vastus lateralis*. A standardized length was measured between lateral epicondyle of the femur and greater trochanter, and the placement of the transducer was standardized to 40% of this length. FIJI (version 1.52k) was used to process the ultrasound images, where the fascicle length and pennation angle variables were manually analyzed, and the thickness variable images were processed using a script, whereby the researcher drew lines on the superficial and deep aponeurosis. Approximately 230 measurements were drawn automatically between the lines of the superficial and deep aponeurosis, which then computes reliable mean variables. The ultrasound test-retest of 14 subjects in the present study showed overall good reliability from baseline 1–2 (MT, r=0.98, CV=3.5%; PA, r=0.95, CV=6.3%; FL, r=0.95, CV=8.2%) and post 1–2 (MT, r=0.96, CV=3.3%; PA, r=0.996, CV=1.6%; FL, r=0.99, CV=3.8%). Body composition was measured by Dual-energy X-ray absorptiometry (DXA) (General Electric Company, Madison, USA). Participants were instructed to not engage in strenuous physical activity for the least twelve hours prior to testing, nor drink or eat the last four hours before the measurement *(Appendix I)*.

3.6 Statistical analysis and power

One-way ANCOVA was used to assess statistical differences between groups, and one-way ANOVA and dependent samples T-test for individual group changes in pre- to post-tests. For all statistical analyses, a P value (α) of ≤ 0.05 was accepted as the level of significance, and a P value of ≤ 0.10 for plausible changes (i.e., tendencies). Pearson's correlation coefficient was used to analyze correlations. All statistical analyses were performed using SPSS version 24 (IBM, Chicago, IL, USA). Figures were made with GraphPad (GraphPad Prism 7.03, GraphPad Software, Fay Avenue, CA, USA). Tables were made with Microsoft Word version 15.32 (MS, Redmond, WA, USA). Descriptive data are presented as mean ± standard deviation (SD), whereas between and individual group differences are presented as mean with 95%

confidence intervals (CI), if not otherwise stated. Data were considered as normally distributed after assessing means, medians, skewness, Kolmogorov-Smirnov, Shapiro-Wilk and visual confirmation of histograms. Hence, parametric tests were used in analyses.

3.7 Ethical considerations

The present study is performed in accordance with the Declaration of Helsinki. Approval was requested from the Faculty Ethics Committee (FEK), University of Agder (UiA), Faculty of Health and Sport Sciences, Department of Public Health, Sport and Nutrition, before initiation. Written consent was obtained from the participants and their sports club before entering the study *(Appendix I)*. The subjects' information was sent to the Norwegian Centre for Research Data (NSD) for approval before initiation *(Appendix IX)*. Participation is voluntary, and they can withdraw at any time without any given reason. The collected data is anonymous, and once the information is no longer of use — the data is deleted.

4.0 Methodological discussion

Experimental research attempts to establish cause-and-effect relationships, in which an independent variable is manipulated to judge its effect on a dependent variable (Thomas, Nelson & Silverman, 2018). Cause-and-effect relationships can only be established by a well-designed experiment, and it is crucial that no other reasonable explanation exists for the changes in the dependent variable except the manipulation of the independent variable (Thomas, Nelson & Silverman, 2018). Thus, an experimental design seemed to be the most appropriate method to investigate the *aim* of the present study.

The present study was conducted as a randomized controlled trial (RCT) and was done within subjects longitudinally. RCT-studies are regarded as the «gold standard» for investigation of a hypothesis concerning causal relationships (Polit & Beck, 2013). Although RCT is considered the gold standard for examining causal relationships, there are limitations associated with this type of experiment as well — for instance, the Hawthorne effect (Polit & Beck, 2013). The Hawthorne effect is the term for the phenomenon of affecting behavior in response to the awareness of being observed. The following subchapters highlight different methodological factors that had an impact on the present study.

4.1 Study sample

The study sample consisted of an elite male handball team and two ice hockey teams (U18 & U20). Altogether thirty-five (n=35) athletes belonging to two different sports, were included in the present study. Four (n=4) were excluded due to injuries, and one (n=1) were excluded due to illness not related to the study, leaving thirty (n=30) participants to complete the intervention *(Table 2)*. The low number of total participants divided into three groups affects the statistical power negatively and increases the risk of type II errors (false-negative). For the ultrasonography imaging, out of the nineteen (n=19) subjects, five (n=5) were excluded due to injuries and/or personal conflicts not related to the study, leaving fourteen (n=14) subjects to be presented in results.

4.2 Training intervention

According to the protocol, the aim of workouts was set to two workouts per week. However, the mean number of workouts for all groups were 13.4 ± 2.9 during the 10-weeks of the intervention (i.e., 1.3 workouts per week) *(Table 2)*. Because the subjects maintained sport specific training and competitive activities throughout the intervention, the recovery time between each session was probably not sufficient. Moreover, due to the large amount of exercise beyond the intervention, great variation in the amount of exercise between individuals occurred. This led to a greater variation between groups, which probably affected the results.

4.3 Measurements

In general, testing in sport science is necessary to identify the effects of an exercise intervention. There are some fundamental factors one should have in mind when testing: (a) that the test is valid and reliable, (b) control of the work conditions, (c) accurate measures from equipment, and (d) same standardized protocol before, during and after the test (Thomas, Nelson & Silverman, 2005). To increase the validity and reliability of the measurements, the tests were conducted at approximately the same time of day both pre- and post intervention of the participants. Moreover, to maintain a high degree of reproducibility, standardized protocols were followed and the same test leader supervised the same tests each time.

Vertical jump tests (SJ & CMJ). Jump height and power measurements were reliable from baseline to post**;** vertical jump height in SJ (CV% = 5.5, 3.4; ICC = 0.78, 0.88) and CMJ (CV% = 4.7, 3.8; ICC = 0.82, 0.86), *Pmax* for SJ (CV%, 13.0, 5.3; ICC = 0.46, 0.72) and CMJ (CV%, 4.5, 3.2; ICC = 0.58, 0.81). Due to not including familiarization sessions prior to baseline, may explain the somewhat high coefficient of variation (CV) in SJ, as the subjects were not used to maintain the starting position before jumping. Countermovement in SJ was carefully controlled through a monitor showing motion pulse, as countermovement should not occur in this test. If the requirements were not met, the trial was repeated. Recovery time was set to two minutes between each trial, and 4–5 minutes between load conditions.

30m sprint. Environmental factors that can affect sprint results, such as wind and temperature, was not disturbing factors as the test was performed inside. To further improve the reliability, a contact grid was used at the starting position to provide a more accurate sprint start.

1RM back-squat. 1RM testing is proven to be a valid and reliable method to measure maximal strength in adults when using a sufficient, precise protocol (Levinger et al., 2009). Even with a rest of 2–3 minutes between each 1RM attempt, a degree of fatigue in the working muscles can occur, which can potentially lead to confounding results. However, as an attempt to exclude confounding factors (e.g., fatigue/recovery status), the greatest successful 1RM attempt from both baseline- and post-tests was included.

Keiser leg press. Unfortunately, the ice hockey players had a different depth than the handball players; trochanter major was parallel to the lateral epicondyle of femur versus a knee angle of 90°, respectively. Based on laws of biomechanics (e.g., moment arm and torque), the ability to produce power would be greater in 90° angle compared to a longer movement pattern. The measurement methods provide diversity in the force-velocity mechanical outputs, making harder to detect statistical significances.

Leg extension. Before testing procedures, individual standardized machine settings were acquired to obtain reliable data. As the test-protocol included loads ranging from 40 to 80 kg (40, 50, 60, 70, 80 kg, respectively), and was last in the testing procedure, some subjects did not manage to successfully lift the heaviest loads. The lack of data may have impacted the statistical power negatively.

DXA. When evaluating the validity of body composition measurements of DXA, one would refer to the differentiation between fat-mass and lean-mass estimated by DXA and the true fat-mass and lean mass, which can be measured in cadavers. However, to the authors' knowledge, such cadaver studies have only been done in animals (Clarys et al., 2010). The studies that have assessed the validity and reliability of body composition measurements by DXA in humans are evaluated against the 4-compartment model, which is regarded as the gold standard of body composition measurements (Toombs, Ducher, Shepherd & De Souza, 2012). The different compartments are measured using hydrodensitometry or air displacement plethysmography to determine the fat mass and fat-free mass, isotope dilution to determine total body water, and DXA to determine measure bone mineral (Heymsfield et al., 1990; Withers, Laforgia & Heymsfield, 1999). However, this model is very time consuming, and the equipment was not available in the present study. Although the primary use of DXA is the measurement of bone mineral density to diagnose osteoporosis and other bone diseases (Toombs, Ducher, Sheperd & De Souza, 2012), several studies have proven that DXA can provide valid and reliable assessments of body composition (Brodowicz, Mansfield, McClung & Althoff, 1994; Chauhan, Koo, Hammami & Hockman, 2003; Prior et al., 1997), i.e. the measurement of bodyweight, fat-free and lean mass present in this study.

Ultrasonography. Brightness-mode ultrasound imaging may serve as a simple, portable, inexpensive and accurate measurement of human muscles in vivo – even though magnetic resonance imaging (MRI) is considered the gold standard (English, Fisher & Thoirs, 2012). Worth mentioning, several investigators have suggested ultrasonography to be a worthy alternative to MRI, being both valid and reliable (English et al., 2012; Reeves, Maganaris & Narici, 2004; Scott et al., 2012; Thomaes et al., 2012).

However, some considerations should be mentioned with ultrasound imaging. Too much pressure on the skin with the transducer could lead to a compressed muscle, leading to low accuracy when processing images (Reeves et al., 2004). Further, when measurements are done over time, the relocation of the transducer should be placed on the exact same spot to ensure reliable measurements (English et al., 2012). Unfortunately, to the authors' knowledge, there is currently no automatic technique to process muscle images of fascicle length and pennation angle by ultrasound that can minimize errors of manual processing.

In the present study, a trained researcher conducted the measurements, excessive use of gel was used, and acetate paper relocated identical placement. Further, the subjects' legs were strapped to a standardized box (18 cm wide) to ensure that the joints were in a static position. Moreover, the lack of uniformity with muscle growth and acute swelling of the muscles with physical activity prior measurements could lead to errors (Reeves et al., 2004). To minimize confounding errors, participants were instructed not to conduct hard physical activity prior to testing, and further, the participants were tested approximately at the same time of day both baseline and post. Lastly, the test-retest of 14 subjects in the present study showed overall good reliability; baseline 1–2 (MT, r=0.98, CV=3.5%; PA, r=0.95, CV=6.3%; FL, r=0.95, CV=8.2%) and post 1–2 (MT, r=0.96, CV=3.3%; PA, r=0.996, CV=1.6%; FL, r=0.99, CV=3.8%).

Recovery. As the subjects were competing in season, several subjects appeared not fully recovered during the physical tests. In unfortunate cases, some players had played a full match the day prior to the tests, which resulted in sleep-deprivation and exhaustion. Commonly known within health and sports sciences, the recovery status is a crucial factor to performance (Heidari et al., 2018; Lee et al., 2017).

4.4 Statistical analysis

The data were assumed as normally distributed. One-way ANCOVA was assessed to detect differences between groups, as it eliminated the effect of the covariate (i.e., baseline-values) on the relationship between independent and depended variables. One-way ANOVA was assessed to detect differences within groups, as it can compare levels of a single factor based on a single continuous response variable. Due to the lack of *P*-values from one-way ANOVA, paired samples t-tests were assessed from changes within groups. Tendencies ($p \leq 0.10$) were included in the results to describe trends and nuances of the present data, which may further help to generate new hypotheses in future research.

Further, the data collection was acquired in two different cities, which resulted in a restriction of data collected from DXA and ultrasonography for the ice hockey team. Due to the short time limit when collecting data from the ice hockey team, leg extensions were excluded, and measurements from CMJ were only obtained at bodyweight, 20 and 80 kg. Hence, the statistical power appeared lower in these measurements.

4.5 Main strengths and limitations

The main strengths of the present study were: (a) the strong study design, (b) athletes' physical level, (c) the comprehensive test-protocol with four measurement time-points, and (d) the close control of adherence and follow-up in the workouts during the intervention. We further increased the strength of the present study by using the same equipment, test leaders and technicians during all data collection.

Given the subjects were in season competing and maintaining the normal training schedule, their somewhat poor recovery status during intervention and post-tests made it difficult to conduct this study. In addition, the present study had a relatively short duration intervention (10 weeks), a fairly low number of workouts (13.4 ± 2.9) and small sample size in within groups (n=8, n=11, n=11), which in turn could lead to type II errors (false-negative).

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PART 2

RESEARCH PAPER

A comparison of force-, velocity-, and balanced training approach on force-velocity mechanical outputs and vertical jump height

– of national level athletes during a competitive season

The following paper is written after the standards of the journal:

«Medicine & Science in Sports & Exercise»

https://journals.lww.com/acsm-msse/pages/default.aspx

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May 2019

A comparison of force-, velocity-, and balanced training approach on force-velocity mechanical outputs and vertical jump height

– of national level athletes during a competitive season

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ABSTRACT

INTRODUCTION. Optimizing muscular power output is considered crucial to performance across different sports, but the exact training approach to optimize muscular power is not clear. Therefore, the aim of the present study was to compare the effect of a force- vs. velocity-dominated vs. balanced power training approach on force-velocity mechanical outputs (F_0, V_0 & P_{max}) and vertical jump height.

METHODS. Thirty-five elite male athletes were divided with stratified randomization based on force-velocity profile slope into a force-, velocity-dominated or balanced power training group, and performed a 10-week training intervention. Thirty subjects (age = 20.0 ± 4.8) underwent pre- and post-tests with a test-protocol consisting of: body composition with DXA, muscle thickness and architecture with ultrasonography, force-velocity mechanical profiles during squat- and countermovement-jumps (SJ & CMJ), Keiser leg press and leg extensions, as well as one repetition maximum in back-squat and 30m sprint.

RESULTS. There were no group differences in force-velocity mechanical outputs (F_0, V_0 & P_{max}) in SJ, CMJ, Keiser leg press or leg extension. The Balanced group increased SJ-height by 6% (95% CI, 0.4, 11.5, p=0.036) and 9.8% (1.5, 18.2, p=0.023) more than Force group at 40 and 60 kg, respectively. The Velocity group increased SJ-height 7.8% (1.1, 14.4, p=0.023) more than Balanced group at 0.1 kg, and CMJ-height by 6% (-12.0, -0.1, p=0.048) more than the Force group at 20 kg.

CONLCUSION. A velocity-dominated or balanced training approach may be more beneficial to increase force-velocity mechanical outputs and vertical jump height for national level athletes during a competitive season, compared to a force-dominated power training approach.

KEYWORDS. Power training, force-velocity profile, muscular power, jump performance

INTRODUCTION

The ability to produce high levels of muscular power is considered an essential component during many athletic and sporting activities (7, 28). The evolution in physical demands of competition in sports such as handball or ice hockey, alongside advancements in strength and conditioning methodologies have led to increased relevance of high-intensity, ballistic actions. High levels of force, velocity and power are physical factors that determine the performance of ballistic movements such as jumps, changes of direction, or sprint (4, 7). Maximal power output (P_{max}) is a widely accepted muscular determinant for jump- and sprint performance, which is determined by both force and velocity production capabilities (23, 24). The performance is therefore mainly dependent on the ability of neuromuscular systems to (a) generate high levels of force, (b) ensure the effective application of this force onto the environment (i.e., supporting ground), and (c) produce this effective force at high contraction velocities (19).

Development of training programs aiming to improve maximal power production in dynamic movements is a topic of interest among scientists and coaches (6). An existing fundamental relationship between strength and power dictates that an individual cannot generate high levels of muscular power without first being relatively strong. Thus, enhancing and maintaining maximal strength is essential when considering the long-term development of power (6). Further, consideration of movement pattern, load and velocity specificity is crucial when designing power training programs. Programs containing ballistic, plyometric and/or weightlifting exercises can be used effectively as primary exercises towards maximal power enhancement (3, 4, 8, 10, 13, 18). The external loads in these exercises will partly depend on the specific requirements of each sport and the type of movement being trained (6).

Strength training prescription for power development is not only governed by intensity (% of one repetition maximum), but also the combination of several other factors, including: type of exercises used, volume (sets × repetitions), exercise sequence within a strength training session, repetition velocity, training frequency, and rest interval length between sets (6). Loads of 80–100% of one repetition maximum (1RM) is more effective to enhance the force component of the power equation (2, 20). Using heavy loads with the intention to move explosively may provoke neuromuscular adaptions that allow for improved rate of force development (RFD) (6). Loads of 0–60% of 1RM is sometimes recommended to enhance RFD (15). Both loads are recommended when resistance exercises are used for power training (2, 15, 20).

Neuromuscular power has been highlighted in studies as one of the primary variables related to ballistic performance (5, 11). Ballistic movements, such as jumping, may be defined as: "*the ability to accelerate body mass as much as possible in the shortest duration of time during a push-off phase*" (24). However, neuromuscular power is only a partial representation of the true maximal mechanical capabilities of the athletes (7). Although P_{max} generated by the lower limbs is a significant determinant for ballistic performance such as jump height (33), it is also influenced by an individual combination of the underlying force and velocity mechanical outputs (19, 21, 24).

Inclusion of force-velocity (F-v) profiling may provide a more accurate representation of the athlete's maximal capabilities (24), as it includes the whole F-v spectrum of theoretical maximum force and velocity (F_0 & V_0, respectively) capabilities (19). Improvements of muscular performance in the high-velocity area of the F-v relationship are typically brought about through the use of light loads in power training, while using heavy loads enhances muscular performance in the high-force area of the F-v relationship (6). A combination of loads in power training is theorized to target the entire F-v curve attempting to augment adaptions in power output. Thus, a combination of loads may allow for all-around improvements in the F-v relationship, resulting in superior increases in P_{max} and greater transfer to jumping performance than training with either light or heavy loads alone (6).

Literature regarding developing muscular power is extensive, but few studies have investigated the development of maximal power and jump performance in national level athletes during a competitive season. Therefore, the main aim of the present study was to compare a velocity- vs. force-dominated vs. balanced power training approach on F-v mechanical outputs (F_0, V_0 & P_{max}) and vertical jump height in national level. The main hypothesis was that a balanced approach would be most beneficial to increase F-v mechanical outputs and vertical jump height.

METHODS

Design. The present study was a randomized control trial (RCT), where the subjects were selected with stratified randomization for one of three groups (force-, velocity- or balanced group) to improve F-v mechanical outputs (F_0, V_0 & P_{max}) and vertical jump height. Subjects were randomized into Force-, Velocity- or Balanced group, and underwent a group-specific training program of 10-weeks with a focus on training their group characteristic to optimize their F-v mechanical outputs and vertical jump height. The subjects were ranged based on FV_{imb}

from squat jump, and then divided into sections of three. To divide FV_{imb} equally, each subject of the sections was randomized into one of the three groups.

Study sample. Thirty-five (n=35) elite male athletes (age, 20.1 ± 4.7 years; body mass, 79.4 ± 14.7 kg; stature, 184.6 ± 8.7 cm) gave their written informed consent to participate in the present study after standards by the Declaration of Helsinki, and was approved by the Faculty Ethical Committee and the Norwegian Centre for Research Data before initiation. All subjects were national level handball or ice hockey players with a strength-training background ranging from 1 to more than 3 years.

Testing procedures. The subjects arrived fasted at the local facilities for body composition analyses with Dual-energy X-ray absorptiometry (DXA). Ultrasound measurements of muscle thickness, pennation angle and fascicle length were conducted by a trained researcher. Further, the subjects had a brief 10-minutes warm-up, consisting of jogging with different knee-raisings, before they were tested in vertical jumps (SJ & CMJ). After the jump-tests, the subjects a few test-runs before being tested in 30m horizontal sprints. After initial sprints, they were tested in one repetition maximum (1RM) back-squats, Keiser leg-press and leg extensions.

Vertical jump (SJ & CMJ). The subjects underwent an anthropometric assessment before the mean mechanical outputs were calculated using Samzino's method (22). Using this method, mean force, velocity and power can be established with calculations from vertical jump height and squat jump (SJ) positions. Force, velocity and power were calculated using three equations from simple input values: body mass, jump height and push-off distance. The latter corresponds to the extension range of lower limbs from the starting position to take-off (22) and was previously measured for each subject by the difference between the extended lower limb length (iliac crest to toes with plantarflexed ankle) and the height in the individual standardized starting position (iliac crest to ground vertical distance).

To determine the individual F-v mechanical profile, each subject performed maximal vertical squat jumps without loads and against five additional loads ranging from 0.1 to 80 kg (0.1, 20, 40, 60, 80 kg, respectively). The tests were performed on a modified squat rack, measured by an infrared optical contact grid (Musclelab, Ergotest innovation AS, Langesund, Norway) with a linear position transducer (Musclelab Force sensor, Ergotest innovation AS, Langesund, Norway) attached to the bar, to quantify jump height and F-v mechanical outputs, respectively. Moreover, a force plate (Musclelab, Force plate 2000 kg, ML6FPL01, Ergotest innovation AS, Langesund, Norway) was used for visual feedback of the jumps. In addition, countermovement was controlled carefully on a monitor showing motion impulse facing the test leaders and subjects. Before each SJ condition, participants were instructed to stand straight and still on the center of the force plate, as well as to keep their hands on their hips during each condition. Furthermore, the subjects were instructed to maintain their starting position (90º knee angle) for about two seconds — and then apply force as fast as possible and jump for maximum height. If the requirements were not met, the trial was repeated. Two valid trials were performed with each load, with two minutes of recovery between trials, and 4–5 minutes between loads condition.

