Precision of Different Methods to Assess Lower Limb Force-Velocity Relationship

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Abbreviations

CMJ	Countermovement jump
CV	Coefficient of variation
F	Force
F_0	Theoretical maximal force
F-V	Force-Velocity
ICC	Intraclass correlation coefficient
P	Power
P_{max}	Maximal power output
S_{FV}	Force-Velocity slope
SJ	Squat jump
V	Velocity
V_0	Theoretical maximal velocity

ABSTRACT

INTRODUCTION. Earlier studies have reported large variability in the reliability of different measuring methods in Force-Velocity (F-V) tests. Further, the agreement in training-induced changes between measuring methods is not known. Therefore, the aim of the present study was to investigate the realiability and agreement of seven different meauring methods during squat jump (SJ), countermovement jump (CMJ) and leg-press.

METHODS. F-V parameters (F_0= theoretical maximal force, V_0= theoretical maximal velocity, P_{max}= maximal power, S_{FV}= F-V slope) were derived from Force plate, Linear position transducer and Contact grid during SJ and CMJ, and with Keiser leg-press. Twenty-seven (20 ± 5 years, 182 ± 8 cm, 76 ± 14 kg) highly-trained athletes performed SJ and CMJ under five loading conditions (0.1-80kg) and an incremental F-V test in Keiser leg-press at two baseline trails, followed by a 10 week power-training intervention before two post-intervention trials.

RESULTS. The different measuring methods displayed a large variability in the four F-V parameters: F_0: coefficient of variation (CV)= 6.0-11.2%; intraclass correlation coefficient (ICC)= 0.31-0.92, V_0: CV= 6.3-22.1%; ICC= 0.23-0.79, P_{max}: CV= 4.2-14.2%; ICC= 0.33-0.92, S_{FV}: CV= 12.4-31.9%; ICC= 0.19-0.94.

CONCLUSION. The results in the present study indicate that Keiser leg-press and the Linear position transducer in CMJ were the most reliable measuring methods to assess the F-V relationship in highly-trained national team athletes. The poor agreements to detect training-induced changes between methods indicate that they should not be used interchangeably. Due to the moderate-to-poor reliability in F-V slope (S_{FV}), one should be careful to use it as a monitoring tool in athletes.

KEYWORDS. Squat jump, countermovement jump, leg-press, reliability, highly-trained athletes

SAMMENDRAG

INTRODUKSJON. Tidligere studier har rapportert stor variasjon i reliabilitet til forskjellige målemetoder i Kraft-Hastighets (K-H)-tester. Videre er samvariasjonen i treningsinduserte endringer mellom målemetoder ikke kjent. Derfor var målet med den foreliggende studien å undersøke reliabiliteten og samvariasjonen til syv forskjellige målemetoder i knebøyhopp, svikthopp og benpress.

METODE. K-H-parametere (F_0= teoretisk maksimal kraft, V_0= teoretisk maksimal hastighet, P_{max}= maksimal effekt, S_{FV}= K-H-regresjonslinje) ble uthentet fra kraftplattform, Lineær posisjontransduser og Kontaktmatte under øvelsene knebøyhopp og svikthopp, og med Keiser benpress. Tjuesyv (20 ± 5 år, 182 ± 8 cm, 76 ± 14 kg) elite-utøvere utførte knebøyhopp og svikthopp under fem belastninger (0,1-80 kg) og en trinnvis økende K-H-test i Keiser benpress ved to baseline-tester, etterfulgt av en 10 ukers styrketrenings-intervensjon før to post-tester.

RESULTATER. De syv ulike målemetodene viste stor variasjon i de fire K-H-parametrene: F_0: coefficient of variation (CV)= 6.0-11.2%; intraclass correlation coefficient (ICC)= 0.31-0.92, V_0: CV= 6.3-22.1%; ICC= 0.23-0.79, P_{max}: CV= 4.2-14.2%; ICC= 0.33-0.92, S_{FV}: CV= 12.4-31.9%; ICC= 0.19-0.94.

KONKLUSJON. Resultatene i den foreliggende studien indikerer at Keiser benpress og den lineære posisjonstransduseren brukt i svikthopp var de mest pålitelige målemetodene for å undersøke K-H-forholdet på utøvere av nasjonalt nivå. Den svake samvariasjonen mellom målemetoder til å oppdage treningsinduserte endringer indikerer at de ikke bør brukes om hverandre. På grunn av den store målevariasjonen i K-H-regresjonslinjen (S_{FV}), bør man være forsiktig med å bruke den som et treningsverktøy på idrettsutøvere.

NØKKELORD: Styrketrening, kraft-hastighet, reliabilitet, knebøyhopp, svikthopp, benpress

DELIMITATION OF THE THESIS

The thesis is divided into two parts, where part 1 presents a theoretical framework of the studied topic, a method chapter of how the methodological study was conducted, and a chapter of method discussion. Part 2 will present a research paper regarding the present methodological study and is written after the standards of the journal “Scandinavian Journal of Medicine and Science in Sports”. Due to the word-limitation of the master thesis, results, discussion and conclusion of the present methodological study are only included in part 2.

Part 1:

THEORETICAL BACKGROUND AND METHODS

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1.0 Introduction

The explosiveness of movements is highly related to athletic performance and is essential in the vast majority of sports (Cormie, McGuigan, & Newton, 2011a, 2011b). In an applied sports and exercise science perspective, explosiveness is the ability to generate high power over a short period of time. Power (P) is expressed as force times velocity, where force (F) is the amount of newton produced during a muscle contraction, whereas velocity (V) is the speed of the muscle contraction (Sleivert & Taingahue, 2004; Young et al., 2005). The muscles intrinsic properties which enable them to produce high levels of F, V and P have previously been assessed under a single load (Feriche et al., 2014; Hansen, Cronin, Pickering, & Newton, 2011). However, the single-load values of these variables do not represent the maximum capacity of the muscles to develop F, V and P (Jaric, 2015). For instance, if an athlete develops more F, the acceleration will be higher, which will subsequently lead to a higher V. Therefore, the single load approach does not allow to distinguish wether the athlete´s improvement in F or V produced is a consequence of enhanced F capacity, maximal contraction V, or both (García-Ramos, Feriche, Pérez-Castilla, Padial, & Jaric, 2017).

The limitations of the single-load approach can be solved by obtaining parameters from the linear Force-Velocity (F-V) relationship to identify the theoretical maximal mechanical capacities of the muscles involved to generate F, V and P (Jaric, 2015; Samozino, Rejc, Di Prampero, Belli, & Morin, 2012). The F and V data are most commonly obtained under 4-6 loading conditions, although recent studies have investigated the use of only two loads referred to as the 2-point method (Garcia-Ramos & Jaric, 2018). The multiple-load method allow us to determine the F-V relationship parameters by applying the following regression model: ($F[V] = F_0 - S_{FV}V$), where F_0 represents the F intercept (i.e., theoretical maximal force at null velocity), V_0 is the V intercept (i.e., theoretical maximal velocity the limbs can extend during 1 extension under zero load) and S_{FV} is the slope that corresponds to F_0/V_0. Due to the F-V relationship´s linearity, the maximum power output (P_{max}) can be calculated as (F_0 x V_0)/4. The multiple-load approach can be used to determine selective gains in maximum F, V and P outputs since F_0 and V_0 are independent of each other (i.e., a change in F_0 can be observed without a change in V_0 and vice versa) (Jaric, 2015).

Within strength and conditioning the F-V parameters (F_0, V_0, P_{max} and S_{FV}) have received increasing recognition as means to monitor training adaptations (Colyer, Stokes, Bilzon, Holdcroft, & Salo, 2018; Djuric et al., 2016; Jiménez-Reyes, Samozino, Brughelli, & Morin, 2017), and to determine the optimal balance between the maximal F and V capacities of the lower limbs neuromuscular system based on the S_{FV} parameter (Jiménez-Reyes, Samozino, Brughelli, et al., 2017; Samozino et al., 2014). Earlier studies have reported large variability in the reliability of the F–V parameters in various exercises such as vertical jumps (Feeney, Stanhope, Kaminski, Machi, & Jaric, 2016; García-Ramos et al., 2017; Giroux, Rabita, Chollet, & Guilhem, 2015; Jiménez-Reyes, Samozino, Pareja-Blanco, et al., 2017; Samozino, Morin, Hintzy, & Belli, 2008), the bench press (Djuric et al., 2016; García-Ramos et al., 2015), the leg-press (Alcazar et al., 2017; Meylan et al., 2015) and during sprints (Helland et al., 2019). The large variability can lead to difficulties when applying the individualized training approach to improve explosive performance (Jiménez-Reyes, Samozino, Brughelli, et al., 2017). Further, the best measuring method is not known, as agreement of training-induced changes between methods in F-V parameters has not been investigated.

Vertical jumps, such as squat jump (SJ) (Cuk et al., 2014; Samozino et al., 2014) and countermovement jump (CMJ) (Cuk et al., 2014; Jiménez-Reyes et al., 2014) are important functional movements and the most commonly exercises employed to assess the F-V parameters of the lower limb muscles in addition to leg-press (Colyer et al., 2018). Furthermore, newly developed devices (e.g., Linear position transducer, Optical infrared contact grid) and force plate can be used to assess F-V parameters in SJ and CMJ. Giroux and colleagues (Giroux et al., 2015) have previously investigated the reliability of these, but only in SJ and merly using average values of F, V and P, not the entire F-V spectrum´s parameters (F_0, V_0, P_{max} and S_{FV}). Furthermore, to the authors knowledge, no study has investigated the reliability of a Keiser leg-press apparatus. Lastly, the agreement of post-intervention changes between different measuring methods in SJ, CMJ and leg-press is not known.

1.1 Research question

To investigate the mentioned limitations, we designed a study to comprehensively explore the F-V relationship of lower limb muscles when performing vertical jumps and leg-press. The aims were to investigate the reliability of leg muscles F-V parameters when obtained from (a) Force plate, (b) linear position transducer (Encoder), (c) Optical infrared contact grid (Contact grid) in both SJ and CMJ, and (d) from Keiser leg-press. Furthermore, we investigated the agreement between measuring methods, both on (a) cross-sectional measures and (b) of training-induced changes.

2.0 Theoretical background

2.1. Muscular power and explosive performance

As mentioned in the introduction, the explosiveness of movements is highly related to athletic performance (Kraemer & Newton, 2000; Newton & Kraemer, 1994; Sleivert & Taingahue, 2004) and essential in the vast majority of sports (Cormie et al., 2011a, 2011b). In sports and exercise sciense, explosiveness, is from an applied perspective the ability to generate high power over a short period of time. Maximal power represents the greatest instantaneous power during a single movement performed with the goal of producing maximal velocity at take-off, release or impact (Kraemer & Newton, 2000; Newton & Kraemer, 1994). These movements include jumping, sprinting, change of direction, throwing, kicking and striking. Therefore, improved maximal power usually results in enhanced athletic performance (Kraemer & Newton, 2000; Newton & Kraemer, 1994; Sleivert & Taingahue, 2004). In addition to the typical explosive sports, improvements in maximal power can facilitate endurance athletes during the final sprint of a race and also improve work economy (Paavolainen, Hakkinen, Hamalainen, Nummela, & Rusko, 1999). Improvement in maximal power may even help elderly individuals to exert a rapid rice in muscle force to reduce the incidence of falls, as falls often lead to fractured bones for elderly (Horak, 2006; Raastad, Paulsen, Refsnes, Rønnestad, & Wisnes, 2010; Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002).

Due to the benefits of being more explosive, strength training has become a common method to stimulate physiological mechanisms and improved maximal power output (Cormie et al., 2011a, 2011b). However, the power continuum consists of several components and can be targeted by either high-velocity plyometric training with low to no additional load, traditional strength training with heavy loads and low velocity or by a combination of both (Cormie et al., 2011b). How explosive you can perform a movement is influenced by a wide variety of physiological mechanisms such as neuromuscular factors, the type of muscle action involved as well as the muscle environment (Cormie et al., 2011a).

2.2. Mechanisms contributing to explosive performance.

2.2.1. Neuromuscular factors.

The neuromuscular factors affecting maximal power output include muscle fibre composition, cross-sectional area, fascicle length, pennation angle, motor unit recruitment, firing frequency, synchronization and intermuscular coordination (Cormie et al., 2011a).

Muscle fibre composition.

The three muscle fibre types (Type I, Type IIa and Type IIx) have unique characteristics, and how explosive a muscle can be is largely determined by the fibre type composition (Edgerton, 1986). Type II fibres have a greater capacity to generate power per unit cross-sectional area (CSA) compared with Type I fibres (Cormie et al., 2011a). Although the amount of force the different fibre types can produce is somewhat controversial in muscle physiology (Cormie et al., 2011a), it is consensus that maximal velocity is significantly greater in type II fibres (Cormie et al., 2011a). Thus, muscles with a high percentage of type II fibres display greater P_{max} in comparison to muscles with a high percentage of type I fibres (McCartney, Heigenhauser, & Jones, 1983; Thorstensson, Grimby, & Karlsson, 1976).

Cross-sectional area.

How much force a single muscle fibre can generate is mainly down to the cross-sectional area, irrespective of the fibre type (Cormie et al., 2011a), and since power is heavily influenced by maximal force production, a muscle fibre with greater CSA can therefore generate higher P_{max} (Cormie et al., 2011a).

Fascicle length.

Assuming a constant level of activation, the maximal velocity of a muscle fibre is proportional to its length (Bodine et al., 1982; MacIntosh & Holash, 2000), and since explosiveness is heavily influenced by maximum velocity (V_{max}) a longer muscle fibre can therefore generate higher P_{max} (Cormie et al., 2011a).

Pennation angle.

The pennation angle of a muscle is defined as the angle between the muscle´s fascicles and the line of action (Cormie et al., 2011a), and as the pennation angle increases, more sarcomeres can be arranged in parallel, which increases force production and a higher P_{max} can be achieved (Gans, 1982; Sacks & Roy, 1982).

Motor unit recruitment.