The F-v profile was determined using the best trials of each loading condition and least squares linear regressions. F-v curves were extrapolated to obtain F_0 (then normalized to body mass) and V_0, which respectively correspond to the intercepts of the F-v curve with the force and velocity axis. The F-v profile, that is the slope of the F-v linear relationship, was then computed from F_0 and V_0 using the method of Samozino et al. (2012). Values of P_{max} (normalized to body mass) were determined as: $P_{max} = F_0 \text{ x } V_0 / 4$ (26, 29). From P_{max} and h_{po} (the vertical distance covered by the contact mat during push-off corresponding to the extension range of lower limbs) values, there is an individual theoretical optimal F-v profile (normalized to body mass, in N.s.kg^{-1}.m^{-1}) maximizing vertical jumping performance, that was computed for each subject using equations proposed by Samozino et al. (2012). The F-v imbalance (FV_{imb} in %), was then individually computed as recently proposed by Samozino et al. (2014):

$$Fv_{imb} = 100. \left|1 - \frac{S_{Fv}}{S_{Fv}\ opt}\right|$$

An FV_{imb} value around 0% indicates an F-v profile equal to 100% of the optimal profile (perfect balance between force and velocity qualities), whereby an F-v profile value higher or lower than the optimal indicates profile too orientated toward force or velocity capabilities, respectively.

Keiser leg press. The leg press was performed using an Air300 leg press machine (Keiser, Fre11sno, CA, USA) that allows the muscles to remain active and engaged throughout the entire range of motion and velocities, with reduced shock loading to the muscles, connective tissues and joints. The Keiser leg press is connected to a computer programmed with Musclelab software that can make individual F-v profiles from the obtained data. The subjects performed leg presses (6-step 1RM & 10-step test at baseline 1 and 2, respectively) against force cells with maximal velocity on each load, with a full range of motion (0–90°). The loads increased until 1RM was obtained at baseline. Based on this data, F-v mechanical outputs for each participant was acquired.

Leg extension. The leg extension was performed in a versatile device for the knee extension (G- and F200 Knee Extension, David health solutions LTD, Helsinki, Finland). To measure force and velocity, an encoder (Musclelab, Encoder, SKU 1320, Ergotest innovation AS, Langesund, Norway) was attached to the weights of the machine. The subjects had two bilateral lifts at each load, ranging from 40 to 80 kg (40, 50, 60, 70, 80 kg, respectively). The obtained data provided F-v profile on each leg, separately. Recovery time was set to 10–20 seconds between each attempt, and 2–minutes between each load.

1RM back-squat. One repetition maximum (1RM) was assessed with the back-squat exercise. Prior to the test, participants completed a brief warm-up consisting of submaximal squats with 2–4 repetitions at 50% and 60% of 1RM, and one repetition at 80%, 90% and 95% of 1RM (self-estimated at the first time-point). Squat depth was standardized to parallel (thighs parallel to the ground) for each participant individually, using a box and additional weight plates to obtain a parallel between the thighs and ground for all subjects. Participants had 2–3 trials at 1RM with an inter-repetition rest of three minutes. After successful 1RM attempts, the loads increased with a minimum of 2.5 kg until no further weights could be lifted. The largest load successfully lifted to the standardized depth was recorded as the participant's 1RM.

30m sprint. The 30-meter sprint test was measured horizontally by infrared optical contact grid and wireless timing gates placed with intervals of 5-meter (Musclelab, Ergotest innovation AS, Langesund, Norway). Further, a contact grid was used as a starting position. The sprint trial started as soon as the subjects' foot left the sensors. Participants performed 2–3 test-runs before data was obtained. Each participant completed 2–4 runs and the data obtained provided F-v parameters for each participant. Recovery time was five minutes between each run, as explosive movements require long restitution to achieve maximum power.

Ultrasonography & body composition. Ultrasound (LogicScan 128 CEXT-1Z kit, Telemed, Vilnius, Lithuania) was used to measure the subjects' fascicle length (FL), muscle thickness (MT), and pennation angle (PA) of the *m. vastus lateralis*. FIJI (version 1.52k) was used to process the ultrasound images, where the fascicle length and pennation angle variables were manually analyzed, and the thickness variable images were processed using a script, whereby the researcher drew lines on the upper and lower aponeurosis. Approximately 230 measurements were drawn automatically between the lines of the upper and lower aponeurosis, which then computes reliable mean variables. The ultrasound test-retest of 14 subjects in the present study showed overall good reliability from baseline 1–2 (MT, r=0.98, CV=3.5%; PA, r=0.95, CV=6.3%; FL, r=0.95, CV=8.2%) and post 1–2 (MT, r=0.96, CV=3.3%; PA, r=0.996, CV=1.6%; FL, r=0.99, CV=3.8%). Body composition was measured by Dual-energy X-ray absorptiometry (DXA) (General Electric Company, Madison, USA). Participants were instructed to not engage in strenuous physical activity for the least twelve hours prior to testing, nor drink or eat the last four hours before the measurement.

Training intervention. After initial testing of their individual F-v properties, participants were randomized by stratified randomization into one of three groups: (a) Force group (*n*=8; body mass, 74.8 ± 11.6 kg; stature, 179.4 ± 8.1 cm), (b) Velocity group (*n*=11; body mass, 82.3 ± 21.3 kg; stature, 186.5 ± 8.8 cm), and (c) Balanced group (*n*=11; body mass, 76.9 ± 13.8 kg; stature, 184.7 ± 10.7 cm) *(Table 1)*. All training programs involved two sessions per week, separated by at least 48 hours of recovery. Subjects refrained from any additional lower body resistance training outside the experimental training in the present study. Competitive activities and sport-specific training were maintained throughout the intervention. The training programs proposed in the present study included maximal efforts and were mainly designed by setting the loads to vary the movement velocity and intensity, and in turn to target the different parts of the F-v curve. For example, «strength»-exercises used heavy loads moved at a low velocity such as >80% of 1RM back-squat to target the force components, whereas «speed»-exercises used the force of body mass moved at very high velocity or reduced the internal resistance with elastic bands (i.e., assisted jumps) to further increase the velocity aspects of the F-v curve. The Balanced group followed a training program covering the entire F-v spectrum in equal proportions: heavy loads, power, and ballistic training *(Supplementary 1–3)*.

Statistical analysis and power. One-way ANCOVA was used to assess statistical differences between groups, and one-way ANOVA and dependent samples T-tests for individual group changes in pre- to post-tests. For all statistical analyses, a *P* value (α) of ≤ 0.05 was accepted as the level of significance. Pearson's correlation coefficient was used to analyze correlations. All statistical analyses were performed using SPSS version 24 (IBM, Chicago, IL, USA). Figures were made with GraphPad (Prism 7.03, GraphPad Software, Fay Avenue, CA, USA).

Tables were made with Microsoft Word version 15.32 (MS, Redmond, WA, USA). Descriptive data are presented as mean ± standard deviation (SD), whereas between and individual group differences are presented as mean with 95% confidence intervals (CI), if not otherwise stated. Data were considered as normally distributed after assessing means, medians, skewness, Kolmogorov-Smirnov, Shapiro-Wilk and visual confirmation of histograms. Hence, parametric tests were used in analyses.

RESULTS

Subject characteristics. Five (n=5) participants dropped out due to injuries (n=4) and illness (n=1) not related to the study, leaving thirty (n=30) participants to complete the intervention *(Table 1)*. There was no significant difference in bodyweight between groups at baseline, nor the number of completed workouts after the intervention. Total bodyweight tended to increase in the Force group (1.6 kg, 95% CI [-0.5, 3.7], p=0.078), while it remained unchanged in the Balanced group (0.3 kg [-2.0, 2.0], p=0.967), and in the Velocity group (-2.0 kg [-4.6, 0.6], p=0.105).

Squat jump & CMJ. The Balanced group increased squat jump-height with 40 kg (6% [0.4, 11.5], p=0.036) and 60 kg (9.8% [1.5, 18.2], p=0.023) resistance more than the Force group. The Velocity group increased squat jump-height more than Balanced group with 0.1 kg (7.8% [1.1, 14.4], p=0.023) resistance, and CMJ-height more than the Force group with 20 kg (6% [0.1, 12.0], p=0.048). The Velocity group tended to increase squat jump-height more than force group at 0.1 kg (6.9% [-0.2, 14.1], p=0.057). Additionally, the Balanced group tended to increase CMJ-height more than Force group with 20 kg resistance (5% [-1.0, 10.9], p=0.098) *(Figure 2 & 4, Table 2)*.

Compared to baseline, the Balanced group increased squat jump-height with bodyweight (6.7% [0.5, 12.9], p=0.048), at 20 kg (6.5% [1.3, 11.6], p=0.017) and with 40 kg resistance (6.1% [1.8, 10.4], p=0.011). The Velocity group increased squat jump-height with 0.1 kg (8.8% [4.7, 13.0], p=0.001) and 20 kg resistance (3.2% [0.5, 6.0], p=0.023). In CMJ, Balanced-, Force and Velocity group increased jump-height with bodyweight by 7.6% (1.8, 13.4, p=0.025), 3.9% (0.9, 6.8, p=0.018) and 6.3% (2.5, 10.2, p=0.005), respectively. The Velocity group increased CMJ-height significantly with 0.1 kg (5.3% [1.8, 8.8], p=0.013) *(Figure 2 & 4, Table 3)*.

F-v parameters (F_0, V_0, P_{max}). No significant group changes were observed in F-v mechanical outputs. However, the Balanced group tended to increase squat jump-F_0 (5.3% [-1.1, 11.7], p=0.100) and CMJ-P_{max} (8% [-1.2, 17.3], p=0.085) more than Force group *(Table 2)*.

Compared to baseline, the Force group increased squat jump-V_0 (11.9% [0.3, 23.5], p=0.041). The Balanced group increased squat jump-V_0 (12.2% [1.0, 23.4], p=0.039) and squat jump-P_{max} (10.1% [3.4, 16.9], p=0.013), while the Velocity group decreased in squat jump-F_0 (-4.9% [-8.6, -1.2], p=0.020) and increased squat jump-V_0 (12% [4.3, 19.6], p=0.018). The only significant changes in CMJ were found in the Velocity group with a decrease in F_0 (-5.6% [-9.7, -1.6], p=0.012) and increases in V_0 (14.5% [5.0, 24.0], p=0.008) and P_{max} (7.3% [2.1, 12.5], p=0.018) *(Figure 1 & 3, Table 3).*

Keiser leg press, leg extensions, 30m sprint and 1RM back-squat. No significant group differences were observed, besides peak velocity in sprint where the Force group increased 4% more than Velocity group (0.3, 7.7, p=0.035) *(Figure 8, Table 4).*

Compared to baseline, the Velocity group increased V_0 in the Keiser leg press (3.7% [0.4, 7.1], p=0.033). The Balanced-, Force- and Velocity group increased P_{max} in leg extensions by 11.9% (4.5, 19.2, p=0.009), 11.6% (3.3, 19.8, p=0.016) and 7.4% (3.6, 11.3, p=0.029), respectively. The Balanced group increased 1RM back-squat (4% [0.9, 7.2], p=0.010) and the Velocity group decreased peak velocity in 30m sprint (2.9% [-5.8, -0.1], p=0.042). The Balanced group tended to increase V_0 in leg extensions (8.9% [-2.4, 20.2], p=0.070), while the Force group tended to increase F_0 in leg extensions (7.9% [-1.6, 17.4], p=0.067) *(Figure 5–8, Table 5).*

Ultrasonography and body composition. The Balanced group increased right leg FL by 10.2% (1.9, 18.5, p=0.021) more than Force group and 6.4% (-0.6, 13.5, p=0.034) more than Velocity group *(Figure 9, Table 6).*

Compared to baseline, the Balanced group increased right leg FL (5.1% [-0.2, 10.4], p=0.046). The Velocity group increased right leg muscle thickness (3.5% [1.1, 6.0], p=0.036). The Balanced group tended to increase fat-free mass (3.5% [-0.4, 7.3], p=0.071), as well as a decrease of body fat percentage (-0.9% [-1.8, 0.9], p=0.067). The Force group tended to increase fat-free mass (5.4% [-0.6, 11.5], p=0.063). The Balanced group increased fat-free mass in the right leg (4.8% [0.66, 8.89], p=0.023) and left leg (5.1% [2.83, 7.34], p=0.001). The Velocity group increased in fat-free mass in the left leg (3.7% [0.64, 6.66], p=0.025). Additionally, the Velocity group tended to increase fat-free mass in the right leg (4.1% [-0.30, 8.57], p=0.080) *(Figure 9 & 10, Table 7).*

F-v mechanical profiles. All groups reduced their F-v slope. The Force group changed the FV_{imb} from 86% to 73%, the Velocity group from 83% to 74%, and the Balanced group from 84% to 74% *(Figure 11)*.

Correlations between workouts and performance. Positive correlations were found between number of workouts and performance in SJ-bodyweight (r=0.64, p=0.036), CMJ-bodyweight (r=0.89, p=0.001) and Keiser-V_0 (r=0.66, p=0.027) for the Balanced group. No correlations were found between number of workouts and performance in the same variables for both Force group; SJ-bodyweight (r=-0.52, p=0.191), CMJ-bodyweight (r=-0.63, p=0.097), Keiser-V_0 (r=0.23, p=0.592), and Velocity group; SJ-bodyweight (r=0.27, p=0.425), CMJ-bodyweight (r=0.52, p=0.103), Keiser-V_0 (r=-0.04, p=0.913).

Negative correlations were found between number of workouts and performance in SJ with 0.1 kg (r=-0.80, p=0.018) and in SJ-P_{max} (r=-0.72, p=0.044) for the Force group. No correlations were found in SJ with 0.1 kg (r=0.26, p=0.444) and SJ-P_{max} (r=0.48, p=0.137) for the Balanced group, nor in SJ with 0.1 kg (r=-0.26, p=0.442) and SJ-P_{max} (r=-0.34, p=0.239) for the Velocity group.

Correlations between fascicle length and performance. A positive correlation was found between right leg FL and leg extention-V_0 (r=0.95, p=0.012) for the Balanced group. No correlations were found between right leg FL and leg extention-V_0 (r=-0.99, p=0.093) for the Force group, nor in the Velocity group (r=-0.95, p=0.203).

DISCUSSION

The present study compared the effects of three different training approaches (Force-dominated vs. Velocity-dominated vs. Balanced power training) to increase F-v mechanical outputs (F_0, V_0, P_{max}) and vertical jump height (SJ and CMJ). The main findings were: no group differences were observed in F-v mechanical outputs; however, the Balanced group increased SJ-height significantly by 6% and 9.8% more than the Force group with 40- and 60 kg resistance, respectively. Moreover, the Balanced group tended to increase CMJ-height by 5%

with 20 kg resistance (p=0.098), the SJ-F_0-variable by 5.3% (p=0.100), and CMJ-P_{max} by 8% (p=0.085) more than Force group. The Velocity group increased SJ-height significantly by 7.8% with 0.1 kg resistance more than the Balanced group, and CMJ-height significantly by 6% more than Force group with 20 kg resistance. Additionally, the Velocity group tended to increase SJ-height more than Force group by 6.9% with 0.1 kg resistance (p=0.057).

According to the main hypothesis, a Balanced training approach would be most beneficial to increase F-v mechanical outputs and vertical jump performance. The results present various changes throughout the groups; however, the Velocity- and the Balanced group had overall greater benefits compared to the Force group. Moreover, the Velocity group performed better at jumps near bodyweight (e.g., lighter loads), in contrast to the Balanced group, that performed better at jumps with heavier loads.

Even though no group differences in F-v mechanical outputs were present, there were several significant group differences in the vertical jump tests. It appears that the velocity approach is reflected in the jump tests, whereby a greater response occurred to relatively lighter loads (i.e., training specificity). Interestingly, at heavier loads, the Balanced group were superior to the Force group in squat jump, even though improvements in jumps with heavier loads were expected in the Force group. However, the number of workouts was negatively associated with performance in the Force group, which might indicate that the total load was too great compared to the other training programs (Velocity- and Balanced group) when implemented concurrently with sport specific training. Regarding this negative association, and based on verbal feedback from the subjects, the force-dominated training program appeared to be most exhausting. Thus, the combination of competing in season and executing a physically demanding training program simultaneously may have been too exhausting to allow for performance gains, probably due to poor recovery status (12).

Several studies have shown positive effects of strength training on improving vertical jump performance, although with contradictory results, and inconsistencies in the training prescription, e.g. heavy loads for all subjects (4, 8, 10, 18), while other studies used light loads (i.e., 0–50% of 1RM) (3, 10, 18, 32), or combined strength training (i.e., combination of heavy strength and power training) (8, 10, 13). Common features from these studies were: the subjects had the same training program within groups and great variability in performance response to training (3, 4, 8, 10, 13, 18). However, the training status of the aforementioned studies are evaluated as far less trained compared to the subjects in the present study, with subjects varying from healthy athletes, physical education students and trained athletes to division 1 male athletes. The changes may therefore be easier to provoke, as adaptations of better-trained athletes are expected to require greater stimulus and longer time (4, 9).

Given the seemingly high physical demands and exposure to physical contact in ice hockey and handball, a body composition that possesses high levels of muscular strength, lean body mass, and speed seems preferable. A meta-analysis by Schoenfeld, Grgic, Ogborn and Krieger (2017) reported that training with light loads provided similar changes in muscle hypertrophy when compared with heavy-load training (25). However, other studies report that relatively light loads in ballistic power training are typically too small to affect the necessary mechanical stimulus required for significant muscle growth response (e.g., hypertrophy) (14, 31). Although, there seems to be flexibility in the loading ranges that can be prescribed to promote muscular strength and mass (25).

Training with heavy loads (90–95% 1RM) is commonly believed to improve muscular strength qualities (27). Heavy strength training programs present in Cormie et al. (2010) and McBride et al. (2002) reported significant increases in 1RM squat, with increases of 31.2% and 10.2% respectively, compared to a non-significant increase of 2.4% in the Force group of the present study. Interestingly, the training volume was considerably lower in both Cormie et al. (2010) (3 sets of squats thrice a week) and McBride et al. (2002) (4 sets of squats twice a week) compared to the force-dominated program in the present study (22 sets of moderate to heavy lower-body exercises per week). Notably, the training status were evaluated as weak and recreationally trained, respectively (4, 18). In contrast to the Force group of the present study, the strength-training group present in Cormie et al. (2010) increased lean muscle mass in the legs, muscle thickness, and pennation angle significantly. However, due to the training status of the subjects, it is not surprising that significant increases in muscle mass and muscle architecture occurred. The strength gains in the two aforementioned studies were probably caused by neurological adaptions alongside with the significant increases in muscle mass and muscle architecture in Cormie et al. (2010).

Regarding muscle architecture, the only group difference in the present study was a significantly increased right leg FL in the Balanced group compared to both Force- and Velocity group. Although an increased FL might be associated with improvements in jump height (5), correlation analyses of the present study found no associations between increased FL and improvements in jump height. However, there was an association between increased FL and leg extension-V_0, which may indicate an importance of a relatively longer FL to generating force rapidly (5). Further, it is unknown how changes in FL affects the F-v mechanical outputs, as the adaptive response of FL following training is not well understood (5).

Since the ability to produce high levels of muscular power is considered an important component during sporting activities (7, 28), the nature of the training stimulus should therefore be directed at the enhancement of power output as opposed to load lifted or speed of execution (32). Assisted jumping, which was emphasized in the Velocity-dominated program, can be used to acutely decrease an athlete's bodyweight with the aim of resulting in an over-speed stimulus by moving faster (1, 17), spending less time on the ground (16), and jumping higher (30) – all of which would be desirable training adaptations for athletes who must quickly propel their own bodyweight during competition (e.g., jumping and sprinting). The over-speed stimulus may have been a contributing factor for the significant group differences with light loads in favor of the Velocity group. Assisted training may be particularly beneficial for athletes who have already obtained high levels of strength but lack the ability to produce higher power outputs or movement velocity, especially at low loads (1). These findings support the concept of velocity specificity in strength training as in previous ballistic power training studies (4, 17)

Furthermore, de Villarreal et al. (2011) provide evidence to suggest that both heavy strength training (full-squat >80% 1RM) and power-oriented strength training (loaded CMJ & maximal velocity parallel squats) alone, or in combination with plyometric training (rebound jumps), would provide a positive training stimulus to enhance jumping performance in recreationally trained young adults (8). In compliance with the main hypothesis of the present study, de Villarreal et al. (2011) expected the combined training group to have greater improvements in vertical jump height. However, the results disclosed that all the aforementioned training approaches affected vertical jump performance equally. Although the effects of the force-dominated training approach of the present study does not correspond with the effects of the heavy strength training program of de Villarreal et al. (2011). The effects of both the power-oriented strength- and combined training programs corresponded with the effects of both the velocity-dominated and balanced training approach on vertical jump height, respectively. Further, the subjects also participated in different kinds of sports and implemented the training programs concurrently, however, both initial training status of the subjects and the volume of the training programs were considerably lower compared to the present study. Thus, improvements in jump performance may have been easier to provoke, as adaptions in better-trained athletes are expected to require greater stimulus and longer time (4, 9).

Moreover, Harris et al. (2000) investigated the short-term (4 weeks) effects of a high-force- (80% of 1RM) and high-power training program (30–45% of 1RM) and a combination of the two. In accordance with the hypothesis of the present study, Harris et al. (2000) suggested that using a combination of heavy strength training and high-power exercises improves a wide variety of performance measures encompassing strength, power, and speed parameters better than these training approaches alone. However, according to the present results, this suggestion is partly indicative.

In summary, as mentioned in a previous section, training with heavy loads benefits muscular strength (27). However, given the nature of strength phase goals (e.g., enhanced force production and early RFD development), it may be useful to implement a program that uses the combination of heavy and light loads (27). Previous literature indicated that both maximal strength and RFD underpin power (26, 28, 29). Therefore, while the primary emphasis will be using heavier loads during maximal and absolute strength phases, lighter loads may benefit an athlete’s RFD, ultimately facilitating RFD and power development during subsequent phases that are often termed strength-speed and speed-strength (27). Having these factors in mind, choosing a given training program should emphasize following factors: training status, individual F-v mechanical profile, total training load, and whether competing in season or not.