The force capable of being generated during a movement is affected by which motor units are recruited (Cormie et al., 2011a). Thus, when an explosive movement is required it is very beneficial if high-threshold motor units are recruited (Cormie et al., 2011a). The recruitment of high-threshold motor units is beneficial due to the fact that they innervate a large number of high force-producing muscle fibres (Enoka & Fuglevand, 2001).

Firing frequency.

Another mechanism influencing force-production is the firing frequency, defined as the rate a motoneuron can transmit neural impulses to the muscle fibres (Cormie et al., 2011a). When the firing frequency of a motor unit is increased from minimum to maximum rate, the force of contraction may increase by 300-1500 % (Enoka, 1995).

Synchronization and intermuscular coordination.

A concurrent activation of two or more motor units is called motor unit synchronization (Cormie et al., 2011a). While this mechanism still is debated throughout the literature, it is hypothesized that synchronization may increase force production (Komi, 1986; Semmler & Enoka, 2000) in addition to be a strategy for inter-muscular coordination during multi-joint movements (Cormie et al., 2011a). Inter-muscular coordination describes the appropriate activation of agonist, synergist and antagonist muscles during a movement (Cormie et al., 2011a).

2.2.2 Type of muscle action.

The type of muscle action involved in sport specific movements also affects P_{max} (Cormie et al., 2011a). These contributing mechanisms are stretch reflexes, the time available to develop force, storage and utilization of elastic energy, as well as interactions and potentiation of contractile and elastic filaments (Cormie et al., 2011a).

Stretch reflexes.

The most common type of muscle function is a successive combination of eccentric and concentric actions (Cormie et al., 2011a). This function, when a muscle fibre is activated, stretched and immediately shortened is termed the stretch-shortening cycle (SSC) and produces greater force and power than a concentric-only contraction (Cavagna, Saibene, & Margaria, 1965; Edman, Elzinga, & Noble, 1978). Stretch reflexes during the eccentric phase of SSC movements is one of the proposed mechanisms that might contribute to the enhanced P_{max} (Cormie et al., 2011a). The stretch reflex increases muscle stimulation, resulting in higher contraction force during the concentric phase and ultimately contributes to the enhanced P_{max} in SSC movements (Cormie et al., 2011a).

Time to develop force.

In addition to the stretch reflex, the time to develop force is another mechanism driving the superior maximal power output observed during the SSC (Cormie et al., 2011a). During the eccentric action of an SSC movement the agonist muscles can develop considerable force prior to the concentric contraction (Van Zandwijk, Bobbert, Baan, & Huijing, 1996).

Storage and utilization of elastic energy.

The storage and utilization of elastic energy is believed to be the main mechanism to drive the SSC-induced enhancement of muscular power (Schenau, Bobbert, & de Haan, 1997). By stretching an active muscle-tendon unit, potential energy can be stored and then potentially be used to increase the mechanical energy and force production at the beginning of the following concentric contraction in an SSC movement and therefore enhance maximal power production (Cormie et al., 2011a).

Interactions of contractile and elastic elements

The interactions between the contractile and elastic elements play an important role in enhancing explosive performance in SSC movements (Cormie et al., 2011a). In SSC movements, tendinous recoil has been shown to influence the contribution of the contractile component of work produced (Cormie et al., 2011a). In an SSC movement, the contractile element acts as a force generator producing high forces at relatively low shortening velocities, while the tendinous structures act as an energy redistributor and power amplifier (Fukashiro, Hay, & Nagano, 2006). This is because the higher force at the beginning of the concentric phase in an SSC movement results in greater tendinous lengthening with less fascicle lengthening (Cormie et al., 2011a), but as the concentric contraction progress, the muscle fibre contracts at a nearly constant length, while the rapid shortening of the muscle-tendon unit mostly depends on the shortening of the tendinous structure (Cormie et al., 2011a). These components interaction is vital in an SSC movement as it allows for the muscle-tendon unit to generate superior maximal power output (Cormie et al., 2011a).

Potentiation of contractile and elastic filaments

Another mechanism thought to contribute to enhancement of P_{max} during SSC movements is the potentiation of the actin-myosin crossbridges (Cormie et al., 2011a). Enhanced work output of the contractile element in muscles after an active stretch followed by a shortening is thought to enhance force production per crossbridge rather than an increase in the number of active crossbridges, which may lead to an increase in maximal power output (Cormie et al., 2011a).

2.2.3. Muscle environment.

In addition to neuromuscular factors and the type of muscle action, the acute changes in the muscle environment in terms of fatigue, changes in hormone milieu and muscle temperature impacts our muscles ability to generate maximal power (Cormie et al., 2011a).

Fatigue.

During fatigue, numerous alterations of muscle properties affect P_{max} negatively through impairing of force generation and/or the velocity of shortening during contractions (Allen, Lamb, & Westerblad, 2008; Fitts, 2008). These alterations include ionic changes on the action potential, extracellular and intracellular ions and intracellular metabolites (Allen et al., 2008; Fitts, 2008).

Hormone milieu.

Longitudinal changes in muscular function by influencing endocrine factors on adaptational mechanisms have been well reviewed (Cormie et al., 2011a; Kraemer & Ratamess, 2005), but acute hormonal changes may also potentially impact the ability to generate maximal power immediately (Cormie et al., 2011a). It is observed an increase in force and phosphorylation of myosin light chains of type II fibres when treating muscle fibres with physiological concentrations of the androgenic hormone dihydrotestosterone, which may result in an acute impact on maximal muscular power (Hamdi & Mutungi, 2010).

Muscle temperature.

Changes in muscle temperature may influence maximal power production (Cormie et al., 2011a). When muscle temperature decreases both V_{max} and P_{max} decreases and therefore also P_{max} (De Ruiter & De Haan, 2000; De Ruiter, Jones, Sargeant, & De Haan, 1999; Ranatunga, 1982).

In addition to these muscle properties and mechanisms, it is the Force-Velocity relationship that dictates our muscles ability to produce power and hence explosive movements in sports (Cormie et al., 2011a).

Summary of 2.2

Firstly, muscles maximal power output is influenced by a wide variety of neuromuscular factors such as cross-sectional area, muscle fiber composition, pennation angle, fascicle length, motor unit recruitment, firing frequency, synchronization and inter-muscular coordination. Secondly, maximal power is affected by the type of muscle action involved including the time available to develop force, interactions of contractile and elastic elements, storage and utilization of elastic energy, stretch reflexes, as well as potentiation of contractile and elastic filaments. Lastly, acute changes in the muscle environment, in particular, alterations resulting from fatigue, hormone milieu changes and muscle temperature impact muscles ability to produce maximal power.

2.3 Force-Velocity relationship.

The Force-Velocity (F-V) relationship represents a characteristic property of muscle that dictates its power production capacities (Cormie et al., 2011a). This characteristic property is an inverse relationship, where when the velocity of concentric muscle action is increased, less force is capable of being generated during that contraction (Hill, 1938). This is due to the decrease in total attached cross bridges with increasing muscle contraction velocity, because it takes a fixed amount of time for actin-myosin cross bridges of the muscle fibre to attach and detach (Piazzesi & Lombardi, 1995). Since all human movements are similarly limited by this fundamental property of muscles, power is maximized at a combination of submaximal force and velocity values (Cormie et al., 2011a). The F-V relationship is presented in figure 1 where the x-axis represents the muscle's ability to generate force when contracting and the y-axis represents the velocity of the contraction. By increasing velocity with a specific force, or increasing force at a specific velocity, will lead to an improved power (Coyle et al., 1981).

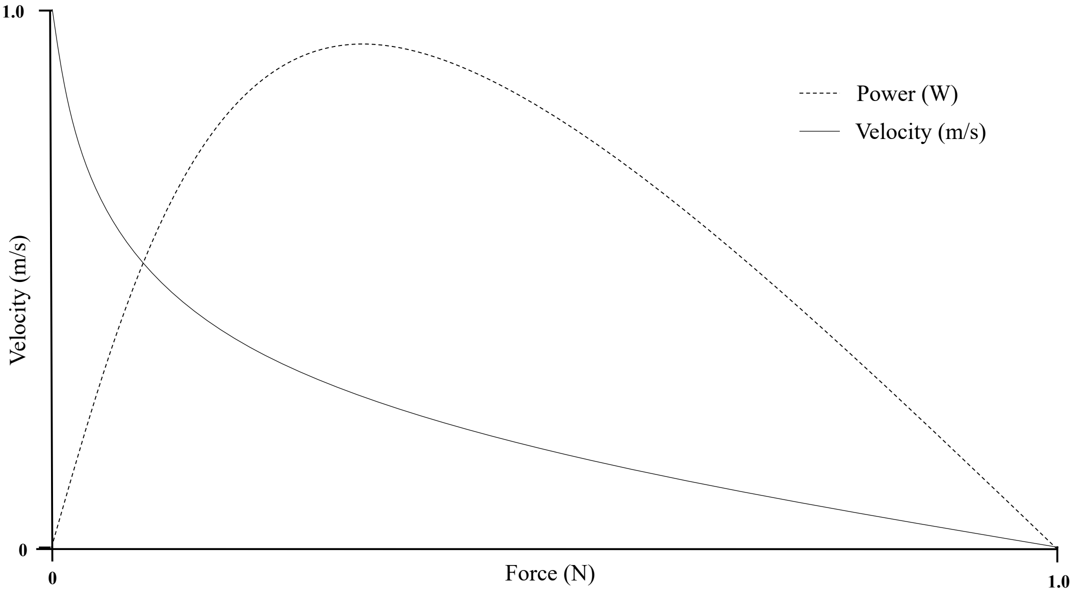

Figure 1: The force-velocity curve. Force, velocity and power are normalized to the maximal isometric force, the maximal velocity of shortening and the maximal power output, respectively. The Force-Velocity relationship is represented by the solid line, while the dotted line represents the power output. The figure is adapted and modified after Cormie et al. (2011a).

2.3.1 Force-Velocity profiling.

Numerous studies have highlighted that the maximal power output of the lower limbs is the main variable related to explosive performance, but this analysis may only provide a partial insight into an athlete´s true maximal mechanical capabilities (Cronin and Sleivert, 2005; Cormie et al., 2011a). Although explosive performance, such as jumping, is mainly determined by the lower limbs P_{max} (Yamauchi & Ishii, 2007), it is also influenced by the combination of the underlying mechanical parameters, known as the F-V profile (Samozino et al., 2014). Therefore, the inclusion of F-V profiling with the F-V relationship´s contribution to explosive performance may provide a more accurate mechanical representation of an athlete´s maximal explosive capabilities (Samozino et al., 2012).

To develop a F-V profile of an athlete, a F-V test can be conducted (Samozino et al., 2008). In principle, it is done by measuring the speed of a given movement with increasing resistance. The mechanical capabilities of the lower limb´s neuromuscular system can be measured in the SJ or CMJ exercise (vertical F-V test) (Jiménez-Reyes, Samozino, Pareja-Blanco, et al., 2017; Samozino et al., 2008). First, you measure the speed of the movement without any external load, only body weight. Then the speed is measured with 20 kg, then 40 kg, etc. (usually 4-6 loading conditions). It is important that the athlete tries to make the movement as quickly as possible in all attempts. By then plotting resistance and speed, a regression line with a slope can be established. It is also possible to calculate power by multiplying force and velocity. If we match a line through the power data points (as a function of resistance) we typically get a parable, with the peak of the parable being the maximal power. After conducting a F-V test, we can determine an athlete´s mechanical F-V parameters: theoretical maximal force (F_0), theoretical maximal velocity (V_0), maximal power (P_{max}) and the F-V slope (S_{FV}) as presented in figure 2. It is also possible to develop a horizontal F-V profile based on the same principle as described above, but the athlete sprints instead of jumping/lifting vertically (Helland et al., 2019).

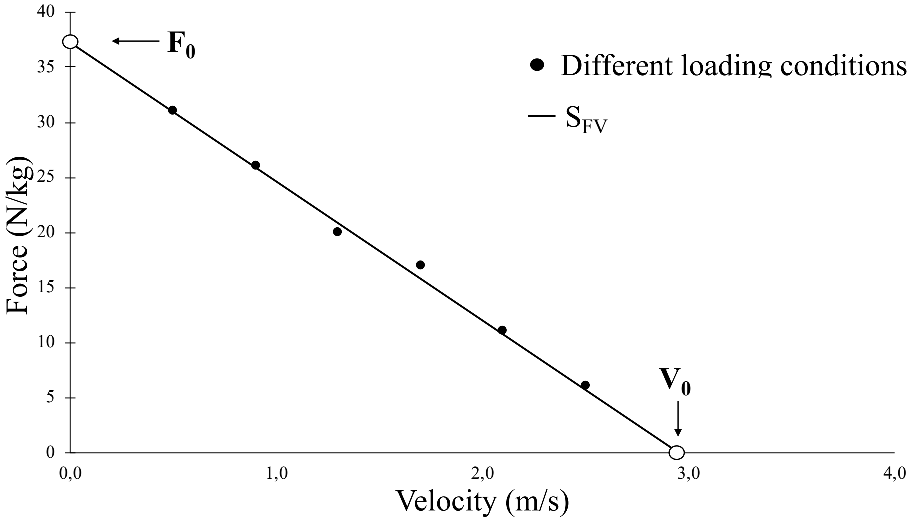

Figure 2: Force-Velocity profile. The points represent the avgerage F and V produced on different loading conditions. F_0 is the theoretical maximal force at zero velocity, V_0 is the theoretical maximal velocity under zero load

As described theoretically (Samozino et al., 2008; Samozino et al., 2012) and later shown experimentally (Samozino et al., 2014), there might be, for each individual, an optimal F-V profile that represents the balance between force and velocity qualities where the explosive performance (e.g., vertical jumping) is maximized (Samozino et al., 2012; Samozino et al., 2014). The individual F-V profile and P_{max} can be determined in the same manner as explained above, while the optimal F-V profile can be computed using equations based on a biomechanical model (Samozino et al., 2012; Samozino et al., 2014). The relative difference between actual and optimal F-V profile (Figure 3), will for an individual represent the magnitude and the direction of the unfavorable balance between force and velocity qualities.