Strength and limitations. The present study had a strong study design, national level athletes, a comprehensive test-protocol with four measurement time-points and close control of adherence and follow-up in the workouts during the intervention. We further increased the strength of the present study by using the same equipment, test leaders and technicians during all data collection. Despite the importance of the current data, some limitations need to be considered: including small sample size within groups (n=8, n=11, n=11), low number of completed workouts (13.4 ± 2.9), as well as the poor recovery status due to the athletes being in season competing throughout the whole study period. However, even with only 1.3 workouts per week, several significant increases occurred, as well as some negative correlations between the number of workouts and performance variables for the Force group. Body composition and muscle architecture results may not be credible in the comparisons conducted in the present study, as these data were only obtained from one of two teams.

Conclusion. The data from the present study provides evidence that power training alone, or in combination with heavy strength training, may be more beneficial than heavy strength training alone to increase F-v mechanical outputs and vertical jump height for national level athletes during a competitive season. However, several factors such as training- and recovery status and total load should be considered when implementing a training program as they may influence individual responses to training during a competitive season. More research is required to investigate what type of training (force-dominated vs. velocity-dominated vs. balanced approach) that is most beneficial to increase force-velocity mechanical outputs and vertical jump height.

Perspectives and practical applications. Further research is required to investigate the true effect of F-v profiling on F-v mechanical outputs (F_0, V_0 & P_{max}) and performance variables (e.g., vertical jump height & sprint) during competitive season, and what kind of training approach that is most beneficial for well-trained, national level athletes.

Acknowledgments. The present study was performed in collaboration with the University of Agder and Olympiatoppen. The authors wish to grant a thank to the dedicated participants for their time and effort.

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FIGURE AND TABLE LEGENDS

Figure 1. *Squat jump (F-v parameters).* #, significant ($p \leq 0.05$) change from baseline; Balanced, balanced group; Force, force group; Velocity, velocity group.

Figure 2. *Squat jump (Jump height).* *, significant ($p \leq 0.05$) change between groups; #, significant ($p \leq 0.05$) change from baseline; Balanced, balanced group; Force, force group; Velocity, velocity group.

Figure 3. *CMJ (F-v parameters).* #, significant ($p \leq 0.05$) change from baseline; Balanced, balanced group; Force, force group; Velocity, velocity group.

Figure 4. *CMJ (Jump height).* *, significant ($p \leq 0.05$) change between groups; #, significant ($p \leq 0.05$) change from baseline; Balanced, balanced group; Force, force group; Velocity, velocity group.

Figure 5. *Keiser leg press (F-v parameters).* #, significant ($p \leq 0.05$) change from baseline; Balanced, balanced group; Force, force group; Velocity, velocity group.

Figure 6. *Leg extension (F-v parameters).* #, significant ($p \leq 0.05$) change from baseline; Balanced, balanced group; Force, force group; Velocity, velocity group.

Figure 7. *1RM back-squat.* #, significant ($p \leq 0.05$) change from baseline; Balanced, balanced group; Force, force group; Velocity, velocity group.

Figure 8. *Sprint (30m).* *, significant ($p \leq 0.05$) change between groups; #, significant ($p \leq 0.05$) change from baseline; Balanced, balanced group; Force, force group; Velocity, velocity group.

Figure 9. *Muscle architecture.* *, significant ($p \leq 0.05$) change between groups; #, significant ($p \leq 0.05$) change from baseline. PAngle-R, pennation angle right; PAngle-L, pennation angle left; FLength-R, fascicle length right; FLength-L, fascicle length left; MThickness-R, muscle thickness right; MThickness-L, muscle thickness left; Balanced, balanced group; Force, force group; Velocity, velocity group.

Figure 10. *Body composition.* #, significant ($p \leq 0.05$) change from baseline, BF%, body-fat percentage; FFM, fat-free mass; FFM-R, fat-free mass right leg; FFM-L, fat-free mass left leg; Balanced, balanced group; Force, force group; Velocity, velocity group.

Figure 11. *F-v profiles.* Individual F-v slope changes from baseline to post of force-, velocity and balanced group.

Table 1. *Descriptive data of participants.* Workouts, number of workouts during the training intervention. No significant changes between groups. All values are presented as mean ± SD.

Table 2. *Mean change in jump height and F-v relationship parameters between groups in percent (One-way ANCOVA).* Mean, percentage change within highlighted group adjusted for baseline; Mean difference, percentage change between groups adjusted for baseline; Values of significance (≤ 0.05) are highlighted with bold font.

Table 3. *Mean change in jump height and F-v relationship parameters within groups in percent (One-way ANOVA).* Baseline, mean values; Post, mean values; Change, mean change within highlighted group. Values of significance ($p \leq 0.05$) are highlighted with bold font.

Table 4. *Mean change in F-v relationship parameters, strength and sprint between groups in percent (One-way ANCOVA).* Mean, mean change within highlighted group adjusted for baseline; Mean difference percentage change pre-post between groups adjusted for baseline; Values of significance (≤ 0.05) are highlighted with bold font.

Table 5. *Mean change in F-v relationship parameters, strength and sprint within groups in percent (One-way ANOVA).* Baseline, mean values; Post, mean values; Change, mean change within highlighted group; LE, leg extensions; P-V, peak velocity; P-P, peak power; Values of significance ($p \leq 0.05$) are highlighted with bold font.

Table 6. *Mean change in muscle architecture and body composition between groups in percent (One-way ANCOVA).* Mean, mean values within highlighted group adjusted for baseline; Mean difference, difference between highlighted groups adjusted for baseline; PA, pennation angle; FL, fascicle length (mm); MT, muscle thickness (mm); BF %, body-fat percent; FFM (kg), fat-free mass; FFM-R (kg), fat-free mass right leg; FFM-L (kg), fat-free mass left leg; Values of significance ($p \leq 0.05$) are highlighted with bold font.

Table 7. *Mean change in muscle architecture and body composition within groups in percent (One-way ANOVA).* Baseline, mean values; Post, mean values; Change, mean change adjusted for baseline; PA; pennation angle; FL, fascicle length (mm); MT, muscle thickness (mm); BF %, body-fat percent; FFM, fat-free mass (kg); FFM-R (kg), fat-free mass right leg; FFM-L (kg), fat-free mass left leg; Values of significance ($p \leq 0.05$) are highlighted with bold font.

Supplementary 1. Force group training program.

Supplementary 2. Velocity group training program.

Supplementary 3. Balanced group training program.

FIGURES

Figure 1.

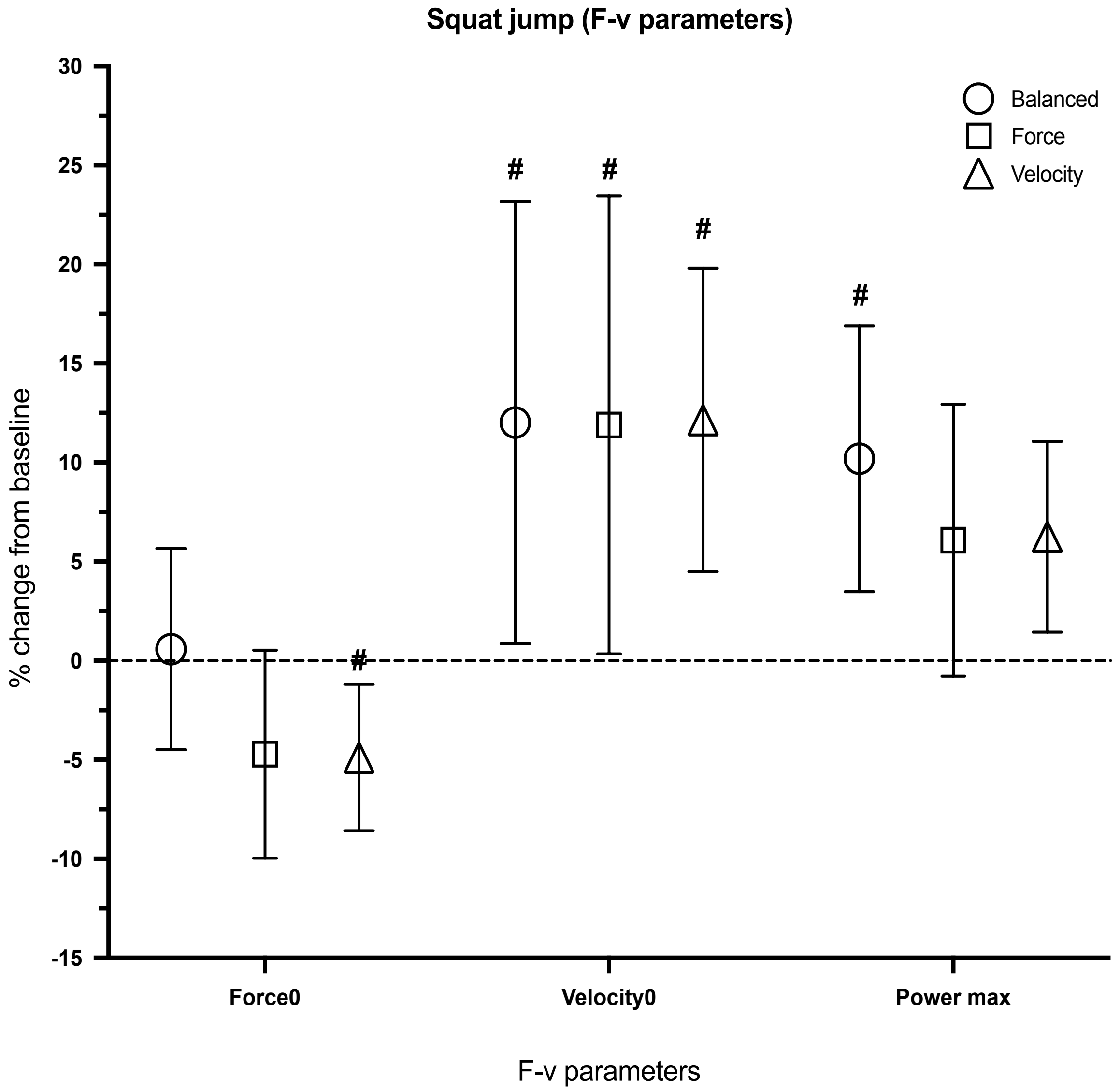


Figure 2.

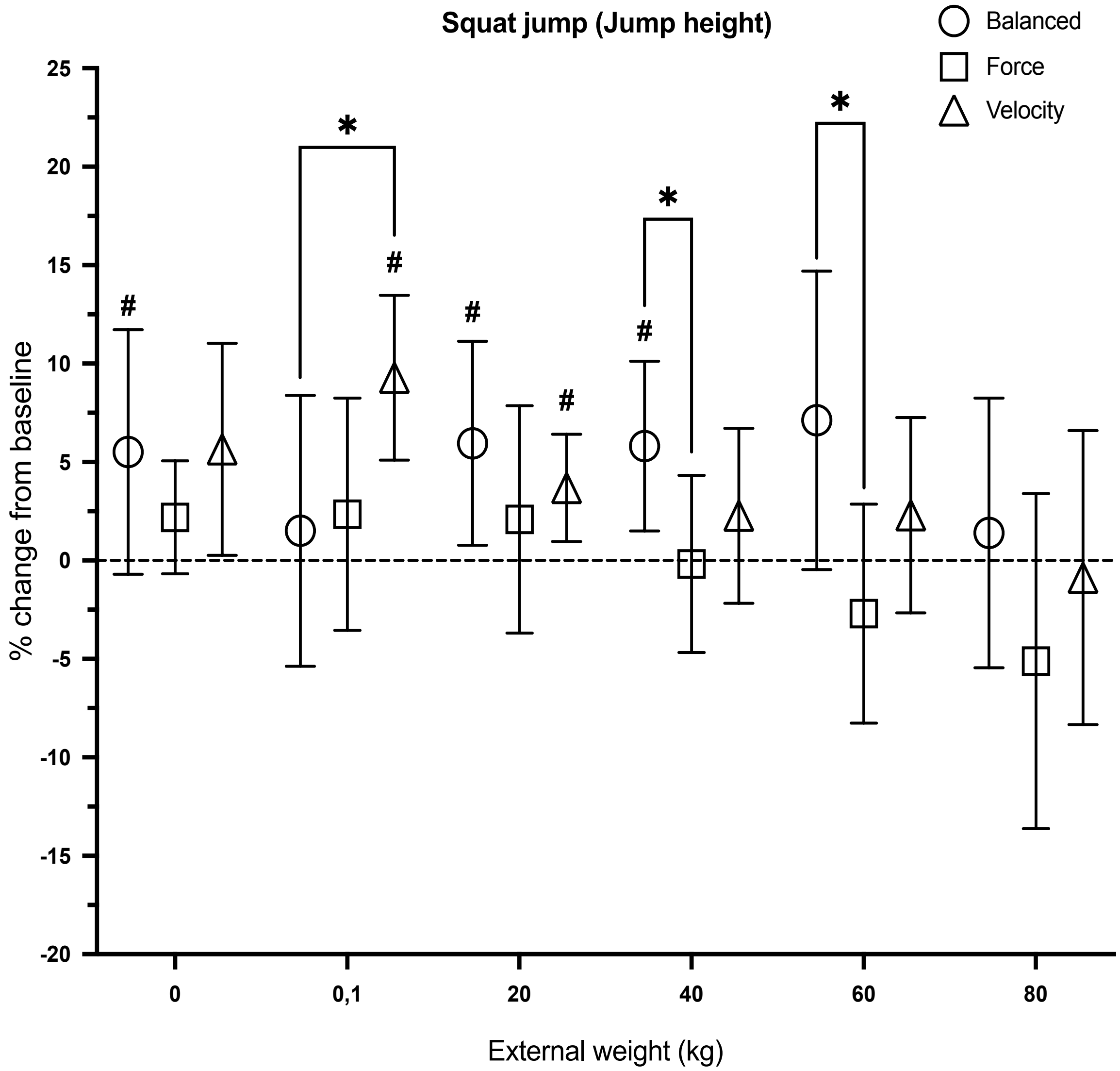
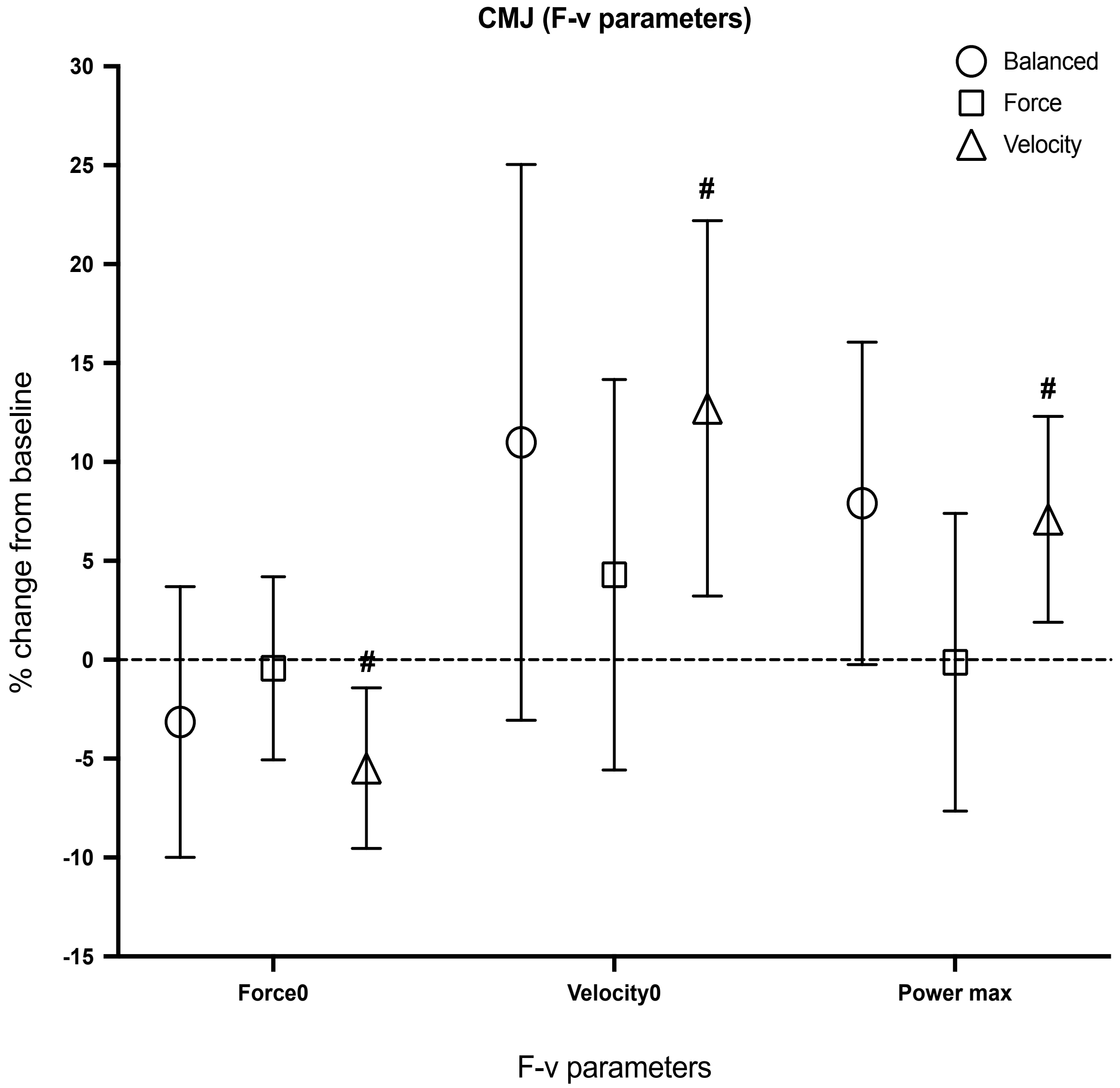

Squat jump (Jump height)
Balanced
Force
Velocity
25
20
15
10
5
0
-5
-10
-15
-20
% change from baseline
0
0,1
20
40
60
80
External weight (kg)
#
#
#
#
#
*
*
*

Figure 3.



CMJ (F-v parameters)
Balanced
Force
Velocity
30
25
20
15
10
5
0
-5
-10
-15
% change from baseline
#
#
#
Force0
Velocity0
Power max
F-v parameters

Figure 4.

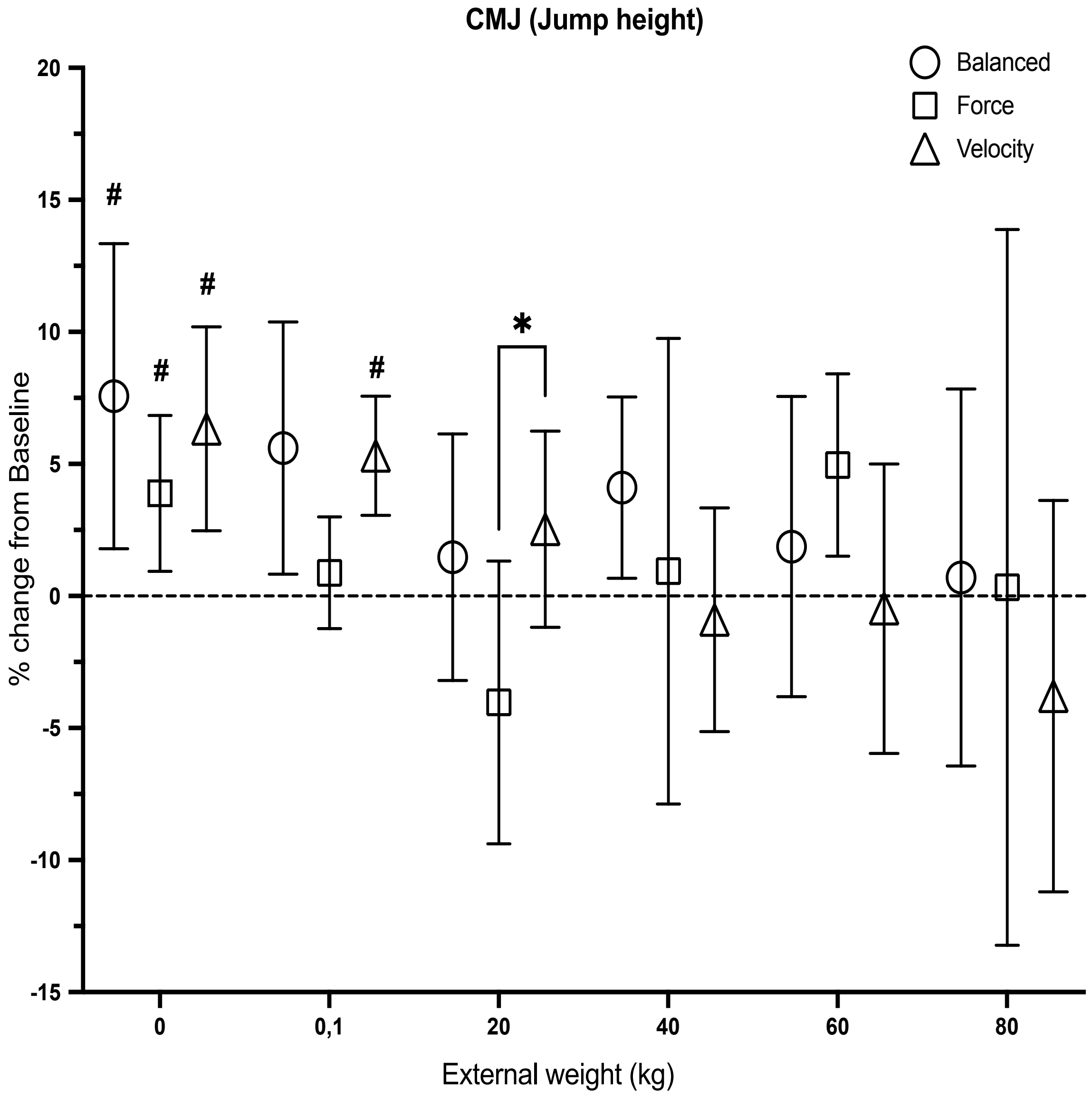

CMJ (Jump height)
Balanced
Force
Velocity
% change from Baseline
20
15
10
5
0
-5
-10
-15
#
#
#
#
*
0
0,1
20
40
60
80
External weight (kg)

Figure 5.

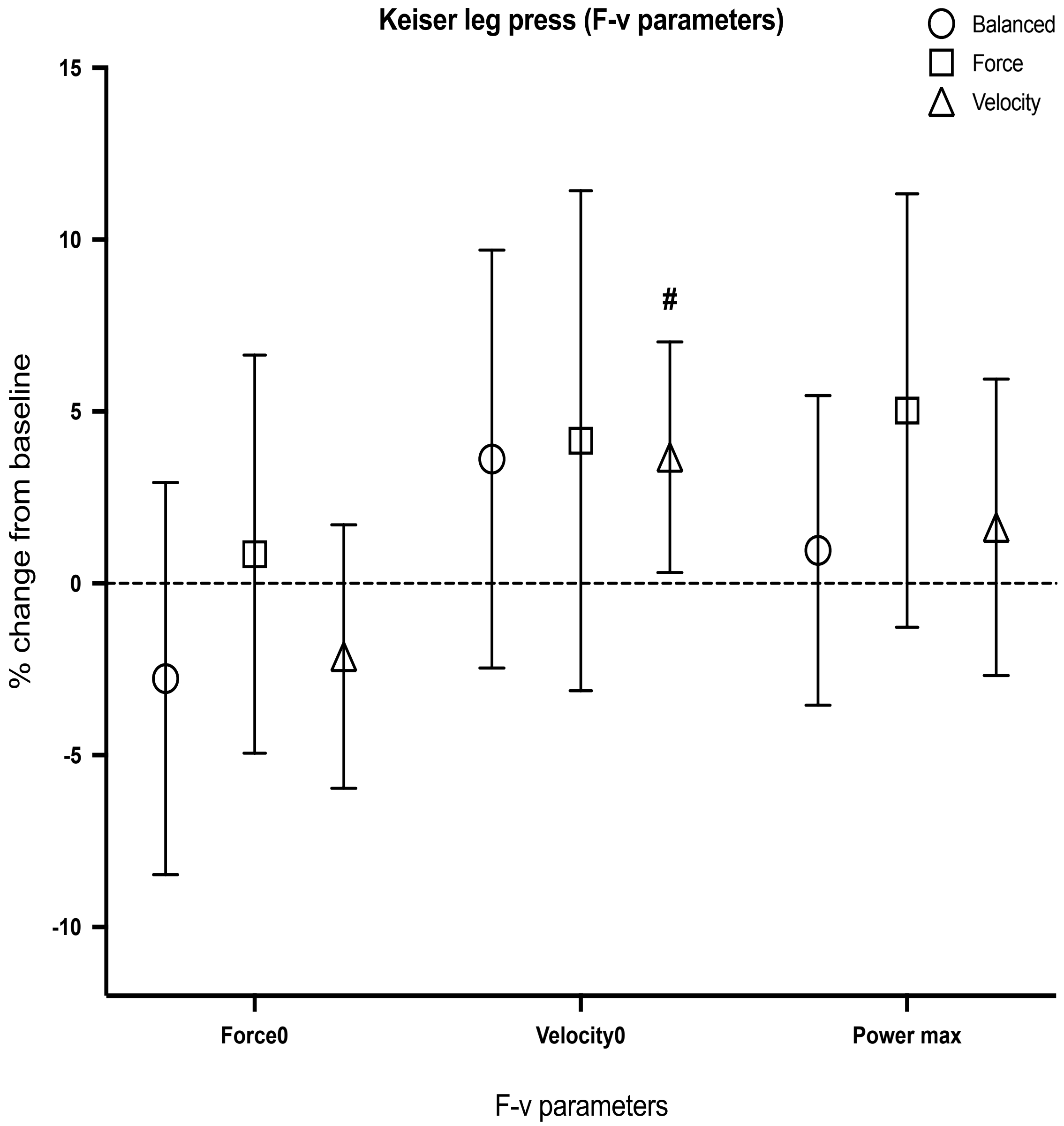

Keiser leg press (F-v parameters)
Balanced
Force
Velocity
15
10
5
0
-5
-10
% change from baseline
#
Force0
Velocity0
Power max
F-v parameters

Figure 6.

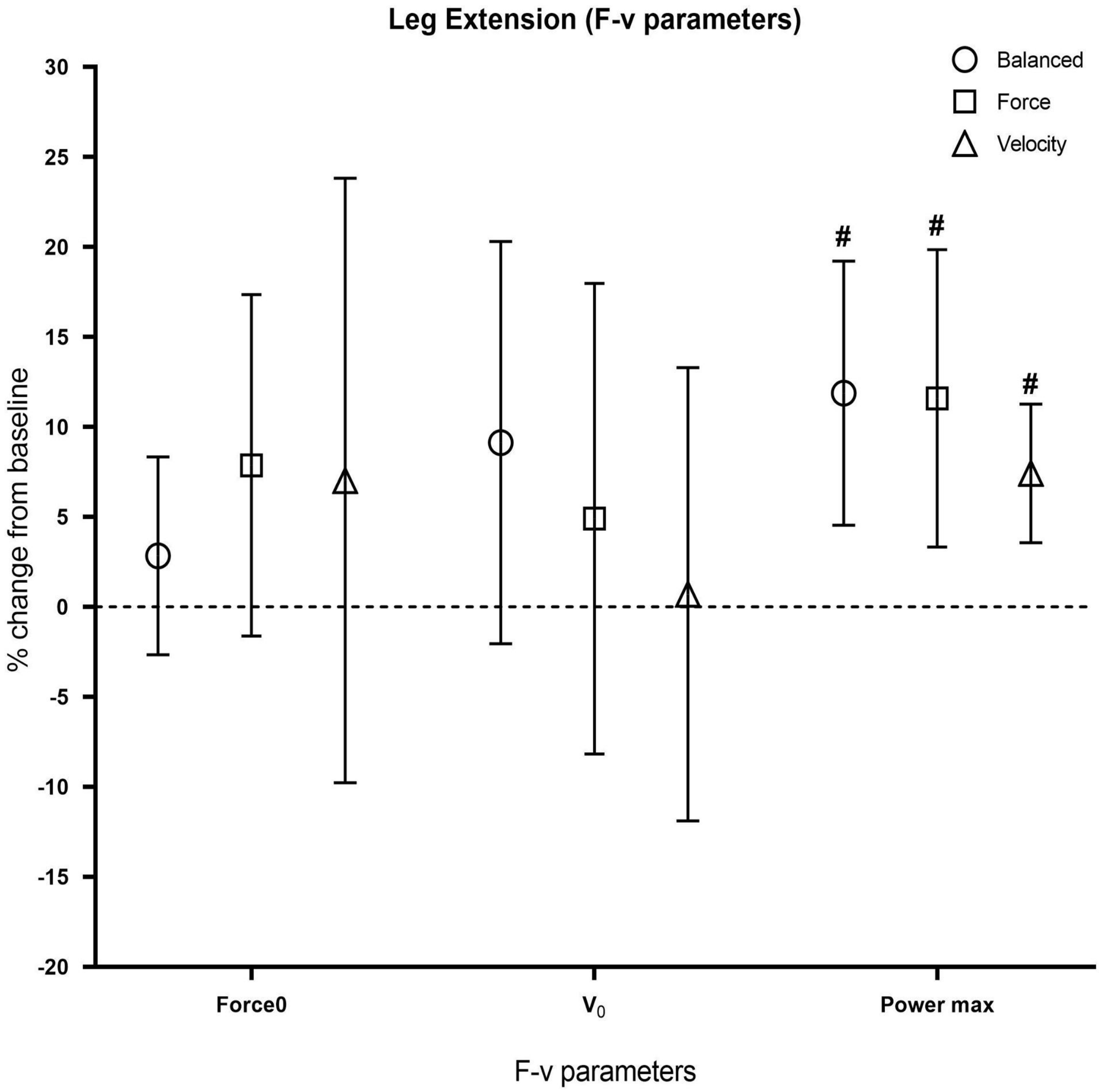

Leg Extension (F-v parameters)
Balanced
Force
Velocity
30
25
20
15
10
5
0
-5
-10
-15
-20
% change from baseline
#
#
#
Force0
V0
Power max
F-v parameters

Figure 7.

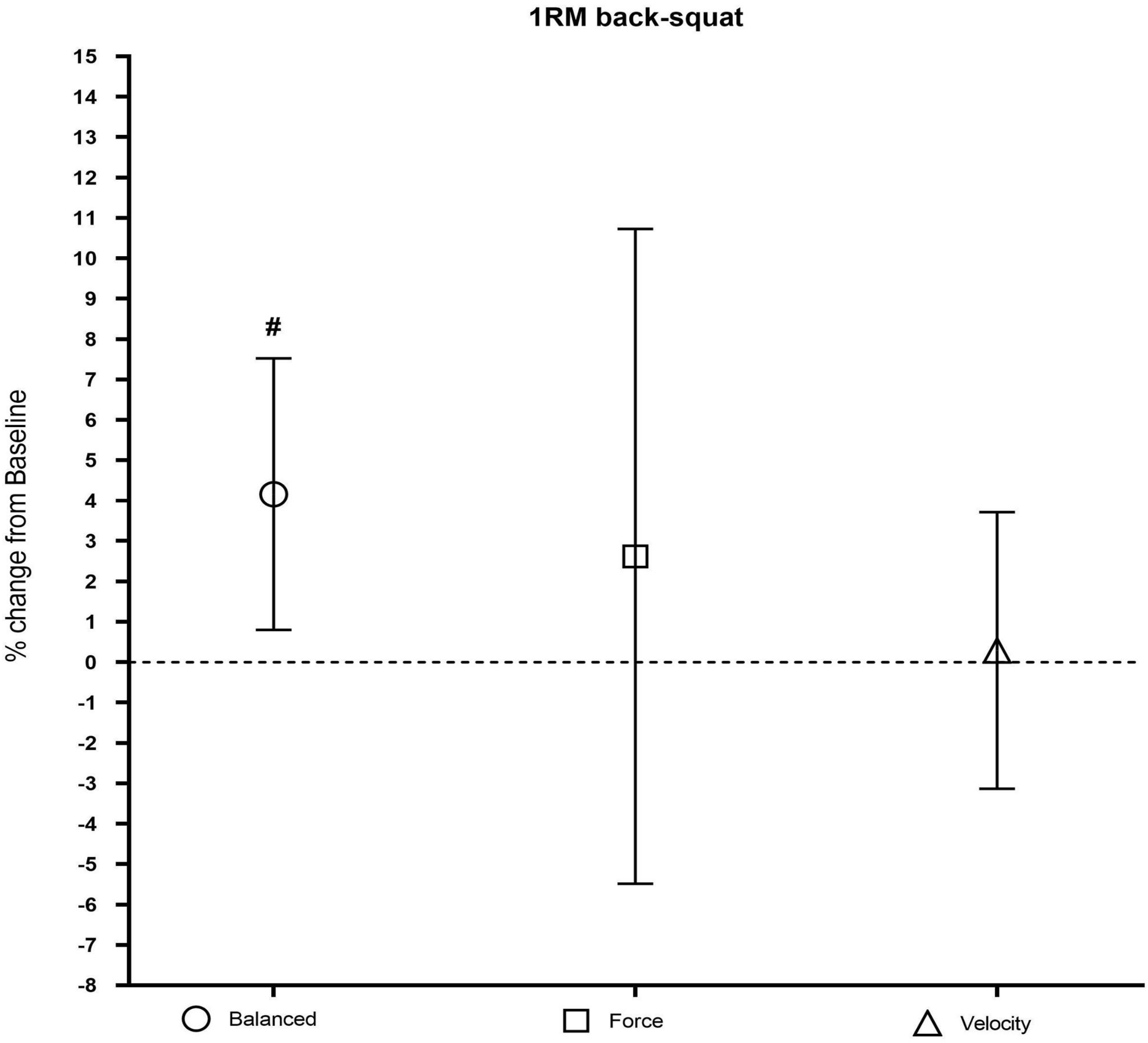

1RM back-squat
% change from Baseline
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
#
Balanced
Force
Velocity

Figure 8.

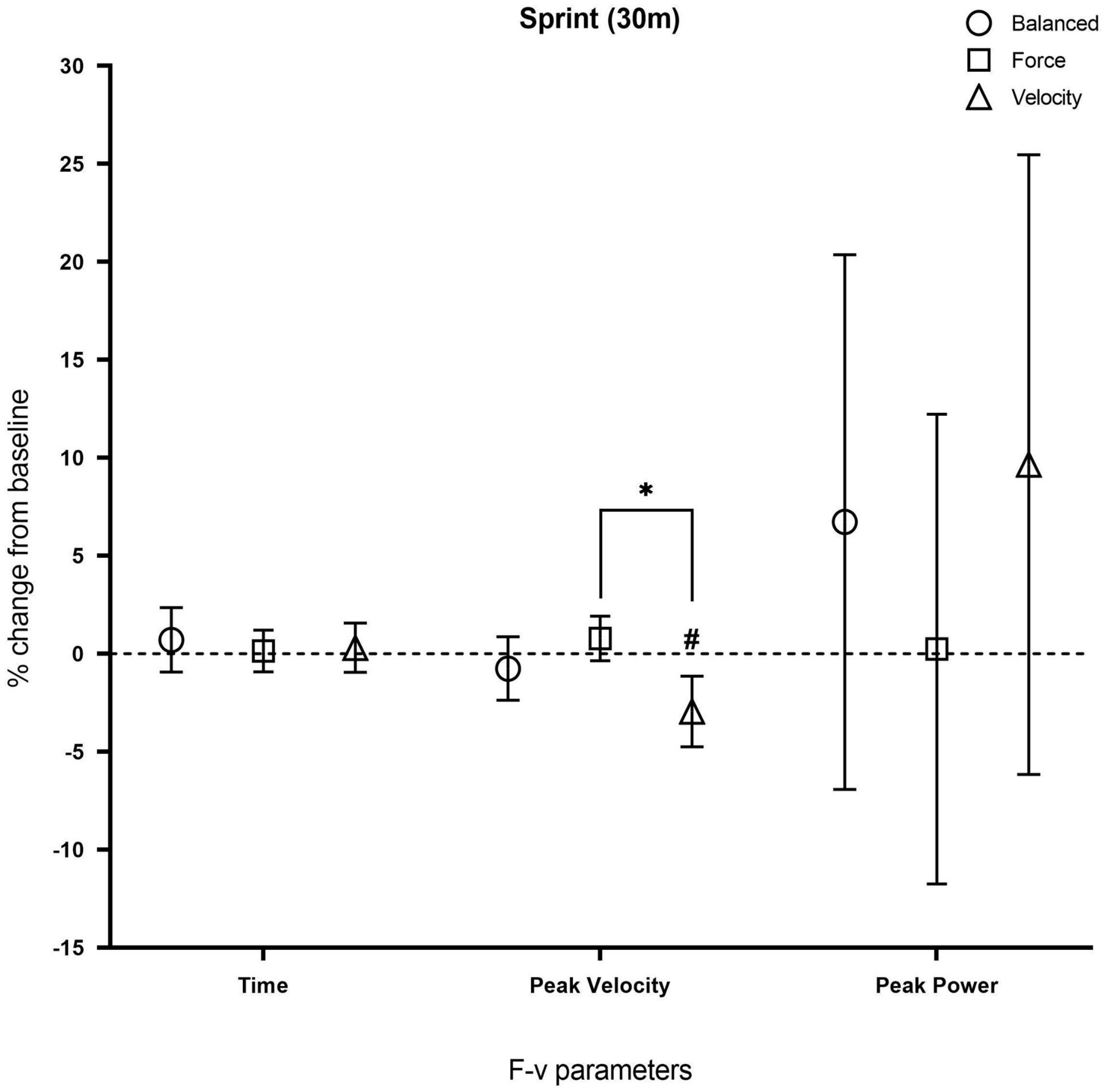

Sprint (30m)
○ Balanced
□ Force
△ Velocity
30
25
20
15
10
5
0
-5
-10
-15
% change from baseline
*
#
Time
Peak Velocity
Peak Power
F-v parameters

Figure 9.

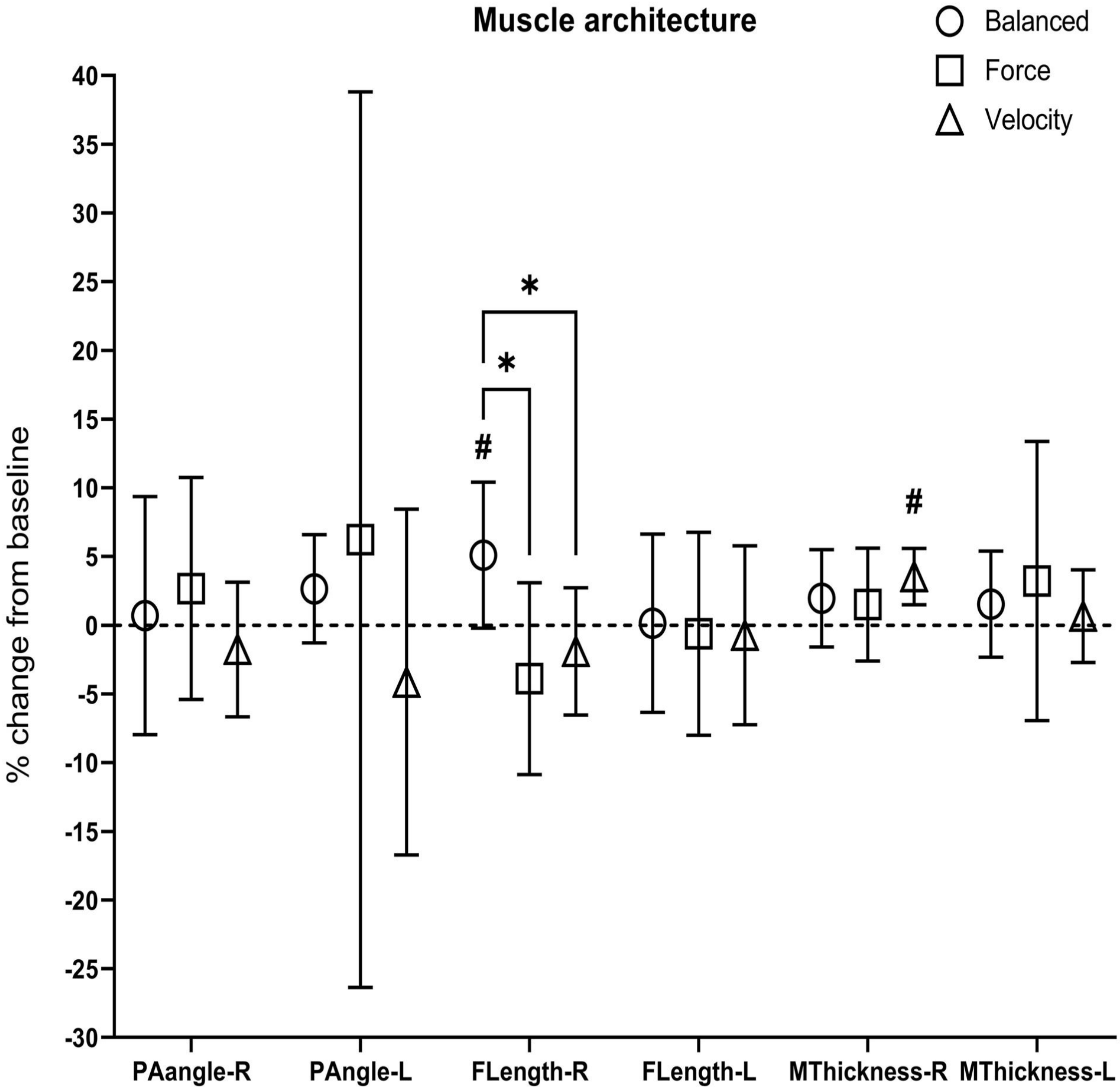

Muscle architecture
○ Balanced
□ Force
△ Velocity
% change from baseline
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
*
*
#
#
PAangle-R
PAngle-L
FLength-R
FLength-L
MThickness-R
MThickness-L

Figure 10.