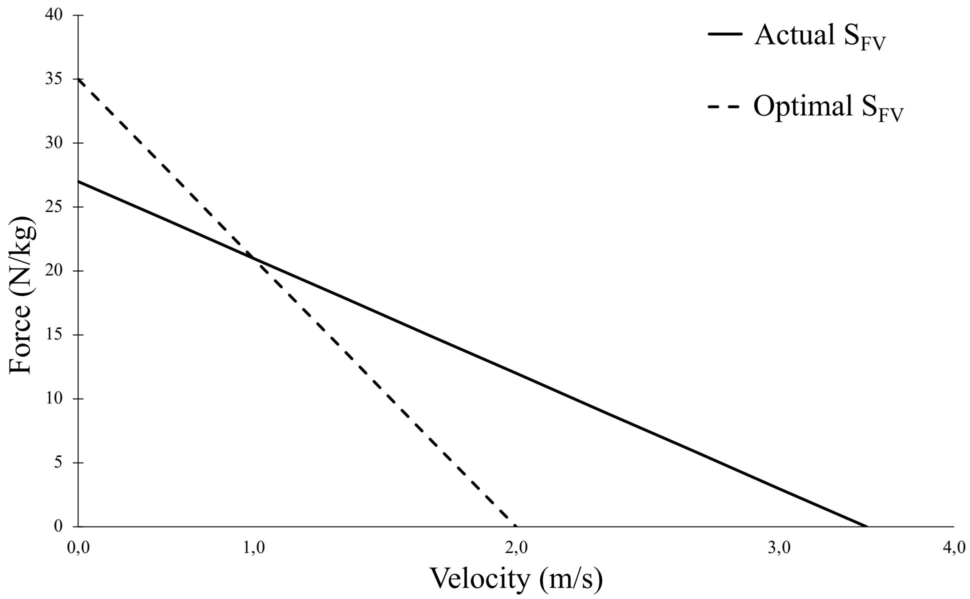

Figure 3: Actual- versus optimal Force-Velocity profile. This athlete is velocity-dominated. *S_{FV} force-velocity slope*

Theoretically, the establishing of imbalance between force and velocity makes it possible to determine if an individual has a force deficit, velocity deficit or have a well-balanced F-V profile (i.e., optimal profile) (Samozino et al., 2012; Samozino et al., 2014). With the method by Samozino et al. (2012), an individual with force deficit will have a F-V profile less than 100% (e.g., 75 %), an individual with velocity deficit will have a F-V profile greater than 100% (e.g., 125 %), while an individual with a balanced relationship between force and velocity qualities will have a F-V profile close to 100% (Samozino et al., 2012; Samozino et al., 2014). Samozino and colleagues have shown that for a given P_{max}, vertical jump performance is negatively correlated to the F-V imbalance (F-Vimb), which supports the theory of considering individual F-V characteristics in addition to P_{max} when designing training programs to improve explosive performance (Morin & Samozino, 2016; Samozino et al., 2014; Samozino et al., 2012). By quantifying F-Vimb, individualized training programs has recently shown to improve explosive performance (unloaded jump height) through an effective shift in the individuals´ actual F-V profiles towards the optimal F-V profile (by increasing either F_0 or V_0) irrespective of an increased P_{max} (Jiménez-Reyes, Samozino, Brughelli, et al., 2017). It is important to note that, while the athletes P_{max} on the entire F-V spectrum does not increase, the power produced during unloaded squat jumps does (Samozino et al., 2012). As recently shown by Jimenes-Reyes et al., (2017), traditional power training may not be the optimal approach to improve explosive performance.

2.3.2 Force-Velocity training.

Traditionally, training to improve explosive performance have been divided into power and ballistic training (Cormie, McCaulley, & McBride, 2007; Cormie, Mcguigan, & Newton, 2010; Markovic, Vuk, & Jaric, 2011; Sheppard et al., 2011), heavy-load training where the focus is more on strength (Chelly et al., 2009; Harris, Stone, O'bryant, Proulx, & Johnson, 2000; Rønnestad, Hansen, & Nygaard, 2017; Rønnestad, Kojedal, Losnegard, Kvamme, & Raastad, 2012) or a combination of both (Cormie et al., 2007; Cormie et al., 2010; Zaras et al., 2013). This general approach, without individualized training programs, has led to varying results regarding jumping performance (Jiménez-Reyes, Samozino, Brughelli, et al., 2017) Jimenez-Reyes et al., (2017) discuss that this is likely because of the various levels and F-V characteristics of the individuals tested. While a traditional power training program might lead to increased maximal power, the optimal balance between force and velocity might decrease, leading to a lack of change or even a decrease in jumping performance (Jiménez-Reyes, Samozino, Brughelli, et al., 2017).

Training targeting the force aspect.

In the case of a force deficit, it may be beneficial to aim training towards increasing force capabilities (i.e., F_0) and thereby decrease FVimb and improve P_{max} (Samozino et al., 2012). When performing heavy-load strength training (high loads at low movement velocity) maximal force is increased by an induced overload stimulus. The effectiveness of training targeting the force-aspect have previously been shown to increase maximal force capabilities (Cormie et al., 2007, 2010; Rønnestad et al., 2012, 2017) and thanks to gravity, it is quite easy to increase the load for maximal strength training (Samozino, Rivière, Rossi, Morin, & Jimenez-Reyes, 2018).

Training targeting the velocity aspect.

In the case of a velocity deficit, it may be beneficial to aim training towards increasing maximal velocity capabilities (i.e., V_0) to improve explosive performance (Jiménez-Reyes, Samozino, Brughelli, et al., 2017). This targeted training resolves around the capacity to produce force at very high contraction velocities (Samozino et al., 2018). Decreasing the load to increase movement velocity during velocity training can be complicated, especially when body weight is involved such as during squat jumps (Samozino et al., 2018).

Different types of power and ballistic training have been proposed to increase movement velocity including maximal effort with no deceleration phase at the end of the movement (with bar throw or jump (Newton, Kraemer, Häkkinen, Humphries, & Murphy, 1996) using low loads (< 30 % of the 1RM) or assistance to reduce loads (Markovic et al., 2011; Sheppard et al., 2011). Training protocols with removed deceleration phase during lifting have been shown to be effective in shifting the F-V relationship toward more velocity-related capabilities (Newton et al., 1996; Cormie et al., 2010). Training protocols that employ negative loads, where loads are lower than body mass have also shown to shift force-time curves towards the velocity aspect (Jiménez-Reyes, Samozino, Brughelli, et al., 2017; Sheppard et al., 2011). However, it often requires specific and complicated training equipment when assistance to reduce loads is applied to improve jumping velocity (Samozino et al., 2018): assisted vertical jumps with a rubber band pulling to the top (Markovic et al., 2011; Sheppard et al., 2011), low pneumatic resistances (Frost, Cronin, & Newton, 2008) or lying horizontally in supine position on a rolling device (e.g., long board) and pushing with the feet onto a wall (Jiménez-Reyes, Samozino, Brughelli, et al., 2017). During the rolling device push-off exercise, the inertia may remain equal to body mass, but the resistive forces are only the rolling friction forces, not body weight (Samozino et al., 2018).

Training with an optimal F-V profile.

Individuals displaying an actual F-V profile close to the computed optimal profile is thought to utilize a training program that targets a balanced combination of power (optimal loads), force (heavy loads) and velocity (ballistic loads) (Cormie et al., 2007; Harris et al., 2000; Jiménez-Reyes, Samozino, Brughelli, et al., 2017). This balanced approach may lead to an increased P_{max} by shifting the entire F-V relationship to the right while still maintaining an F-V profile close to the optimal value (Cormie et al., 2007; Harris et al., 2000; McBride, Triplett-McBride, Davie, & Newton, 2002).

2.3.3 Force-Velocity tests.

Numerous tests and methods have been used in the last decade to determine maximal power production and the F-V capacities the lower limbs produce. These tests include squat jump (Samozino et al., 2014), countermovement jump (Jiménez-Reyes, Samozino, Pareja-Blanco, et al., 2017), leg-press (Colyer et al., 2018), and recently, even during sprinting (Helland et al., 2019). In addition to all these tests, there are different equipment/methods that can be used to derive a F-V profile and P_{max} from. For instance, in the squat jump and countermovement jump you can use a force plate which directly measures average force produced with average velocity either from flight time or take-off velocity, a linear position transducer which uses an encoded wire directly fixed to a barbell or athlete, or using Samozino´s simple method by measuring jump height with a contact grid and computing body weight and the push-off distance (distance between the starting-position of the concentric phase and position of take-off) (Samozino et al., 2008). In the leg-press exercise you can either use a regular leg-press apparatus with a linear position transducer fixed to the weight plates (Meylan et al., 2015) or a Keiser leg-press dynamometer that uses pneumatic resistance and measures force and velocity across each effort (Colyer et al., 2018).

The present master thesis seeks to explore the reliability and the agreement of different F-V tests and methods to increase the knowledge of the F-V tests used daily in the Norwegian Olympic Training Centers.

Summary of 2.3

The F-V relationship dictates muscles ability to perform explosive movements. Therefore, it can be beneficial to determine athletes F-V parameters: theoretical maximal force (F_0), theoretical maximal velocity (V_0), maximal power (P_{max}) and the F-V slope (S_{FV}) as a means to monitor training adaptations. F-V parameters can be determined by performing a F-V test such as squat jump, where subjects commonly jump under 4-6 loading conditions. In recent years, a few studies have supported that training to enhance explosive performance can be individualized based on the direction and magnitude of the F-V imbalance. An athlete with a force deficit might benefit from prioritizing heavy strength training to increase F_0. In case of a velocity deficit, the athlete might benefit from focusing on ballistic training with high velocity movements to increase V_0. When the athlete already possesses a balanced relationship between F and V capabilities, he or she might benefit from a balanced approach doing power, heavy strength and ballistic training to increase P_{max} by possibly shifting the entire F-V sprectrum to the right.

2.4. Precision of measurement.

When conducting a data collection, researchers must strive for the highest possible quality data (Polit & Beck, 2018). Several aspects contribute to the quality of the data collected, as measures generally contain some error. These aspects include personal states (e.g., fatigue and mood), response set biases, situational factors (e.g., temperature and environment) and measurement equipment (Polit & Beck, 2018). Additionally, the people collecting the data should be properly trained and monitored to ensure that procedures and standardized testing protocols are followed. This can be further improved by conducting pilot studies (O'Donoghue, 2012).

All the aspects mantioned above can lower the precision of your measurements. The lower the precision of measurements are, the more subjects are needed to make up for the "noise" in the measurements, but noisy data can still be difficult to interpret even with a larger sample (Hopkins, 2000). When a new measure is developed, one must be aware of these factors and understand how to interpret the data of noisy tests. The two most important aspects of precision are reliability and validity (Hopkins 2000; Polit & Beck, 2018). Reliability is the reproducibility of a measurementm and can be quantified by taking several measurements on the same subjects (Hopkins, 2000). If the reliability is poor, the precision of a single measurement is poor and will reduce the ability to track changes in measurements in an experimental study (Hopkins, 2000). Validity is the agreement between the value of measurement and its true value and is quantified by comparing the measurements with values that are as close to the true values as possible (Hopkins, 2000). If the validity is poor, so will the precision of a single measurement be and the ability to characterize relationships between variables in descriptive studies will be reduced (Hopkins, 2000).

Measurements can be reliable and not valid, but a valid measurement must be reliable. Therefore, are the concepts of reliability and validity related (Hopkins, 2000). Both in sports and exercise science and in other scientific areas are these two concepts applied separately, either because most researchers study them separately, or because its mathematically difficult to bring the two concepts together (Hopkins, 2000).

2.4.1 Reliability.

The word "reliability" has different uses in different contexts, even within sport and exercise science (O'Donoghue, 2012). Broadly speaking, reliability is the extent to which scores are free from measurement error (Polit & Beck, 2018). In sport and exercise science, reliability can be divided into four different types: inter-rater reliability, parallel forms reliability, internal consistency and test-retest reliability (O´Donoghue, 2012). Inter-rater reliability refers to when the same performance or performances are independently measured by different trained personnel, either live or using video recordings of the performance (O´Donoghue, 2012). When some concept of interest is measured using two alternative techniques and the consistency of those different techniques is being evaluated is referred to as parallel forms reliability (O´Donoghue, 2012). In sport and exercise science, where one of the techniques is a gold standard measurement of the concept of interest, is often referred to as validation testing rather than reliability testing (O´Donoghue, 2012). Firstly, parallel forms reliability involves applying two measurement procedures to the same set of participants, where the participants perform a single test with different measurement processes being applied to their performance (O´Donoghue, 2012). Secondly, parallel forms of reliability involve the participants having to perform two different tests, e.g., squat jump and countermovement jump and then compare how the maximal power output produced by the participants correlates between the two tests (O´Donoghue, 2012). Internal consistency is a type of reliability mostly used by sports psychologists to test the consistency of components that make up some overall construct that cannot be directly observed (e.g., intelligence, anxiety and mood) (O´Donoghue, 2012).

Test-retest reliability, the most relevant form for this master thesis, refers to the reproducibility of values of a variable when you measure the same subjects twice or more (Hopkins, 2000; O´Donoghue, 2012). There are numerous types of reliability statistic that can be used to assess test-retest reliability, and even numerous ways to calculate these (O´Donoghue, 2012). O´Donoghue (2012) reports that there are at least six different methods of calculating intraclass correlation coefficient which produce different values. Therefore, the present master thesis will explain and use reliability statistics and formulas developed by Hopkins (2000) to make things more transparent.