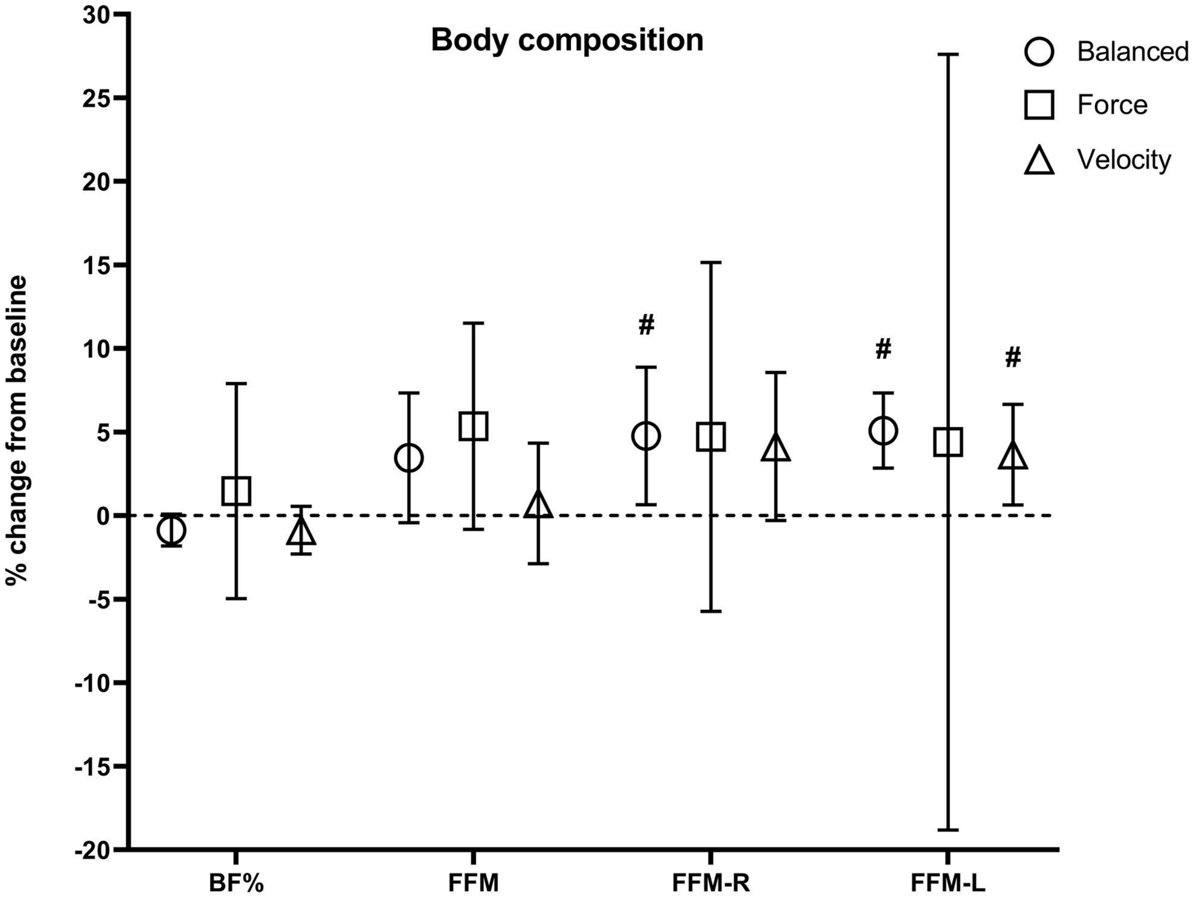
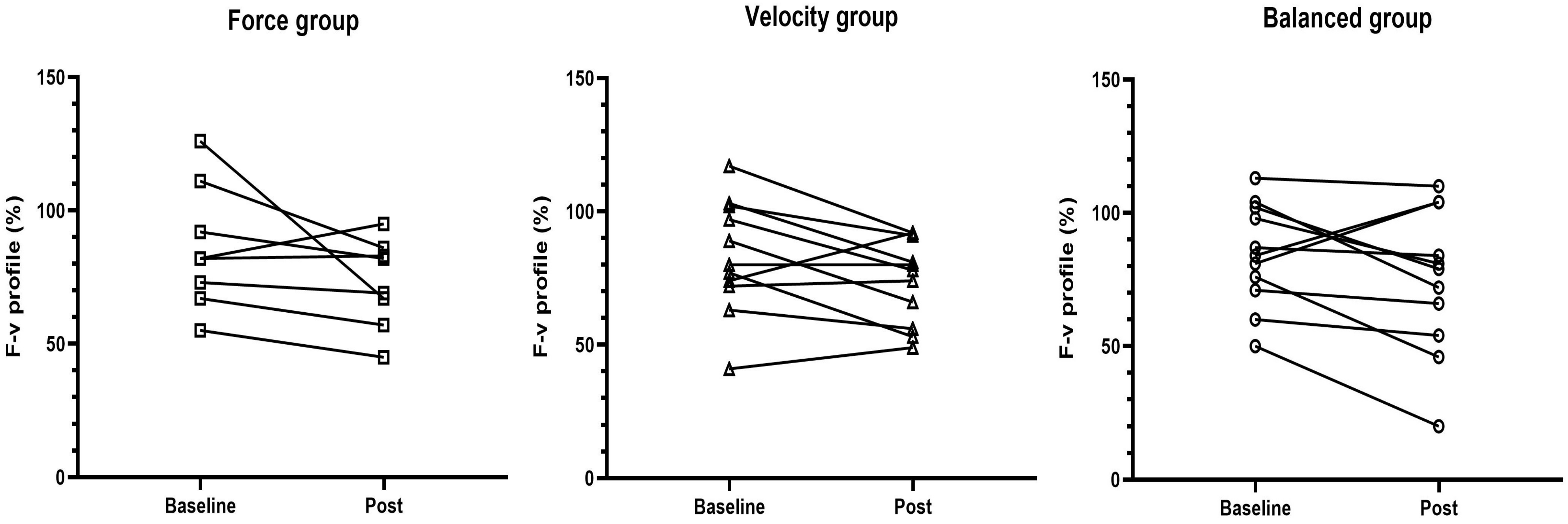

Body composition
○ Balanced
□ Force
△ Velocity
% change from baseline
30
25
20
15
10
5
0
-5
-10
-15
-20
BF%
FFM
FFM-R
FFM-L
#
#
#

Figure 11.


Force group
Velocity group
Balanced group
F-v profile (%)
150
100
50
0
Baseline
Post

TABLES

Table 1.

Group	N	Age (years)	Height (cm)	Weight (kg)	Workouts (n)
All groups	30	20.0 ± 4.8	180.0 ± 9.4	78.2 ± 15.8	13.4 ± 2.9
Force	8	17.9 ± 1.7	179.4 ± 8.1	74.8 ± 11.6	13.3 ± 3.9
Velocity	11	21.3 ± 5.9	186.5 ± 8.8	82.3 ± 21.3	12.7 ± 2.9
Balanced	11	20.8 ± 5.0	184.7 ± 10.7	76.9 ± 13.8	14.2 ± 1.9

Table 2.

	Balanced vs Force		**Force** vs Velocity		**Velocity** vs Balanced	
Test	**Mean (95% CI)**	**Mean difference (95% CI)**	**Mean (95% CI)**	**Mean difference (95% CI)**	**Mean (95% CI)**	**Mean difference (95% CI)**
SJ						
0 kg	5.51 (1.37,9.65)	3.32 (-3.08,9.72)	2.19 (-2.61,6.99)	-3.46 (-9.73,2.82)	5.65 (1.56,9.73)	0.14 (-5.73,6.00)
0.1 kg	1.51 (-3,17,6.19)	-0.83 (-8.04,6.37)	2.35 (-3.11,7.80)	-6.94 (-14.12,0.23)	9.29 (4.62,13.96)	**7.78 (1.14,14.42)**
20 kg	5.95 (2.18,9.72)	3.86 (-1.93,9.65)	2.09 (-2.29,6.47)	-1.60 (-7.37,3.11)	3.69 (-0.74,7.45)	-2.26 (-7.63,3.11)
40 kg	5.81 (2.21,9.41)	**5.97 (0.44,11.51)**	-0.17 (-4.38,4.05)	-2.44 (-7.99,3.12)	2.27 (-1.34,5.88)	-3.54 (-8.66,1.58)
60 kg	7.12 (1.73,12.51)	**9.82 (1.50,18.15)**	-2.70 (-9.04,3.64)	-5.01 (-13.35,3.33)	2.3 (-3.10,7.71)	-5.01 (-13.35,3.33)
80 kg	1.40 (-5.14,7.93)	6.51 (-3.58,16.59)	-5.11 (-12.78,2.56)	-4.24 (-14.31,5.84)	-0.87 (-7.40,5.65)	-2.27 (-11.50,6.96)
F_0	0.58 (-3.54,4.70)	5.29 (-1.10,11.68)	-4.42 (-9.54,0.12)	0.18 (-6.15,6.50)	-4.89 (-8.99,-0.80)	0.18 (-6.15,6.50)
V_0	12.02 (3.11,20.93)	0.13 (-13.58,13.84)	11.90 (1.48,22.32)	-0.26 (-13.96,13.45)	12.15 (3.25,21.06)	0.13 (-12.49,12.76)
P_{max}	10.12 (4.81,15.56)	4.11 (-4.20,12.41)	6.08 (-0.24,12.40)	-0.18 (-8.50,8.14)	6.26 (0.88,11.63)	-3.93 (-11.53,3.67)
CMJ						
0 kg	6.93 (3.29,10.58)	2.35 (-3.31,8.01)	4.58 (0.31,8.86)	-1.87 (-7.46,3.72)	6.46 (2.84,10.07)	-0.48 (-5.62,4.67)
0.1 kg	5.34 (0.75,9.93)	3.73 (-4.38,11.84)	1.61 (-4.98,8.20)	-3.59 (-11.64,4.47)	5.20 (0.63,9.80)	-0.14 (-6.61,6.32)
20 kg	1.33 (-2.50,5.16)	4.96 (-0.98,10.90)	-3.63 (-8.15,0.89)	**-6.00 (-11.95,-0.06)**	2.38 (-1.45,6.21)	1.05 (-4.36,6.46)
40 kg	3.96 (-2.33,10.24)	3.06 (-7.80,13.91)	0.90 (-7.96,9.76)	1.63 (-9.24,12.51)	-0.73 (-7.03,5.56)	-4.69 (-13.63,4.25)
60 kg	1.20 (-5.82,8.22)	-5.51 (-18.35,7.33)	6.7 (-3.62,17.04)	7.40 (-5.14,19.93)	-0.69 (-7.59,6.22)	-1.88 (-11.68,7.91)
80 kg	0.97 (-6.50,8.44)	1.71 (-9.90,13.32)	-0.74 (-9.58,8.10)	2.53 (-9.12,14.19)	-3.28 (-10.76,4.21)	-4.24 (-14.80,6.31)
F_0	-3.15 (-7.93,1.64)	-2.72 (-10.35,4.91)	-0.43 (-6.14,5.28)	5.05 (-2.39,12.49)	-5.48 (-10.19,-0.78)	-2.34 (-9.02,4.35)
V_0	10.99 (1.86,20.13)	6.70 (-8.08,21.47)	4.30 (-6.90,15.48)	-8.42 (-23.17,6.33)	12.71 (3.59,21.84)	1.72 (-11.05,14.50)
P_{max}	7.91 (1.94,13.89)	8.04 (-1.18,17.27)	-0.13 (-7.15,6.89)	-7.23 (-16.47,2.01)	7.10 (1.12,13.09)	-0.81 (-9.27,7.65)

Table 3.

	Balanced			Force			Velocity		
Test	Baseline (95% CI)	Post (95% CI)	Change (95% CI)	Baseline (95% CI)	Post (95% CI)	Change (95% CI)	Baseline (95% CI)	Post (95% CI)	Change (95% CI)
SJ									
0 kg	34.71 (31.75,37.66)	36.81 (34.28,39.34)	**6.71 (0.50,12.92)**	36.51 (33.92,39.09)	36.94 (34.95,38.92)	1.36 (-1.51,4.23)	36.30 (34.41,38.46)	38.03 (35.76,40.31)	5.05 (-0.34.10.44)
0.1 kg	31.55 (28.93,34.17)	32.04 (29.45,34.63)	2.10 (-4.78,8.98)	32.29 (30.13,34.46)	32.98 (30.22,35.73)	2.15 (-3.75,8.05)	32.54 (30.50,34.58)	35.32 (33.44,37.20)	**8.84 (5.66,13.03)**
20 kg	25.17 (22.49,27.85)	26.67 (24.07,29.27)	**6.46 (1.28,11.64)**	25.99 (23.74,28.25)	26.49 (23.91,29.07)	2.01 (-3.77,7.79)	26.52 (24.55,28.49)	27.33 (25.49,29.16)	**3.24 (0.51,5.96)**
40 kg	19.38 (17.02,21.74)	20.52 (18.05,22.99)	**6.10 (1.78,10.41)**	19.58 (16.57,22.60)	19.46 (17.17,21.75)	-0.03 (-4.53,4.67)	20.25 (18.35,22.14)	20.55 (18.82,22.27)	1.88 (-2.56,6.33)
60 kg	14.66 (12.20,17.12)	15.66 (13.06,18.25)	7.09 (-0.50,14.67)	14.21 (11.44,16.99)	13.82 (11.30,16.33)	-2.41 (-7.97,3.15)	14.86 (12.95,16.77)	15.06 (13.36,16.76)	2.12 (-2.84,7.09)
80 kg	10.92 (8.86,12.99)	11.08 (8.82,13.35)	1.26 (-5.59,8.11)	10.37 (7.60,13.14)	9.73 (7.46,12.01)	-4.85 (-13.36,3.67)	10.81 (9.24,12.39)	10.64 (9.10,12.18)	-0.93 (-8.40,6.54)
F_0	2876 (2571,3183)	2897 (2529,3264)	0.44 (-4.63,5.52)	2711 (2282,3140)	2568 (2255,2881)	-4.56 (-9.81,0.69)	2785 (2558,3011)	2648 (2411,2885)	**-4.87 (-8.56,-1.17)**
V_0	2.73 (2.38,3.08)	3.07 (2.52,3.63	**12.21 (1.00,23.43)**	2.79 (2.53,3.04)	3.12 (2.66,3.58)	**11.89 (0.33,23.45)**	2.84 (2.47,3.21)	3.14 (2.84,3.44)	**11.97 (4.30,19.64)**
P_{max}	1974 (1578,2370)	2178 (1692,2663)	**10.14 (3.43,16.85)**	1872 (1605,2139)	2001 (1633,2369)	6.24 (-0.63,13.10)	1981 (1634,2329)	2079 (1802,2356)	6.19 (1.38,11.00)
CMJ									
0 kg	37.07 (34.05,40.07)	39.70 (36.68,42.71)	**7.57 (1.79,13.35)**	38.64 (36.29,41.00)	40.09 (38.28,41.90)	**3.89 (0.94,6.84)**	37.97 (35.54,40.39)	40.29 (37.91,42.66)	**6.33 (2.47,10.19)**
0.1 kg	34.43 (30.22,38.65)	36.24 (32.14,40.35)	5.60 (-.1.87,13.06)	36.28 (29.88,42.69)	35.57 (31.59,41.54)	0.88 (-5.41,7.16)	34.71 (31.79,37.63)	36.57 (33.05,40.09)	**5.31 (1.78,8.83)**
20 kg	27.93 (25.50,30.36)	28.28 (25.81,30.74)	1.47 (-3.20,6.14)	28.84 (27.00,30.68)	27.66 (25.47,29.85)	-4.03 (-9.38,1.31)	27.91 (26.11,29.71)	28.56 (26.85,30.27)	2.53 (-1.19,6.25)
40 kg	22.37 (19.93,24.81)	23.33 (20.13,26.54)	4.10 (-1.26,9.46)	22.57 (16.43,28.70)	22.65 (18.50,26.80)	0.94 (-25.24,27.12)	22.93 (21.07,24.80)	22.69 (20.85,24.53)	-0.90 (-7.51,5.71)
60 kg	17.75 (15.77,19.73)	18.14 (15.22,21.07)	1.87 (-7.00,10.75)	16.12 (12.04,20.19)	16.95 (11.23,22.67)	4.96 (-5.31,15.22)	17.43 (15.86,19.01)	17.36 (15.15,19.56)	-0.48 (-9.04,8.08)
80 kg	11.51 (9.39,13.63)	11.61 (9.25,13.96)	0.71 (-6.43,7.84)	10.47 (7.61,13.33)	10.23 (7.73,12.73)	0.33 (-13.22,13.88)	11.71 (9.93,13.48)	11.16 (9.48,12.83)	-3.79 (-11.21,3.62)
F_0	2894 (2533,3255)	2773 (2410,3136)	-3.78 (-10.62,3.07)	2523 (2138,2907)	2531 (2165,2898)	0.62 (-4.01,5.26)	2785 (2520,3050)	2621 (2378,2864)	**-5.62 (-9.68,-1.56)**
V_0	3.09 (2.62,3.57)	3.42 (3.01,3.83)	12.91 (-1.13,26.94)	3.62 (3.06,4.18)	3.54 (3.20,3.87)	-0.83 (-10.74,9.08)	3.10 (2.79,3.41)	3.54 (3.09,3.99)	**14.52 (5.03,24.02)**
P_{max}	2178 (1821,2535)	2326 (1997,2654)	7.93 (-0.22,16.08)	2233 (1942,2523)	2205 (1978,2432)	-0.46 (-7.98,7.07)	2145 (1842,2448)	2308 (1934,2682)	**7.32 (2.12,12.53)**

Table 4.

	Balanced vs Force		**Force** vs Velocity		**Velocity** vs Balanced	
Test	**Mean (95% CI)**	**Mean difference (95% CI)**	**Mean (95% CI)**	**Mean difference (95% CI)**	**Mean (95% CI)**	**Mean difference (95% CI)**
Keiser						
F_0	-2.34 (-6.17,1.49)	-2.58 (-8.51,3.42)	0.24 (-4.26,4.74)	2.39 (-3.51,8.29)	-2.15 (-5.92,1.67)	0.19 (-5.22,5.60)
V_0	3.58 (-0.77,7.94)	0.40 (-6.37,7.14)	3.18 (-1.98, 8.34)	-1.31 (-8.16,5.54)	4.49 (0.09,8.83)	0.90 (-5.29,7.01)
P_{max}	1.26 (-2.58,5.11)	-2.71 (-8.72,3.30)	3.97 (-0.60,8.55)	1.84 (-4.19,7.88)	2.13 (-1.72,5.98)	0.87 (-4.56,6.29)
Leg Ext						
F_0	3.28 (-1.95,8.51)	-2.29 (-10.49,4.78)	6.14 (0.69,11.58)	-3.00 (-12.21,6.20)	9.14 (2.14,16.14)	5.86 (-2.79,14.50)
V_0	7.71 (1.13,14.28)	2.49 (-6.79,11.77)	5.22 (-1.31,11.74)	2.82 (-7.86,13.51)	2.39 (-6.10,10.88)	-5.32 (-16.13,5.50)
P_{max}	11.80 (6.10,17.49)	1.21 (-7.06,9.49)	10.58 (4.52,16.65)	1.38 (-9.61,12.37)	9.21 (0.95,17.46)	-2.59 (-12.68,7.50)
Squat						
1RM	4.16 (0.11,8.20)	1.54 (-4.68,7.76)	2.62 (-2.15,7.38)	2.33 (-4.02,8.67)	0.29 (-3.81,4.39)	-3.87 (-9.67,1.93)
Sprint						
Time	0.73 (0.51,1.97)	0.58 (-1.32,2.49)	0.15 (-1.30,1.60)	-0.14 (-2.04,1.77)	0.29 (-0.95,1.52)	-0.45 (-2.20,1.31)
Peak Velocity	-0.76 (-2.85,1.34)	-1.73 (-5.38,1.92)	0.97 (-2.02,3.96)	**4.00 (0.33,7.67)**	-3.03 (-5.14,-0.93)	-2.28 (-5.25,0.70)
Peak Power	12.17 (-3.64,27.98)	0.75 (-25.95,27,46)	11.42 (-11.88,34.72)	12.78 (-19.08,44.64)	-1.36 (-18.97,16.25)	-13.53 (-38.81,11.17)

Table 5.