There are three main types of analysis used when assessing test-retest reliability: typical error, changes in the mean and retest correlation (Hopkins, 2000). Typical error (TE) is the values of the change score or difference score for each subject, calculated by dividing the standard deviation (root mean square of the distances/differences) of the difference score by root2 (Hopkins, 2000). For example, if five participants test 1RM squat with one week apart and the difference scores in kg 1RM are 5, -2, 6, 0 and -3, the standard deviation (SD) of these scores is 4.1. You can then divide 4.1 by root2 and get a typical error of 2.9. Another common type of within-subject variation is the coefficient of variation (O´Donoghue, 2012; Hopkins, 2000). The coefficient of variation (CV) is the standard deviation expressed as a percent of the mean and is an important measure of reliability when the SD and mean come from repeated measurements of a single subject (Hopkins, 2000). This is particularly useful for representing the reliability of athletic events or performance tests, and when CV is used, changes in the mean between tests should be presented as percent changes (Hopkins 2000). The CV can be derived from the typical error by log-transforming your variable (using natural logs of the values of the variable in your analysis, rather than the original raw values, to make it normally distributed) (Hopkins, 2000).

Change in the mean represents the difference between the means for two tests and consists of two components: a random change and a systematic change (Hopkins, 2000). Random change in the mean is due to a sampling error where a randomly selected number is added to or substracted from the true value every time you take a measurement. Random change is down to a sampling error as the random change is smaller with larger sample sizes (Hopkins, 2000). Human performance is often tested in sports and exercise science, and a subject's behavior, in terms of motivation and effort (fatigue) can contribute to the outcome of the test. This type of non-random change is referred to as systematic change in the mean (Hopkins, 2000). Therefore, if you want to determine the effects of a training intervention, it is important to perform enough trials (familiarization) to make learning effects or other systematic changes insignificant before initiating the intervention. By calculating and interpreting the confidence limits for the mean, which represent the likely range of the true systematic change, you can determine if an observed change in the mean is a reproducible systematic effect (Hopkins, 2000).

The last type of quantifying reliability is retest correlation, usually in form of intraclass correlation coefficient (ICC) rather than Pearson correlation as it does not have bias with small samples (Hopkins, 2000). ICC is expressed on a scale from 1.00 to -1.00, where 1.00 represents a perfect agreement between the test and re-test, 0.00 represents no agreement, and -1.00 represents a perfect negative correlation (Hopkins, 2000). Even though intraclass correlation and typical error is related (small TE usually means a high correlation), they do not measure the same thing. Typical error is a measure of variation within each subject, whereas a correlation coefficient is referring to the reproducibility of the rank order of subjects on re-test (Hopkins, 2000). Intraclass correlation (and Person´s r) is unaffected by any shift in mean on re-test (Hopkins, 2000). Therefore, ICC can be a useful measure of reliability in addition to TE, especially if the subjects suffer from fatigue from the first test or a game played the day before: the mean will most likely change, but the rank score of the subjects may remain the same.

2.4.2. Reliability of Force-Velocity tests

The first study to use the simple method of computing jump height, body weight and push-off distance to produce a F-V profile was Samozino et al. (2008). Eleven physically active male subjects not specialized in weight-lifting or jumping disciplines underwent test-retest in unloaded squat jumps. Average force, velocity and power was derived from the simple method using a Contact grid in addition to a Force plate. Force displayed an almost identical CV (2.5%) between the two methods, as well as in power (7.2 and 6.3 in Force plate and Contact grid respectively). Average velocity derived from the Force plate displayed a CV of 6.2% and 3.8% from the Contact grid.

Two studies (Alcazar et al., 2017; Meylan et al., 2015) used a linear position transducer attached to a leg press-machine to determine the F-V relationship and power of the lower limbs in 36 adolescent physically active subjects and 31 older adults, respectively. The older adults in Alcazar et al. (2017) performed 2 sets of 1 repetition from 40 % of body weight with increasing loads of 10kg until 1-repetition maximum was reached 2 times with 7 days in between after two familiarization sessions. The F-V parameters reliability was: (CV; ICC) F_0= 5.6%; 0.91, V_0= 4.8%; 0.94, P_{max} = 2.6%; 0.99 and S_{FV} = 10.1%; 0.73. The adolescent subjects (11-15 years) in Meylan et al. (2015) performed a similar protocol with a leg-press machine as in Alcazar et al. (2017) but with one more test-round (i.e., 3 rounds). The reliability of F-V parameters at baseline was: (CV; ICC) F_0=8.0%; 0.71, V_0=16.4%; 0.57, P_{max} =12.2%; 0.91 and S_{FV} =24.8%; 0.35. Reliability from test-round 2 to 3 displayed an overall greater reliability compared to test-rounf 1 to 2, most likely due to familiarization and learning effects: (CV; ICC) F_0=7.2%; 0.78, V_0=11.2%; 0.80, P_{max} =6.1%; 0.97 and S_{FV} =23.6%; 0.54 (Meylan et al., 2015).

A study from 2015 (Giroux et al.) used Linear position transducer, Force plate and Contact grid on 17 subjects (11 sedentary and 6 elite athletes: 23 years) to assess F-V reliability in squat jumps with seven loading conditions from 0-60% of the maximal concentric load. The subjects performed squat jumps on two occasions in addition to a familiarization session. This study used some of the same equipment as in the present master thesis but only investigated reliability of average force, velocity and power, not the mechanical parameters of the F-V profile (i.e., F_0, V_0, P_{max} and S_{FV}). Reliability of average force (F), velocity (V) and power (P) derived from the

Force plate was (CV; ICC) F= 3.1%; 0.98, V= 7.3%; 0.88 and P= 10.6%; 0.91. Similar reliability was shown in the linear position transducer: F= 5.0%; 0.96, V= 9.3%; 0.86 and P= 12.2%; 0.91. Reliability of the Contact grid displayed overall a higher reliability F= 2.7%; 0.99, V= 6,5%; 0.97 and P= 8.6%; 0.97 (Giroux et al., 2015).

Feeney et al. (2016) explored the reliability in CMJ using a weighted west rather than a barbell with 10 physically active male subjects. The subjects performed countermovement jumps in nine loading conditions ranging from 0-40% of body weight. The reliability of F-V parameters derived from the Force plate was (CV; ICC) F_0= 9.9%; 0.72, V_0= 17.3%; 0.83, P_{max}= 8.4%; 0.91 and S_{FV}= 30.23%; 0.67 (Feeney et al., 2016).