Test	Balanced			Force			Velocity		
	Baseline (95% CI)	Post (95% CI)	Change (95% CI)	Baseline (95% CI)	Post (95% CI)	Change (95% CI)	Baseline (95% CI)	Post (95% CI)	Change (95% CI)
Keiser									
F_0	1703 (1317,2090)	1630 (1297,1964)	-2.79 (-8.49,2.92)	1574 (1182,1965)	1570 (1229,1910)	0.83 (-4.99,6.64)	1645 (1390,1900)	1602 (1472,182)	-2.13 (-5.97,1.71)
V_0	2.09 (1.91,2.27)	2.17 (1.97,2.36)	3.68 (-.2.32,9.67)	2.03 (1.82,2.25)	2.10 (1.96,2.25)	4.09 (-3.26,11.44)	2.16 (2.01,2.30)	2.23 (2.11,2.35)	**3.72 (0.36,7.09)**
P_{max}	864 (704,1023)	863 (722,1004)	0.97 (-3.55,5.49)	775 (650,900)	812 (682,942)	5.05 (-1.23,11.33)	876 (748,1004)	886 (766,1005)	1.64 (-2.66,5.94)
LE									
F_0	1185 (1001,1369)	1163 (1039,1286)	2.83 (-2.67,8.33)	1062 (878,1246)	1138 (1009,1266)	7.86 (-1.62,17.35)	1119 (1007,1232)	1278 (908,1646)	7.02 (-9.78,23.83)
V_0	1.23 (1.12,1.35)	1.32 (1.22,1.42)	8.90 (-2.42,20.22)	1.24 (1.09,1.39)	1.29 (1.17,1.42)	4.93 (-7.89,17.75)	1.27 (1.21,1.31)	1.27 (1.16,1.38)	0.88 (-10.96,12.72)
P_{max}	363 (299,427)	382 (342,421)	**11.87 (4.54,19.21)**	325 (290,360)	363 (323,402)	**11.58 (3.33,19.84)**	355 (315,394)	405 (277,532)	**7.41 (3.55,11.26)**
Squat									
1RM	135.45 (119,152)	140.91 (124,158)	**4.00 (0.87,7.15)**	137.50 (118,157)	140.31 (119,161)	2.35 (-5.75,10.45)	126.59 (115,138)	127.05 (117,137)	0.63 (-2.82,4.08)
Sprint									
Time	4.14 (3.97,4.31)	4.17 (3.96,4.38)	0.71 (-0.94,2.36)	4.15 (3.97,4.32)	4.15 (3.96,4.34)	0.14 (-0.92,1.20)	4.,17 (4.04,4.30)	4.18 (4.05,4.31)	0.31 (-0.94,1.57)
P-V	8.47 (8.17,8.77)	8.40 (8.13,8.67)	-0.76 (-3.28,1.77)	8.53 (8.39,8.68)	8.60 (8.35,8.85)	0.78 (-2.59,4.16)	8.43 (8.05,8.82)	8.18 (7.80,8.57)	**-2.94 (-5.75,-0.12)**
P-P	21.53 (20.32,22.74)	22.89 (18.85,26.92)	6.74 (-14.58,28.05)	18.10 (14.73,21.48)	22.41 (18.49,26.33)	0.24 (-35.39,35.87)	18.11 (14.73,21.48)	19.41 (16.30,22.51)	9.67 (-15.04,34.37)

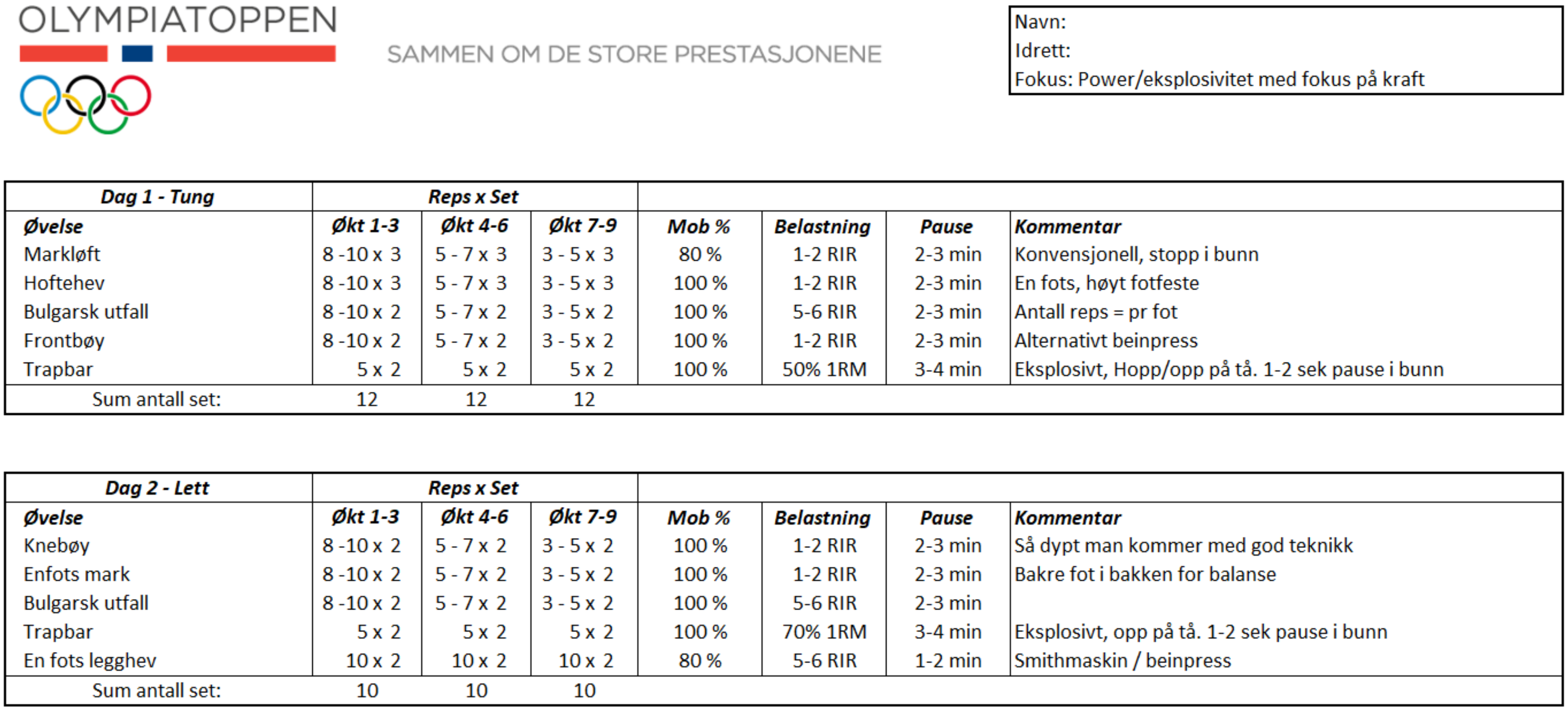
Table 6.

Test	**Balanced** vs Force		**Force** vs Velocity		**Velocity** vs Balanced	
	Mean (95% CI)	**Mean difference (95% CI)**	**Mean (95% CI)**	**Mean difference (95% CI)**	**Mean (95% CI)**	**Mean difference (95% CI)**
PA						
Right	15.25 (14.28,16.23)	-0.22 (-1.91,1.47)	15.47 (14.11,16.84)	0.65 (-1.07,2.37)	14.82 (13.76,15.89)	0.43 (-1.89,1.03)
Left	17.29 (15.94,18.64)	-0.59 (-2.95,1.77)	17.88 (15.96,19.81)	1.79 (-0.65,4.22)	16.10 (14.61,17.58)	-1.20 (-3.20,0.81)
FL						
Right	120.84 (116.09,125.59)	**10.20 (1.89,18.50)**	110.64 (103.85,117.44)	3.76 (-12.37,4.86)	114.40 (109.19,119.62)	**-6.44 (-13.48,0.61)**
Left	112.41 (107.00,117.81)	0.71 (-8.66,10.07)	111.70 (104.17,119.24)	0.52 (-8.96,9.99)	111.19 (105.33,117.04)	-1.22 (-9.30,6.86)
MT						
Right	28.77 (28.03,29.51)	0.14 (-1.19,1.46)	28.64 (27.54,29.73)	-0.65 (-2.08,0.79)	29.28 (28.44,30.12)	0.51 (-0.61,1.64)
Left	29.19 (28.27,30.12)	-0.59 (-2.21,1.04)	29.78 (28.44,31.12)	0.91 (-0.81,2.64)	28.86 (27.84,29.89)	-0.33 (-1.71,1.05)
DXA						
BF %	15.85 (14.83,16.87)	-1.39 (-3.26,0.48)	17.24 (15.72,18.76)	1.45 (-0.42,3.30)	15.80 (14.78,16.82)	-0.52 (-1.48,1.38)
FFM	78.62 (76.59,80.64)	-0.53 (-4.16,3.10)	79.14 (76.19,82.10)	2.54 (-1.08,6.16)	76.60 (74.58,78.62)	-2.02 (-4.86,0.83)
FFM-R	13.62 (13.10,14.13)	0.05 (-0.85,0.94)	13.57 (12.85,14.28)	0.02 (-0.85,0.89)	13.55 (13.05,14.06)	-0.06 (-0.79,0.67)
FFM-L	13.82 (13.37,14.27)	0.35 (-0.45,1.14)	13.47 (12.84,14.11)	-0.70 (-0.84,0.71)	13.54 (13.10,13.99)	-0.28 (-0.92,0.36)

Table 7.

	Balanced			**Force**			**Velocity**		
Test	**Baseline (95% CI)**	**Post (95% CI)**	**Change (95% CI)**	**Baseline (95% CI)**	**Post (95% CI)**	**Change (95% CI)**	**Baseline (95% CI)**	**Post (95% CI)**	**Change (95% CI)**
PA									
Right	15.58 (12.82,18.34)	15.72 (12.50,18.95)	0.70 (-7.95,9.36)	14.79 (11.79,17.78)	15.16 (13.16,17.16)	2.68 (-5.39,10.74)	14.72 (12.99,16.46)	14.45 (12.79,16.10)	-1.76 (-7.56,4.03)
Left	16.75 (12.66,20.84)	17.14(13.13,21.15)	2.65 (-1.29,6.58)	17.63 (8.98,26.28)	18.43 (14.26,22.60)	6.23 (-26.37,38.83)	16.76 (13.43,20.08)	15.95 (12.84,19.06)	-4.14 (-19.03,10.75)
FL									
Right	114.44 (84.45,144.43)	119.58 (92.14,147.02)	**5.10 (-0.21,10.41)**	123.38 (107.13,139.63)	118.47 (111.63,125.31)	-3.88 (-10.86,3.09)	112.55 (77.56,147.53)	111.22 (69.94,152.49)	-1.91 (-7.38,3.57)
Left	122.70 (75.70,169.71)	121.93 (77.63,166.23)	0.15 (-6.34,6.63)	104.93 (69.76,140.09)	104.50 (62.69,146.31)	-0.62 (-7.99,6.76)	105.03 (63.44,146.63)	104.08 (64.46,143.71)	-0.73 (-8.43,6.98)
MT									
Right	28.35 (25.21,31.49)	28.87 (25.93,31.81)	1.96 (-1.58,5.51)	30.29 (24.39,36.20)	30.72 (25.90,35.54)	1.50 (-2.60, 5.60)	26.92 (21.81,32.03)	27.92 (22.04,33.79)	**3.53 (1.11,5.95)**
Left	28.74 (27.06,30.41)	29.17 (27.25,31.09)	1.53 (-2.33,5.39)	30.36 (27.72,33.01)	31.31 (30.82,31.80)	3.22 (-6.93,13.37)	27.82 (20.94,34.71)	27.97 (21.19,34.75)	0.66 (-3.34,4.66)
DXA									
BF %	17.45 (13.63,21.27)	16.58 (13.64,19.53)	-0.87 (-1.82,0.88)	13.20 (8.96,17.44)	14.67 (8.70,20.63)	1.47 (-4.97,7.90)	17.22 (10.77,23.67)	16.35 (11.18,21.52)	-0.87 (-2.29,0.56)
FFM	76.97 (70.06,83.87)	76.45 (74.71,84.19)	3.45 (-0.43,7.33)	72.23 (65.42,79.05)	76.10 (67.65,84.55)	5.35 (-0.61,11.52)	76.78 (68.69,84.87)	77.28 (69.36,85.20)	0.73 (-2.87,4.34)
FFM-R	13.45 (11.93,14.97)	14.07 (12.70,15.44)	**4.77 (0.66,8.89)**	12.60 (9.59,15.61)	13.17 (10.94,15.39)	4.71 (-5.73,15.16)	12.75 (11.36,14.14)	13.30 (11.44,15.16)	4.14 (-0.30,8.57)
FFM-L	13.47 (11.87,15.06)	14.13 (12.65,15.61)	**5.09 (2.83,7.34)**	12.57 (9.09,16.05)	13.03 (12.24,13.83)	4.40 (-18.81,27.61)	12.98 (11.52,14.44)	13.45 (11.96,14.94)	**3.65 (0.64,6.66)**

SUPPLEMENTARY 1.



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Navn:
Idrett:
Fokus: Power/eksplosivitet med fokus på kraft

Dag 1 - Tung	***Reps x Set***						
Øvelse	***Økt 1-3***	***Økt 4-6***	***Økt 7-9***	***Mob %***	***Belastning***	***Pause***	***Kommentar***
Markløft	8 -10 x 3	5 - 7 x 3	3 - 5 x 3	80 %	1-2 RIR	2-3 min	Konvensjonell, stopp i bunn
Hoftehev	8 -10 x 3	5 - 7 x 3	3 - 5 x 3	100 %	1-2 RIR	2-3 min	En fots, høyt fotfeste
Bulgarsk utfall	8 -10 x 2	5 - 7 x 2	3 - 5 x 2	100 %	5-6 RIR	2-3 min	Antall reps = pr fot
Frontbøy	8 -10 x 2	5 - 7 x 2	3 - 5 x 2	100 %	1-2 RIR	2-3 min	Alternativt beinpress
Trapbar	5 x 2	5 x 2	5 x 2	100 %	50% 1RM	3-4 min	Eksplosivt, Hopp/opp på tå. 1-2 sek pause i bunn
Sum antall set:	12	12	12				

Dag 2 - Lett	***Reps x Set***						
Øvelse	***Økt 1-3***	***Økt 4-6***	***Økt 7-9***	***Mob %***	***Belastning***	***Pause***	***Kommentar***
Knebøy	8 -10 x 2	5 - 7 x 2	3 - 5 x 2	100 %	1-2 RIR	2-3 min	Så dypt man kommer med god teknikk
Enfots mark	8 -10 x 2	5 - 7 x 2	3 - 5 x 2	100 %	1-2 RIR	2-3 min	Bakre fot i bakken for balanse
Bulgarsk utfall	8 -10 x 2	5 - 7 x 2	3 - 5 x 2	100 %	5-6 RIR	2-3 min	
Trapbar	5 x 2	5 x 2	5 x 2	100 %	70% 1RM	3-4 min	Eksplosivt, opp på tå. 1-2 sek pause i bunn
En fots legghev	10 x 2	10 x 2	10 x 2	80 %	5-6 RIR	1-2 min	Smithmaskin / beinpress
Sum antall set:	10	10	10				

SUPPLEMENTARY 2.

OLYMPIATOPPEN

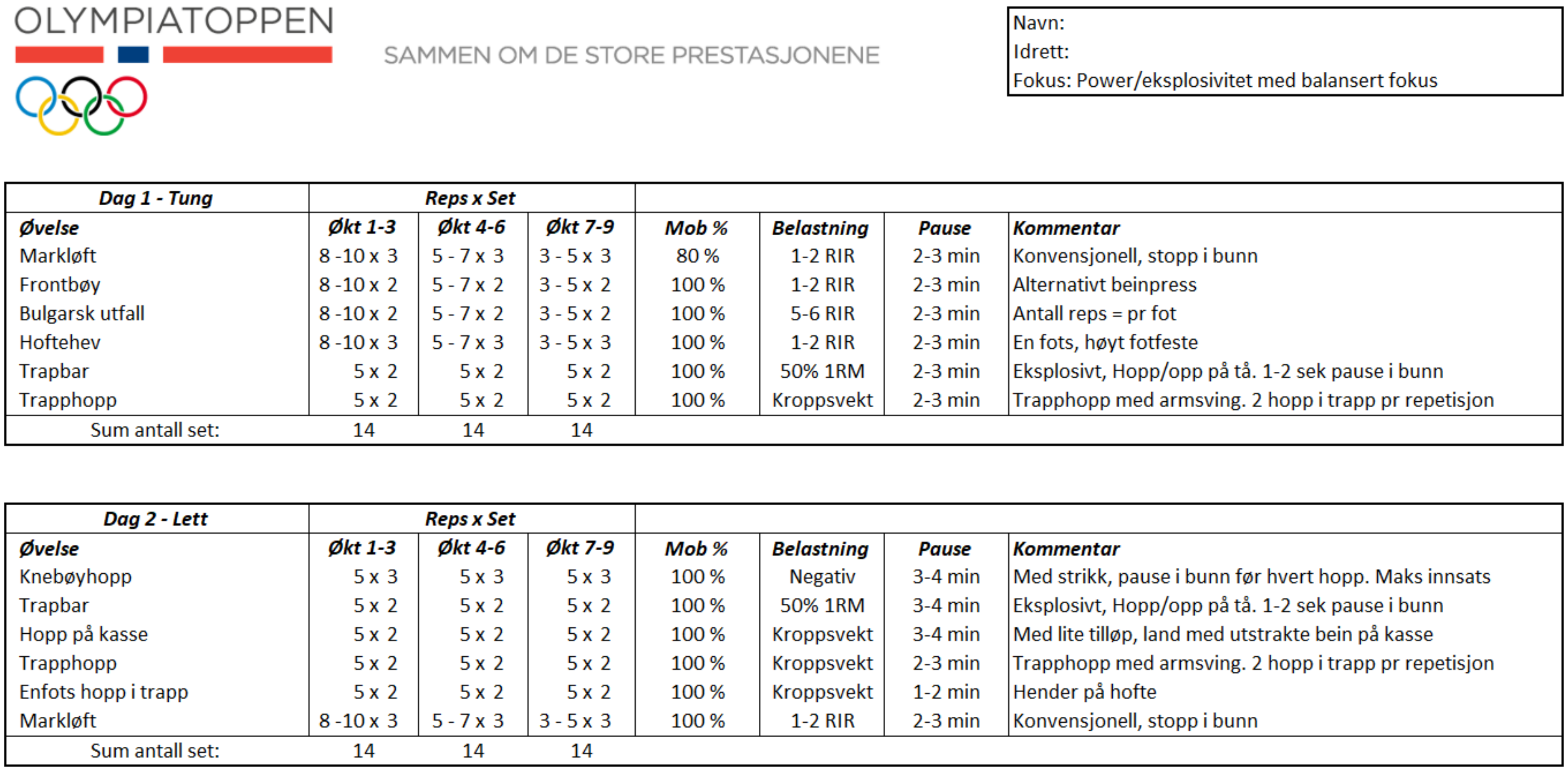
SAMMEN OM DE STORE PRESTASJONENE

Navn:
Idrett:
Fokus: Power/eksplosivitet med fokus på hastighet

Dag 1 - Tung	***Reps x Set***						
Øvelse	***Økt 1-3***	***Økt 4-6***	***Økt 7-9***	***Mob %***	***Belastning***	***Pause***	***Kommentar***
Halve knebøy	8 -10 x 3	5 - 7 x 3	3 - 5 x 3	100 %	1-2 RIR	2-3 min	Eksplosivt opp
Knebøyhopp	5 x 3	5 x 3	5 x 3	100 %	Negativ	3-4 min	Med strikk, pause i bunn før hvert hopp. Maks innsats
Trapbar	5 x 2	5 x 2	5 x 2	100 %	50% 1RM	3-4 min	Eksplosivt, Hopp/opp på tå. 1-2 sek pause i bunn
Step up	5 x 2	5 x 2	5 x 2	100 %	10–20kg	3-4 min	Med manualer, alternere per fot
Hoftehev	8 -10 x 3	5 - 7 x 3	3 - 5 x 3	100 %	1-2 RIR	2-3 min	En fots, Lavt fotfeste
Hopp over list/kosteskaft	5 x 2	5 x 2	5 x 2	100 %	Kroppsvekt	2-3 min	Partner holder eventuelt kosteskaft oppe
Sum antall set:	15	15	15				

Dag 2 - Lett	***Reps x Set***						
Øvelse	***Økt 1-3***	***Økt 4-6***	***Økt 7-9***	***Mob %***	***Belastning***	***Pause***	***Kommentar***
Knebøyhopp	5 x 3	5 x 3	5 x 3	100 %	Negativ	3-4 min	Med strikk, pause i bunn før hvert hopp. Maks innsats
Trapbar	5 x 2	5 x 2	5 x 2	100 %	50% 1RM	3-4 min	Eksplosivt, Hopp/opp på tå. 1-2 sek pause i bunn
Hopp på kasse	5 x 2	5 x 2	5 x 2	100 %	Kroppsvekt	3-4 min	Med lite tilløp, land med utstrakte bein på kasse
Clean Pull	5 x 2	5 x 2	5 x 2	100 %	50% 1RM	3-4 min	Alternativt: Knebøyhopp
Trapphopp	5 x 2	5 x 2	5 x 2	100 %	Kroppsvekt	2-3 min	Trapphopp med armsving. 2 hopp i trapp pr repetisjon
Enfots hopp i trapp	5 x 2	5 x 2	5 x 2	100 %	Kroppsvekt	1-2 min	Hender på hofte
Sum antall set:	13	13	13				

SUPPLEMENTARY 3.



OLYMPIATOPPEN

SAMMEN OM DE STORE PRESTASJONENE

Navn:
Idrett:
Fokus: Power/eksplosivitet med balansert fokus

Dag 1 - Tung	***Reps x Set***						
Øvelse	***Økt 1-3***	***Økt 4-6***	***Økt 7-9***	***Mob %***	***Belastning***	***Pause***	***Kommentar***
Markløft	8 -10 x 3	5 - 7 x 3	3 - 5 x 3	80 %	1-2 RIR	2-3 min	Konvensjonell, stopp i bunn
Frontbøy	8 -10 x 2	5 - 7 x 2	3 - 5 x 2	100 %	1-2 RIR	2-3 min	Alternativt beinpress
Bulgarsk utfall	8 -10 x 2	5 - 7 x 2	3 - 5 x 2	100 %	5-6 RIR	2-3 min	Antall reps = pr fot
Hoftehev	8 -10 x 3	5 - 7 x 3	3 - 5 x 3	100 %	1-2 RIR	2-3 min	En fots, høyt fotfeste
Trapbar	5 x 2	5 x 2	5 x 2	100 %	50% 1RM	2-3 min	Eksplosivt, Hopp/opp på tå. 1-2 sek pause i bunn
Trapphopp	5 x 2	5 x 2	5 x 2	100 %	Kroppsvekt	2-3 min	Trapphopp med armsving. 2 hopp i trapp pr repetisjon
Sum antall set:	14	14	14				

Dag 2 - Lett	***Reps x Set***						
Øvelse	***Økt 1-3***	***Økt 4-6***	***Økt 7-9***	***Mob %***	***Belastning***	***Pause***	***Kommentar***
Knebøyhopp	5 x 3	5 x 3	5 x 3	100 %	Negativ	3-4 min	Med strikk, pause i bunn før hvert hopp. Maks innsats
Trapbar	5 x 2	5 x 2	5 x 2	100 %	50% 1RM	3-4 min	Eksplosivt, Hopp/opp på tå. 1-2 sek pause i bunn
Hopp på kasse	5 x 2	5 x 2	5 x 2	100 %	Kroppsvekt	3-4 min	Med lite tilløp, land med utstrakte bein på kasse
Trapphopp	5 x 2	5 x 2	5 x 2	100 %	Kroppsvekt	2-3 min	Trapphopp med armsving. 2 hopp i trapp pr repetisjon
Enfots hopp i trapp	5 x 2	5 x 2	5 x 2	100 %	Kroppsvekt	1-2 min	Hender på hofte
Markløft	8 -10 x 3	5 - 7 x 3	3 - 5 x 3	100 %	1-2 RIR	2-3 min	Konvensjonell, stopp i bunn
Sum antall set:	14	14	14				

APPENDIX

I – Written consent
II – Training program – Force
III – Training program – Velocity
IV – Training program – Balanced
V – Additional results
VI – Additional results
VII – Additional results
VIII – Questionnaire – BREQ-2
IX – Questionnaire – SVS
X – Approval – FEK
XI – Approval – NSD

Gøran Abusdal
Tommy Larsen

University of Agder
Faculty of Health and Sport Sciences
Department of Public Health, Sport and Nutrition
May 2019

Appendix I

Infoskriv og samtykkeerklæring

Bakgrunn og hensikt

I idretter som stiller krav til hurtighet og spenst må utøveren kombinere styrketrening med tunge vekter på ene siden, samt sprint- og spenst-trening med kroppsvekt eller lett motstand på den andre. I mellom disse ytterpunktene har vi olympiske løft og «power-trening» med moderat tunge vekter. Det er en utfordring for mange utøvere å finne balansen mellom disse treningsmetodene, og i lagidretter trener ofte alle utøvere likt, selv om det er store individuelle forskjeller i fysiske styrker og svakheter. Nye studier peker i retning av en mer individualisert styrketrening, der den prioriterte metoden bestemmes av spesielle kraft-hastighets-tester. Eksempelvis bør muligens en utøver som har stor styrke, men lav hastighet, prioritere spenst- og hurtighetstrening.

Vi kan imidlertid stille spørsmålstegn ved resonnementet ovenfor, om hvorvidt idrettsutøvere bør fokusere på å forbedre «svakheter». Erfaring fra arbeid med toppidrettsutøvere i Olympiatoppen indikerer at man heller bør fokusere på å videreutvikle deres «styrker», da det er nettopp dette som ofte er årsaken til at de presterer på høyt nivå i sin idrett. Med andre ord, en utøver som har en kraft-hastighets-profil som tilsier stor styrke og lav hastighet bør kanskje prioritere tung styrketrening.

Dette er et spørsmål til deg som er idrettsutøver om å delta i et forskningsprosjekt der hensikten er å undersøke effekten av individualisert trening for kraft og hastighet. Studien blir gjennomført av forskere ved Olympiatoppen i Oslo, Region Sør og Region Øst. Testing og trening vil foregår på de respektive treningssentra i Kristiansand/Arendal og Fredrikstad.

Du må være mellom 16 og 35 år og ha erfaring med vektløfting. Du kan ikke delta om du har skader i muskelskjelettapparatet som hindrer deg i å trene og yte maks i styrke-spenst- og sprint-tester. Du kan heller ikke delta om du tar reseptbelagte medisiner som kan påvirke din fysiske prestasjonsevne eller respons på trening.

Hva innebærer det for deg å delta i denne studien?

Studien innebærer at du som deltaker gjennomfører forskjellige tester for styrke, spenst og hurtighet over 2 dager før treningsperioden. Testingen vil ta ca. 3 timer per dag, og det vil være minst 3 dager mellom testdagene. Etter testene blir dine resultater benyttet for å plassere deg i en gruppe som trener med fokus på enten (a) mot å optimalisere kraft-hastighets-forholdet (trener på dine «svakheter»), (b) trener «motsatt» og har som mål å bedre dine «styrker» (enten hastighet eller kraft) eller (c) å bedre begge egenskaper («balansert gruppe», både kraft og hastighet). Det vil være 2 økter per uke i 8 uker. Du vil bli testet igjen etter 8 uker trening.

Det bli gjennomført følgende tester:

DXA
Ultralyd
Squat Jump
Countermovement jump
30m Sprint
1RM knebøy
Keiser leg press
Kne-ekstensjon
Spørreskjema for opplevd overskudd
Spørreskjema for opplevd motivasjon

Du skal også ta en DXA-skann for å undersøke kroppssammensetning tidlig på morgenen (før frokost) på en av testdagene eller i løpet av den uken det er testing.

For utdypende informasjon om prøver og testing, se ***Vedlegg A*** under.

Mulige ulemper ved å delta i denne studien

Risiko eller ubehagene som kan oppstå i forbindelse med deltakelse anses som minimal, men mulige risikofaktorer er utdypet nedenfor:

- Tid må avsettes til testing og trening og dette KAN gå utover annen trening.
- Testing og trening kan føre til stølhet og oppfattes som smertefullt/ubehagelig.
- Det er alltid en risiko for skader ved både trening og testing,
  men disse anses ikke som større enn den treningen du er vant til fra før.
- DXA (måling av kroppssammensetning) medfører en lav røntgenstrålingsdose, men anses ikke som farlig og tilsvarer dosen en utsettes for under en interkontinental flyreise.

Fordeler ved å delta i denne studien

Ved å delta i studien vil du få informasjon som kan være til nytte for din trening:

- Du vil få målt dine styrke- og poweregenskaper
- Du vil få informasjon om din kroppssammensetning
- Du vil få mer informasjon om hvordan spesifikk trening virker på deg

Informasjonen kan hjelpe deg i forbindelse med å optimalisere fremtidige trening. Etter at alle data er gjennomgått vil du motta en personlig skriftlig tilbakemelding på alt som vi har målt på deg under intervensjonen. Din deltakelse bidrar til informasjon for fremtidige idrettsutøvere.

Hva skjer hvis du blir skadet fordi du deltok i denne studien?

Hvis du blir skadet eller blir syk på grunn av deltakelse i denne studien, kontakt Paul Solberg (Telefon: +47 990 94 092) eller Thomas Bjørnsen (Telefon: +47 986 19 299) umiddelbart. Medisinsk behandling vil være tilgjengelig via våre avtaler.

Hvilken informasjon vil bli samlet inn og hva skjer med informasjonen om deg?

Hvis du velger å være i denne studien, vil forskerne få følgende informasjon om deg, inkludert informasjon som kan identifisere deg: alder, tjenestetid, høyde, vekt, kroppsfett, fettfri masse, spenst, styrke, samt informasjon som er relatert til muskelvekst, tilpasning til trening. Samlet vil denne informasjonen benyttes av forskerne til å undersøke effekten av spesifikk trening på idrettsrelaterte egenskaper (Power). Alle testresultater vil bli behandlet uten navn og fødselsnummer eller andre direkte persongjenkjennende opplysninger. En kode knytter deg til dine opplysninger og resultater gjennom en navneliste. Det er kun prosjektleder som har adgang til navnelisten og kan finne tilbake til deg. Listen destrueres så snart studien er gjennomført. Det vil ikke være mulig å identifisere deg i resultatene av studien når disse publiseres.

Du kan ombestemme deg og tilbakekalle din tillatelse til å samle inn eller bruke dine data underveis i studien, så sant de ikke er benyttet i analyser eller publisert. For å tilbakekalle din tillatelse må du skrive til en av de ansvarlige for studien, Paul Solberg, på paul.solberg@olympiatoppen.no eller Thomas Bjørnsen på thomas.bjornsen@uia.no. Når du opphever din tillatelse, vil ingen ny informasjon om deg bli samlet etter den datoen, og du vil ikke lenger få lov til å delta i studien. Se forøvrig *Vedlegg B*.

Ved å signere denne samtykkeformen gir du tillatelse til å bruke resultatene til de formål som er beskrevet i dette skrivet. Hvis du nekter å gi tillatelse, vil du ikke kunne være i denne studien.

Frivillig deltakelse

Det er frivillig å delta i studien. Du kan når som helst og uten å oppgi noen grunn trekke ditt samtykke til å delta i studien. Dersom du ønsker å delta, undertegner du samtykkeerklæringen på siste side. Om du nå sier ja til å delta, kan du senere, når som helst og uten å oppgi grunn, trekke tilbake ditt samtykke uten at det har noen konsekvenser for deg. Dersom du ønsker å trekke deg eller har spørsmål til studien, kan du kontakte Gøran Paulsen, fagansvarlig for Olympiatoppen Sentralt (goran.paulsen@olympiatoppen.no), Paul Solberg, PhD, faglig leder Olympiatoppen Øst (paul.solberg@olympiatoppen.no, tlf: +47 990 94 092), eller Thomas Bjørnsen, fagansvarlig kraft/styrke Olympiatoppen Sør (thomas.bjornsen@uia.no, tlf: +47 986 19 299). Hvis du velger å forlate studien, fortell studiepersonalet så snart du kan, slik at de kan sikre et ordentlig uttak.

Hva om du har spørsmål om studien?

Ikke skriv inn denne samtykkeformularen med mindre du har hatt mulighet til å stille spørsmål og har mottatt tilfredsstillende svar på alle dine spørsmål. For spørsmål om forskningen, kontakt Paul Solberg (Tlf: +47 990 94 092, mail: paul.solberg@olympiatoppen.no) eller Thomas Bjørnsen (Tlf: +47 986 19 299, mail: thomas.bjornsen@uia.no).

Ytterligere informasjon om studien finnes i kapittel A –
Utdypende forklaring av hva studien innebærer.

Ytterligere informasjon om biobank, personvern og forsikring finnes i kapittel B –
Personvern, økonomi og forsikring.

Samtykkeerklæring følger etter kapittel B

Kapittel A – Utdypende forklaring av hva studien innebærer

Kriterier for deltakelse

1. Alder 16–35 år
2. Utøver på minimum nasjonalt nivå
3. Trener styrke regelmessig
4. Ingen betydningsfulle skader, sykdommer eller medisinbruk
5. Ikke-røyker

Tester, trening og annet den inkluderte må gjennom

Tester gjennomføres 2 ganger over 2 uker under intervensjonsperioden (Før start og etter). Følgende tester gjennomføres alle gangene:

1. Spenst på kraftplattform: Knebøyhopp og svikthopp med 5 ulike motstander
2. 30 meter sprint
3. Knebøy – 1RM
4. Benpress (Keiser): Sittende benpress med 10 motstander
5. Kne-ekstensjon: 5 ulike motstander per ben (40-50-60-70-80 kg)

6. Kroppssammensetningsmåling (Lunar iDXA)
7. Ultralyd: Måling av lårmusklenes tverrsnittsareal og pennasjonsvinkel
8. Spørreskjema for opplevd overskudd og motivasjon (SVS & BREQ-2)

Intervensjonen

Etter at oppstartstestene er gjennomført vil dine resultater benyttes til å undersøke om du er styrke-dominert, hastighets-dominert eller midt i mellom. Deretter vil du plasseres i en gruppe som (a) trener spesifikt for å utligne dominansen og dermed øke power (arbeidskapasitet), (b) trener «motsatt» og har som mål å bedre sine «styrker» (enten hastighet eller kraft) eller (c) en «balansert gruppe» som trener mot å bedre begge egenskaper (kraft og hastighet).

De 3 gruppene trener 2 økter per uke i totalt 8 uker, der man enten har fokus på styrkeøkter med typiske baseøvelser og styrketrening (1-12RM), hastighetsfokus som trener sprint- og spensttrening med kroppsvekt eller lett motstand, eller «power-trening» med moderat tunge vekter.

Tidsskjema – Hva skjer og når skjer det?

Testing og trening er planlagt gjennomført høsten 2018 og totalt vil forsøket vare i 10 uker inkludert testing.

Eventuell kompensasjon til og dekning av utgifter for deltakere

Det er ingen økonomisk kompensasjon i forbindelse med studien.

Deltakers ansvar

1. Komme til avtalte tider og følge retningslinjer for forberedelser til trening og testing
2. Registrere treningen i en dagbok

Kapittel B – Personvern, økonomi og forsikring

Personvern

Opplysninger som registreres om deg er idrettsgren, nivå, alder, høyde, vekt, fettmasse, muskelmasse, maksimal styrke, spenst, power, treningsbakgrunn, og trening som gjennomføres utenfor prosjektet.

Alle data er anonymisert og du vil ikke kunne identifiseres.
Universitetet i Agder ved professor Sveinung Berntsen er databehandlingsansvarlig.

Rett til innsyn og sletting av opplysninger om deg og sletting av prøver

Hvis du sier ja til å delta i studien, har du rett til å få innsyn i hvilke opplysninger som er registrert om deg. Du har videre rett til å få korrigert eventuelle feil i de opplysningene vi har registrert. Dersom du trekker deg fra studien, kan du kreve å få slettet innsamlede prøver og opplysninger, med mindre opplysningene allerede er inngått i analyser eller brukt i vitenskapelige publikasjoner.

Økonomi

Studien er finansiert gjennom forskningsmidler fra Olympiatoppens FoU-midler.
Det er ingen interessekonflikter forbundet med studien.

Forsikring

Alle som testes og trener i Olympiatoppens lokaler er forsikret.

Informasjon om utfallet av studien

Du vil få informasjon om resultatene av studien. Det vil bli gjennomført en presentasjon på et informasjonsmøte for forsøkspersonene i etterkant av studien. Resultatene vil bli publisert i et internasjonalt tidsskrift.

Samtykke til å delta i denne studien

Du har lest informasjonen i dette samtykket. Du har fått anledning til å stille spørsmål om denne studien, dens prosedyrer og risiko, samt andre opplysninger i denne samtykkeformen. Alle dine spørsmål er blitt besvart, og du forstår at dette er forskning. Ved å signere under, gir du ditt samtykke til å være i denne undersøkelsen, og du gir autorisasjon til bruk og avsløring av din fysiske informasjon til personer som er oppført i dette samtykket i henhold til de formål som er beskrevet ovenfor. Du har fått en kopi av denne informasjonen og en erklæring som informerer deg om bestemmelsene i Personvernloven.

Jeg er villig til å delta i studien

____

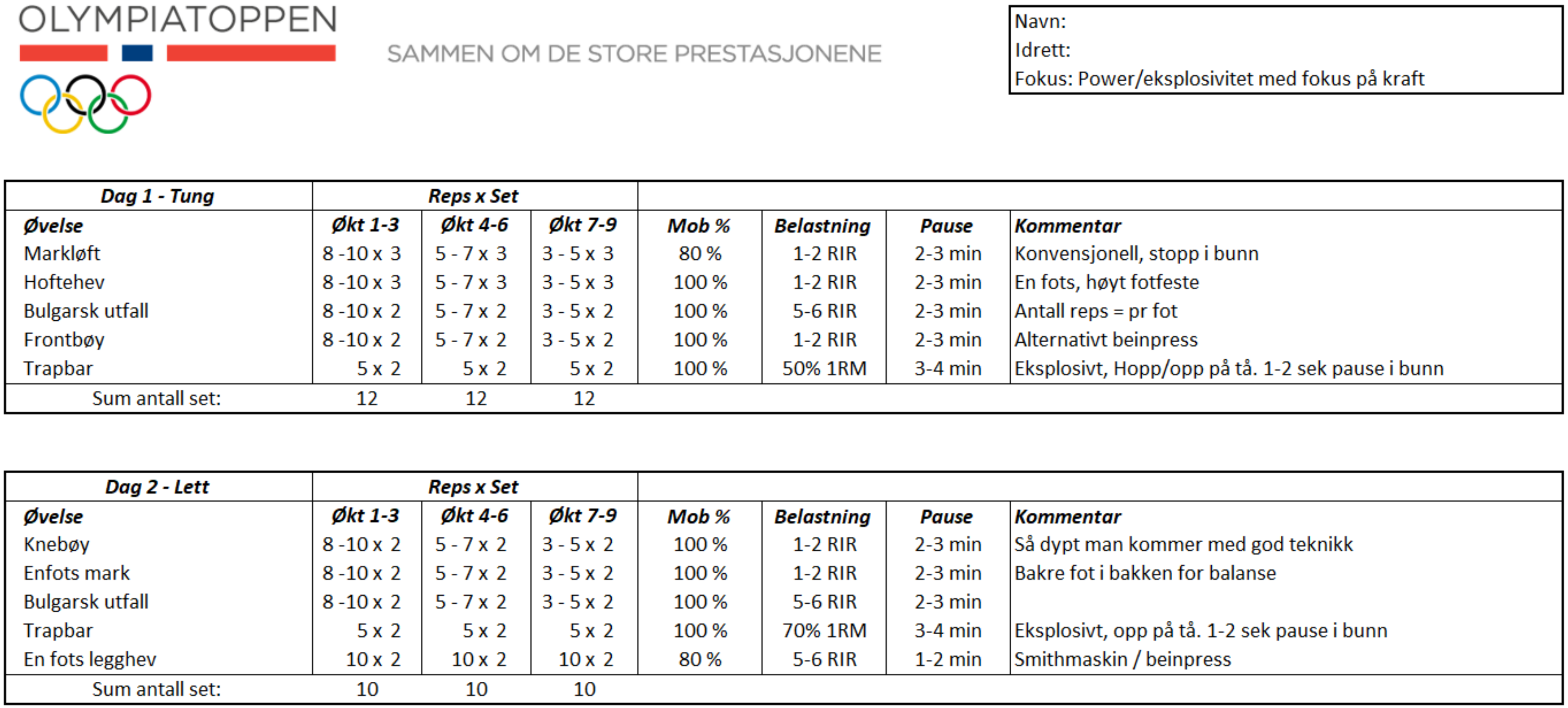
(Signert av prosjektdeltaker, dato)

Jeg bekrefter å ha gitt informasjon om studien

____

(Signert av prosjektleder, dato)

Appendix II



OLYMPIATOPPEN

SAMMEN OM DE STORE PRESTASJONENE

Navn:
Idrett:
Fokus: Power/eksplosivitet med fokus på kraft

Dag 1 - Tung	***Reps x Set***						
Øvelse	***Økt 1-3***	***Økt 4-6***	***Økt 7-9***	***Mob %***	***Belastning***	***Pause***	***Kommentar***
Markløft	8 -10 x 3	5 - 7 x 3	3 - 5 x 3	80 %	1-2 RIR	2-3 min	Konvensjonell, stopp i bunn
Hoftehev	8 -10 x 3	5 - 7 x 3	3 - 5 x 3	100 %	1-2 RIR	2-3 min	En fots, høyt fotfeste
Bulgarsk utfall	8 -10 x 2	5 - 7 x 2	3 - 5 x 2	100 %	5-6 RIR	2-3 min	Antall reps = pr fot
Frontbøy	8 -10 x 2	5 - 7 x 2	3 - 5 x 2	100 %	1-2 RIR	2-3 min	Alternativt beinpress
Trapbar	5 x 2	5 x 2	5 x 2	100 %	50% 1RM	3-4 min	Eksplosivt, Hopp/opp på tå. 1-2 sek pause i bunn
Sum antall set:	12	12	12				

Dag 2 - Lett	***Reps x Set***						
Øvelse	***Økt 1-3***	***Økt 4-6***	***Økt 7-9***	***Mob %***	***Belastning***	***Pause***	***Kommentar***
Knebøy	8 -10 x 2	5 - 7 x 2	3 - 5 x 2	100 %	1-2 RIR	2-3 min	Så dypt man kommer med god teknikk
Enfots mark	8 -10 x 2	5 - 7 x 2	3 - 5 x 2	100 %	1-2 RIR	2-3 min	Bakre fot i bakken for balanse
Bulgarsk utfall	8 -10 x 2	5 - 7 x 2	3 - 5 x 2	100 %	5-6 RIR	2-3 min	
Trapbar	5 x 2	5 x 2	5 x 2	100 %	70% 1RM	3-4 min	Eksplosivt, opp på tå. 1-2 sek pause i bunn
En fots legghev	10 x 2	10 x 2	10 x 2	80 %	5-6 RIR	1-2 min	Smithmaskin / beinpress
Sum antall set:	10	10	10				

Dato:										
Markløft										
Hoftehev										
Bulgarsk utfall										
Frontbøy										
Trapbar										
Kommentarer:										

Dato:										
Knebøy										
Enfots mark										
Bulgarsk utfall										
Trapbar										
En fots legghev										
Kommentarer:										

Appendix III

OLYMPIATOPPEN

SAMMEN OM DE STORE PRESTASJONENE

Navn:
Idrett:
Fokus: Power/eksplosivitet med fokus på hastighet

Dag 1 - Tung	**Reps x Set**						
Øvelse	**Økt 1-3**	**Økt 4-6**	**Økt 7-9**	**Mob %**	**Belastning**	**Pause**	**Kommentar**
Halve knebøy	8 -10 x 3	5 - 7 x 3	3 - 5 x 3	100 %	1-2 RIR	2-3 min	Eksplosivt opp
Knebøyhopp	5 x 3	5 x 3	5 x 3	100 %	Negativ	3-4 min	Med strikk, pause i bunn før hvert hopp. Maks innsats
Trapbar	5 x 2	5 x 2	5 x 2	100 %	50% 1RM	3-4 min	Eksplosivt, Hopp/opp på tå. 1-2 sek pause i bunn
Step up	5 x 2	5 x 2	5 x 2	100 %	10–20kg	3-4 min	Med manualer, alternere per fot
Hoftehev	8 -10 x 3	5 - 7 x 3	3 - 5 x 3	100 %	1-2 RIR	2-3 min	En fots, Lavt fotfeste
Hopp over list/kosteskaft	5 x 2	5 x 2	5 x 2	100 %	Kroppsvekt	2-3 min	Partner holder eventuelt kosteskaft oppe
Sum antall set:	15	15	15				

Dag 2 - Lett	**Reps x Set**						
Øvelse	**Økt 1-3**	**Økt 4-6**	**Økt 7-9**	**Mob %**	**Belastning**	**Pause**	**Kommentar**
Knebøyhopp	5 x 3	5 x 3	5 x 3	100 %	Negativ	3-4 min	Med strikk, pause i bunn før hvert hopp. Maks innsats
Trapbar	5 x 2	5 x 2	5 x 2	100 %	50% 1RM	3-4 min	Eksplosivt, Hopp/opp på tå. 1-2 sek pause i bunn
Hopp på kasse	5 x 2	5 x 2	5 x 2	100 %	Kroppsvekt	3-4 min	Med lite tilløp, land med utstrakte bein på kasse
Clean Pull	5 x 2	5 x 2	5 x 2	100 %	50% 1RM	3-4 min	Alternativt: Knebøyhopp
Trapphopp	5 x 2	5 x 2	5 x 2	100 %	Kroppsvekt	2-3 min	Trapphopp med armsving. 2 hopp i trapp pr repetisjon
Enfots hopp i trapp	5 x 2	5 x 2	5 x 2	100 %	Kroppsvekt	1-2 min	Hender på hofte
Sum antall set:	13	13	13				

Dato:									
Markløft									
Frontbøy									
Bulgarsk utfall									
Hoftehev									
Trapbar									
Trapphopp									
Kommentarer:									

Dato:									
Knebøyhopp									
Trapbar									
Hopp på kasse									
Trapphopp									
Enfots hopp i trapp									
Markløft									
Kommentarer:									

Appendix IV

OLYMPIATOPPEN

SAMMEN OM DE STORE PRESTASJONENE

Navn:
Idrett:
Fokus: Power/eksplosivitet med balansert fokus

Dag 1 - Tung	*Reps x Set*						
Øvelse	***Økt 1-3***	***Økt 4-6***	***Økt 7-9***	***Mob %***	***Belastning***	***Pause***	***Kommentar***
Markløft	8 -10 x 3	5 - 7 x 3	3 - 5 x 3	80 %	1-2 RIR	2-3 min	Konvensjonell, stopp i bunn
Frontbøy	8 -10 x 2	5 - 7 x 2	3 - 5 x 2	100 %	1-2 RIR	2-3 min	Alternativt beinpress
Bulgarsk utfall	8 -10 x 2	5 - 7 x 2	3 - 5 x 2	100 %	5-6 RIR	2-3 min	Antall reps = pr fot
Hoftehev	8 -10 x 3	5 - 7 x 3	3 - 5 x 3	100 %	1-2 RIR	2-3 min	En fots, høyt fotfeste
Trapbar	5 x 2	5 x 2	5 x 2	100 %	50% 1RM	2-3 min	Eksplosivt, Hopp/opp på tå. 1-2 sek pause i bunn
Trapphopp	5 x 2	5 x 2	5 x 2	100 %	Kroppsvekt	2-3 min	Trapphopp med armsving. 2 hopp i trapp pr repetisjon
Sum antall set:	14	14	14				

Dag 2 - Lett	*Reps x Set*						
Øvelse	***Økt 1-3***	***Økt 4-6***	***Økt 7-9***	***Mob %***	***Belastning***	***Pause***	***Kommentar***
Knebøyhopp	5 x 3	5 x 3	5 x 3	100 %	Negativ	3-4 min	Med strikk, pause i bunn før hvert hopp. Maks innsats
Trapbar	5 x 2	5 x 2	5 x 2	100 %	50% 1RM	3-4 min	Eksplosivt, Hopp/opp på tå. 1-2 sek pause i bunn
Hopp på kasse	5 x 2	5 x 2	5 x 2	100 %	Kroppsvekt	3-4 min	Med lite tilløp, land med utstrakte bein på kasse
Trapphopp	5 x 2	5 x 2	5 x 2	100 %	Kroppsvekt	2-3 min	Trapphopp med armsving. 2 hopp i trapp pr repetisjon
Enfots hopp i trapp	5 x 2	5 x 2	5 x 2	100 %	Kroppsvekt	1-2 min	Hender på hofte
Markløft	8 -10 x 3	5 - 7 x 3	3 - 5 x 3	100 %	1-2 RIR	2-3 min	Konvensjonell, stopp i bunn
Sum antall set:	14	14	14				

Dato:									
Markløft									
Frontbøy									
Bulgarsk utfall									
Hoftehev									
Trapbar									
Trapphopp									
Kommentarer:									

Dato:									
Knebøyhopp									
Trapbar									
Hopp på kasse									
Trapphopp									
Enfots hopp i trapp									
Markløft									
Kommentarer:									

Appendix V

	Force			Velocity			Balanced		
Test	F_0	V_0	P_{max}	F_0	V_0	P_{max}	F_0	V_0	P_{max}
SJ	↓	**	↑	**	**	↑	↑	**	**
CMJ	↓	↑	↓	**	**	**	↓	↑	↑
LE	*	↑	**	↑	↑	**	↑	*	**
Keiser	↑	↑	↑	↓	**	↑	↓	↑	↑
	Time	***Peak-V***	***Peak-P***	***Time***	***Peak-V***	***Peak-P***	***Time***	***Peak-V***	***Peak-P***
30m Sprint	↓	↑	↑	↓	**	↑	↓	↓	↑
1RM Squat		↑			↑			**	

SJ, squat jump; CMJ, countermovement jump; LE, leg extension; Keiser, Keiser leg press; Peak-V, peak velocity; Peak-P, peak power; **, value of significance ($p \leq 0.05$); *, tendency of significant value ($p \leq 0.10$); Force, force group; Velocity, velocity group; Balanced, balanced group.

Appendix VI

	Force		Velocity		Balanced	
Test	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
<u>**Ultrasound**</u>						
PA	↑	↑	↓	↓	↑	↑
FL	↓	↓	↓	↓	**	↑
MT	↑	↑	**	↑	↑	↑
<u>**DXA**</u>						
BF (%)	↑		↓		*	
FFM	*		↑		*	
FFM-R	↑		*		**	
FFM-L	↑		**		**	

Left, left leg; Right, right leg; PA, pennation angle; FL, fascicle length; MT, muscle thickness, BF%, body fat percentage; FFM, fat-free mass; FFM-R, fat-free mass right leg: FFM-L, fat-free mass left leg. **, value of significance ($p \leq 0.05$); *, tendency of significant value ($p \leq 0.10$). Force, force group; Velocity, velocity group; Balanced, balanced group.

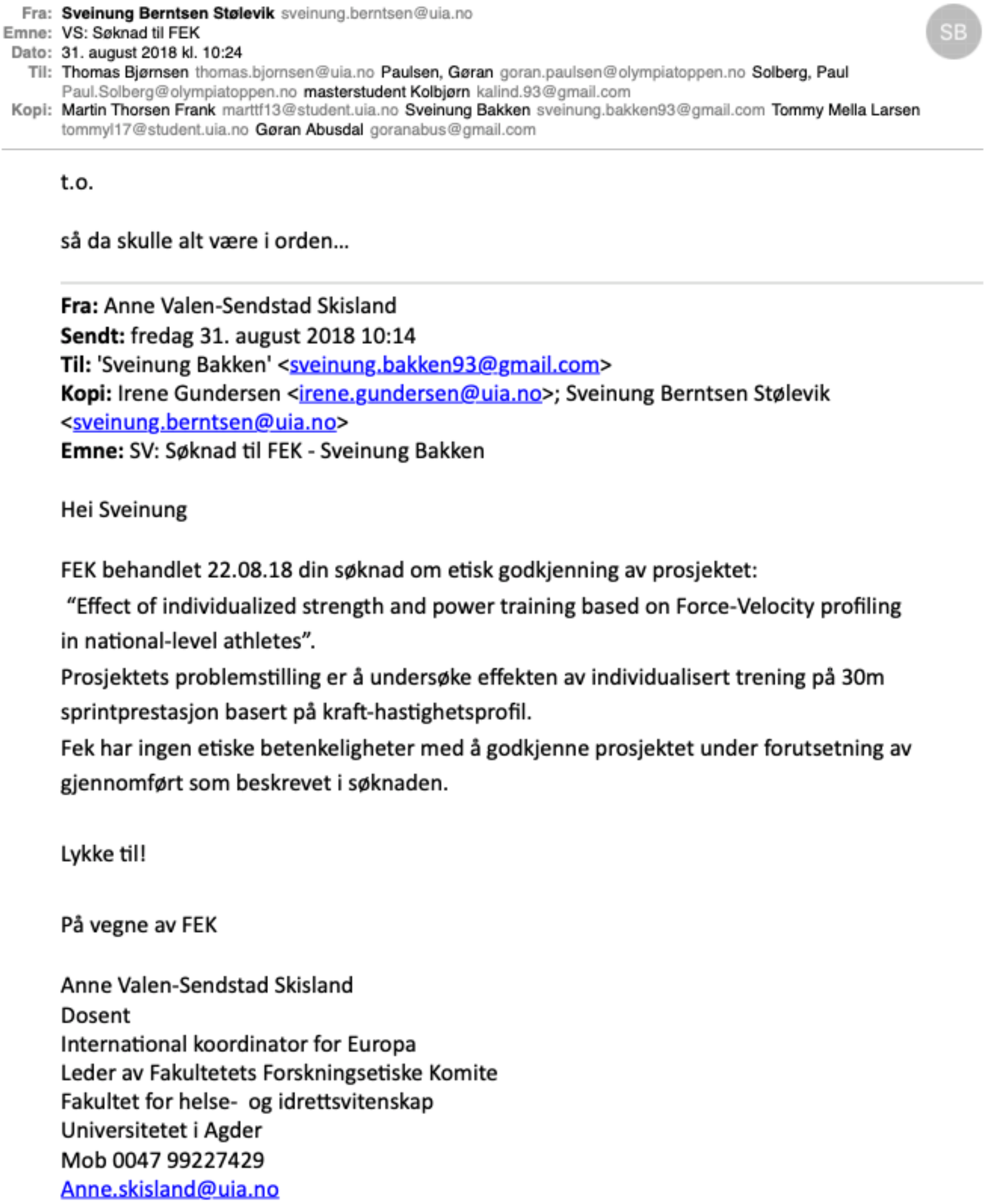
Appendix VII

Test	Force	Velocity	Balanced
SJ			
Bodyweight	↑	↑	**
0.1 kg	↑	**	↑
20 kg	↑	**	**
40 kg	↓	↑	**
60 kg	↓	↑	↑
80 kg	↓	↓	↑
CMJ			
Bodyweight	**	**	**
0.1 kg	↑	**	↑
20 kg	↓	↑	↑
40 kg	↑	↓	↑
60 kg	↑	↓	↑
80 kg	↑	↓	↑

**, value of significance ($p \leq 0.05$); *, tendency of significant value ($p \leq 0.10$). SJ, squat jump; CMJ, countermovement jump; Force, force group; Velocity, velocity group; Balanced, balanced group.

Appendix VIII

Godkjenning fra FEK



Fra: **Sveinung Berntsen Stølevik** sveinung.berntsen@uia.no
Emne: VS: Søknad til FEK
Dato: 31. august 2018 kl. 10:24
Til: Thomas Bjørnsen thomas.bjornsen@uia.no Paulsen, Gøran goran.paulsen@olympiatoppen.no Solberg, Paul Paul.Solberg@olympiatoppen.no masterstudent Kolbjørn kalind.93@gmail.com
Kopi: Martin Thorsen Frank marttf13@student.uia.no Sveinung Bakken sveinung.bakken93@gmail.com Tommy Mella Larsen tommyl17@student.uia.no Gøran Abusdal goranabus@gmail.com

t.o.

så da skulle alt være i orden...

Fra: Anne Valen-Sendstad Skisland
Sendt: fredag 31. august 2018 10:14
Til: 'Sveinung Bakken' <sveinung.bakken93@gmail.com>
Kopi: Irene Gundersen <irene.gundersen@uia.no>; Sveinung Berntsen Stølevik <sveinung.berntsen@uia.no>
Emne: SV: Søknad til FEK - Sveinung Bakken

Hei Sveinung

FEK behandlet 22.08.18 din søknad om etisk godkjenning av prosjektet:
"Effect of individualized strength and power training based on Force-Velocity profiling in national-level athletes".
Prosjektets problemstilling er å undersøke effekten av individualisert trening på 30m sprintprestasjon basert på kraft-hastighetsprofil.
Fek har ingen etiske betenkeligheter med å godkjenne prosjektet under forutsetning av gjennomført som beskrevet i søknaden.

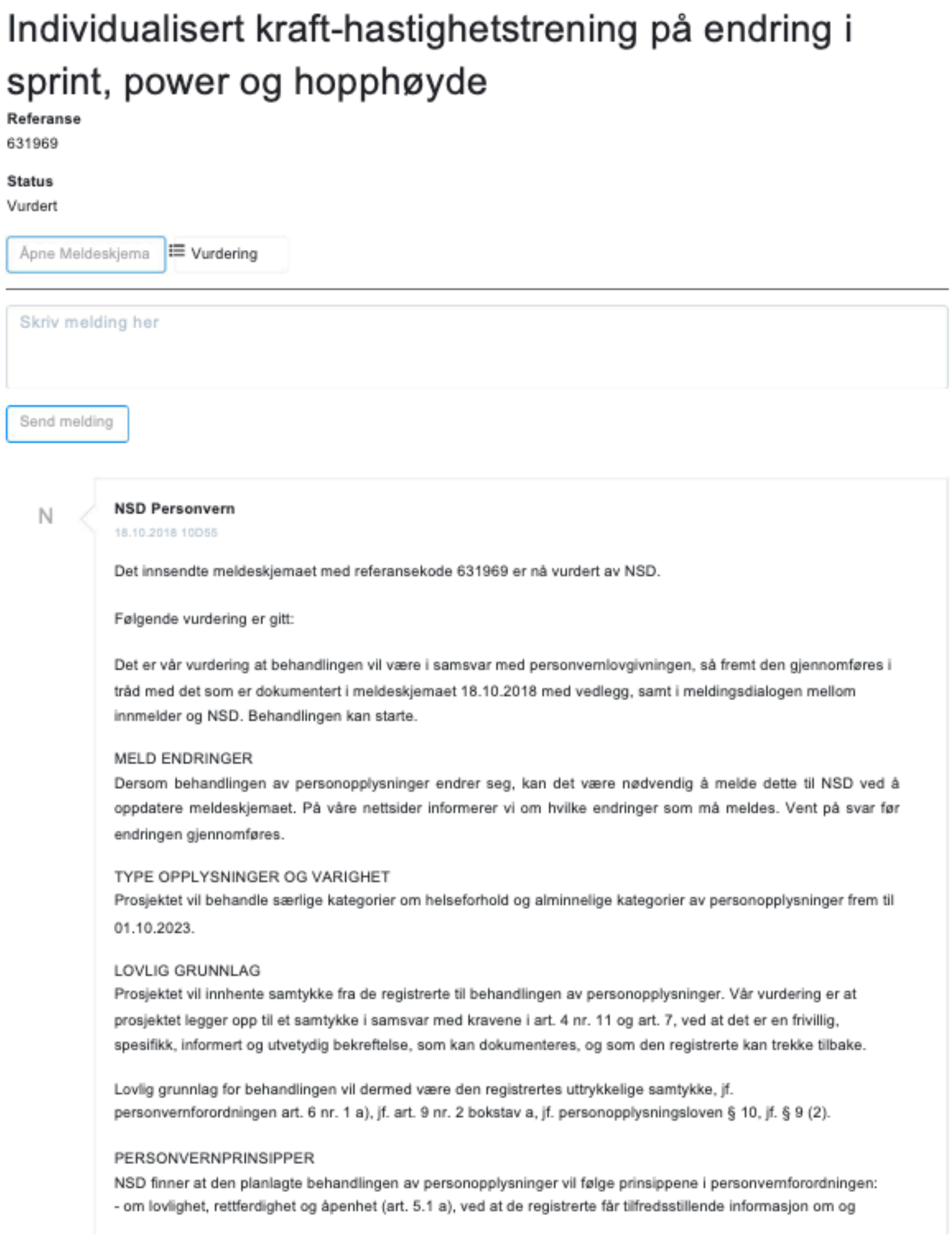
Lykke til!

På vegne av FEK

Anne Valen-Sendstad Skisland
Dosent
International koordinator for Europa
Leder av Fakultetets Forskningsetiske Komite
Fakultet for helse- og idrettsvitenskap
Universitetet i Agder
Mob 0047 99227429
Anne.skisland@uia.no

Appendix IX

Godkjenning fra NSD



Individualisert kraft-hastighetstrening på endring i sprint, power og hopphøyde

Referanse
631969

Status
Vurdert

NSD Personvern
18.10.2018 10D55

Det innsendte meldeskjemaet med referansekode 631969 er nå vurdert av NSD.

Følgende vurdering er gitt:

Det er vår vurdering at behandlingen vil være i samsvar med personvernlovgivningen, så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet 18.10.2018 med vedlegg, samt i meldingsdialogen mellom innmelder og NSD. Behandlingen kan starte.

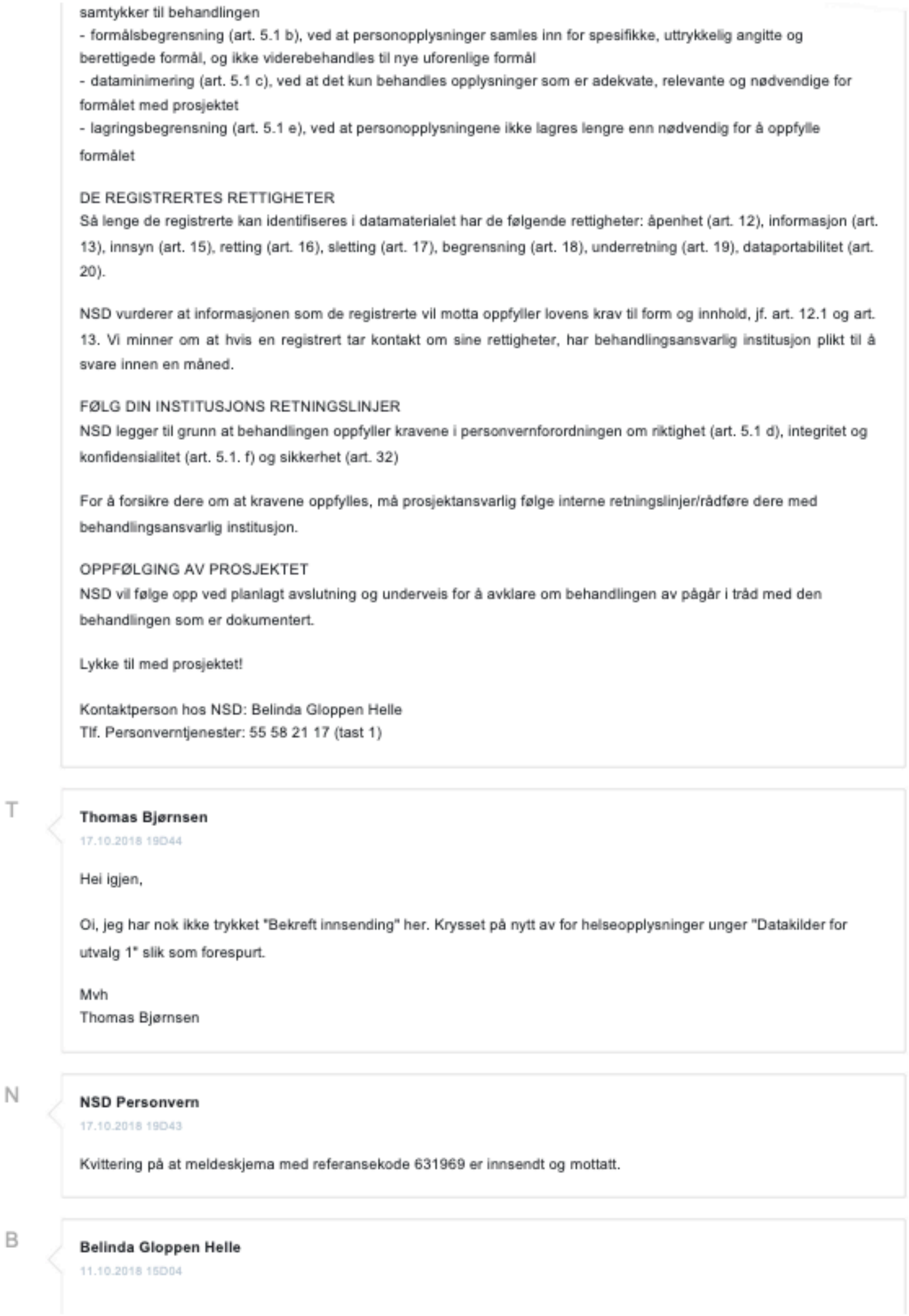
MELD ENDRINGER
Dersom behandlingen av personopplysninger endrer seg, kan det være nødvendig å melde dette til NSD ved å oppdatere meldeskjemaet. På våre nettsider informerer vi om hvilke endringer som må meldes. Vent på svar før endringen gjennomføres.

TYPE OPPLYSNINGER OG VARIGHET
Prosjektet vil behandle særlige kategorier om helseforhold og alminnelige kategorier av personopplysninger frem til 01.10.2023.

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 a), jf. art. 9 nr. 2 bokstav a, jf. personopplysningsloven § 10, jf. § 9 (2).

PERSONVERNPRINSIPPER
NSD finner 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 har de 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)

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

OPPFØLGING AV PROSJEKTET
NSD vil følge opp ved planlagt avslutning og underveis for å avklare om behandlingen av pågår i tråd med den behandlingen som er dokumentert.

Lykke til med prosjektet!

Kontaktperson hos NSD: Belinda Gloppen Helle
Tlf. Personverntjenester: 55 58 21 17 (tast 1)

Thomas Bjørnsen
17.10.2018 19D44

Hei igjen,

Oi, jeg har nok ikke trykket "Bekreft innsending" her. Krysset på nytt av for helseopplysninger unger "Datakilder for utvalg 1" slik som forespurt.

Mvh
Thomas Bjørnsen

NSD Personvern
17.10.2018 19D43

Kvittering på at meldeskjema med referansekode 631969 er innsendt og mottatt.

Belinda Gloppen Helle
11.10.2018 15D04