A recent study by Garcia-Ramos et al. (2017) assessed the reliability of SJ and CMJ with F-V parameters derived from a Force plate using both average and peak values. Twenty-three physically active (none active athletes) men underwent SJ and CMJ twice with both free-weight barbell and in a smith-machine performing six loads from 0kg to 75kg. By deriving average values (the same method as in the present master thesis), free-weight SJ exhibited a CV and ICC of F_0= 6.7%; 0.82, V_0= 6.4%; 0.84, P_{max}= 3.8%; 0.93 and S_{FV}= 12.6%; 0.81. Free-weight barbell CMJ with average values displayed greater reliability than squat jump (CV; ICC): F_0= 3.4%; 0.88, V_0= 4.9%; 0.81, P_{max}= 2.4%; 0.97 and S_{FV}= 8.2%; 0.69 (García-Ramos et al., 2017)

Another recent study assessed the reliability of F-V parameters derived from a Contact grid in CMJ on sixteen trained male national and international-level sprinters and jumpers (23 years) (Jiménez-Reyes, Samozino, Pareja-Blanco, et al., 2017). The F-V parameters displayed a CV and ICC of F_0= 1.2%; 0.99, V_0= 7.6%; 0.97, P_{max}= 5.5%; 0.98 and S_{FV}= 4.8%; 0.98

Summary of 2.4

When a new measuring method is developed, you must be aware of aspects that can lower the precision of your measurements. Reliability and validity are the two most important aspects of precision and usually studied separately. Test-retest reliability, the most relevant form for this master thesis, refers to the reproducibility of values of a variable when you measure the same subjects twice or more. The three statistic most commonly used in test-retest reliability of F-V measuring methods are changes in the mean, coefficient of variation and intraclass correlation coefficient. Earlier studies have reported large variability in the reliability of measuring methods in F-V parameters (F_0, V_0, P_{max}, S_{FV}).

3.0 Methods

3.1. Study design

The present methodological study of this master thesis was part of a larger multicenter experimental study. In the experimental study, the participants underwent six physical tests: SJ, CMJ, 30-meter sprint, 1RM squat, Keiser leg-press and leg-extensions. For the purpose of this methodological study, the F-V relationship was assessed in SJ, CMJ and Keiser leg-press. In SJ and CMJ, the F-V relationship was derived from a Force plate, Infrared optical contact grid (Contact grid) and a Linear position transducer (Encoder) from MuscleLab (Ergotest AS, Porsgrunn, Norway). In the leg-press test a Keiser A300 horizontal leg-press dynamometer (Keiser Sport, Fresno, CA) was used, and F-V parameters were derived from its software. Participants performed baseline tests two times, followed by 10 weeks of strength training, before completing two post-intervention trials.

3.1.1. Pilot study

A pilot study lasting three weeks was conducted before the methodological study in early August 2018. The purpose of this pilot study was to ensure that the different test-leaders knew the test protocols extremely well. Additionally, time limits and logistics for the test measures were controlled for during the pilot study. Data from participants in the pilot study was not included in the methodological study or the multicenter experimental study.

3.2. Participants

Thirty-four athletes volunteered to participate and completed the baseline measurements. Six athletes (two handball players and four ice hockey players) dropped out immediately prior to or during the training intervention due to injury or illness not related to the study. Furthermore, one participant was excluded due to major problems with jump coordination that led to highly inconsistent data. Thus, post-training data from 14 national level handball players and 13 Under-20 national level ice hockey players (n=27, 20 ± 5 years, 182 ± 8 cm, 76 ± 14 kg) formed basis for this methodological study. All players had a strength-training background ranging from 1- to more than 3 years and were well trained. Written informed consent was obtained from each player prior to participation. The study was reviewed by the Internal Ethical Committee (University of Agder), approved by the Norwegian Centre for Research Data and performed in agreement with the Declaration of Helsinki.

3.3 Test procedures

All players were instructed to prepare for the test-days as they would for a regular match in terms of nutrition, hydration, sleep and handball/ice hockey conditioning. The jump tests and leg-press were performed indoors with identical conditions for all tests. They were also instructed to use identical footwear and kit for each of the tests, as data derived from the Contact grid uses body mass to calculate F-V parameters. Body mass was assessed with footwear and kit included prior to testing and tests were performed in the same order on each test day. A standardized 15 min warm-up procedure was carried out after the body mass measurements. It consisted of jogging, local muscle warm-up (hamstring- and hip mobility), running drills (high knees, skipping, butt-kicks, explosive lunges) and four body weight SJs. After the warm-up, participants performed loaded incremental SJs with 0.1, 20, 40, 60 and 80 kg. Participants were asked to stand in the middle of the force plate. The contact grids were placed on each side of the force plate using weight-plates to match the hight of the force plate, while the encoder was placed on the ground and connected to the barbell. A broomstick was used as the 0.1 kg load. In order to make the SJ-test as reliable as possible, participants were asked to maintain their individual starting position (~90◦ knee angle) for about 2 seconds and then apply force as fast as possible and jump for maximum height before landing with ankles in extended position. Countermovement was verbally forbidden and carefully checked visually from the output. If all these requirements were not met, the trial was repeated. Two valid trials were performed with each load. The recovery time between each attempt was 2-3 min.

After performing the SJ-test, the participants performed CMJ. The CMJ-test was performed in the same procedure as SJ, but there was no pause in the bottom position (~90◦ knee angle) in CMJ. The CMJ-test is performed as a rapid eccentric-concentric movement. The handball players performed CMJ with the same loads as in SJ. The ice hockey players performed CMJ with external loads of 20 and 80 kg due to time limitations. Although 4-6 loads are preferred, the 2-point method, with one point close to the force intercept (heavy load) and the other close to the velocity intercept (light load), is recently shown to be a valid method to assess the F-V relationship in multiple-joint movements (Garcia-Ramos & Jaric, 2018).

The last F-V test included in the present study was a leg-press test. The Keiser leg-press was performed as a 6-repetition 1RM test followed by a 10-repetition F-V test with incremental loads based on each player´s 1RM leg-press (Colyer et al., 2018). Seating position was adjusted for each participant (~90º knee angle) and feet placed with heals at the bottom end of the platform. Participants were asked to extend both legs with maximum velocity during the 10-repetition F-V test.

3.3.1 Data analysis

Squat Jump.

Force plate: F-V parameters derived from the force plate were analyzed using a customized Microsoft Excel spreadsheet (Microsoft Office Professional Plus 2018, version 16.23). In SJ, the start of the concentric phase was defined as when force exceeded 20N from the body mass + external load. The end of the concentric phase was defined as when the participant left the force plate (i.e., take off). Average velocity was calculated using the following equation: $\overline{v} = \sqrt{\frac{gh}{2}}$ where g is gravitational acceleration and h is jump height (Samozino et al., 2008).

Contact grid: Data derived from the contact grid was based on Samozino´s simple method and Newton´s second law of motion, where mean force, velocity and power can be calculated during a vertical jump movement from the jump height and position measurements in SJ and CMJ (Jiménez-Reyes, Samozino, Pareja-Blanco, et al., 2017; Samozino et al., 2008). Average force ($\overline{F}$) and average velocity ($\overline{v}$) were calculated using two equations considering only simple input variables: body mass, jump height and push-off distance.

$$\overline{F} = mg\left(\frac{h}{h_{PO}} + 1\right)$$

$$\overline{v} = \frac{h_{PO}}{t_{PO}}$$

In these equations m is body mass (kg), g is the gravitational acceleration ($\text{m}\cdot\text{s}^{-2}$), h is the jump height (m), *hpo* is the vertical push-off distance (m), and *tpo* is the push-off phase duration (s). Anterior iliac crest was selected as anatomical marker to calculate the vertical push-off distance (h_{PO}). The vertical push-off distance corresponded to the displacement of the marker between the starting position and the moment of take-off. The vertical position of the marker was determined with two stadiometers and a rubber band in the starting position. For deciding take-off moment position, the participants were lying on their back, ankles in maximal extension with tip of toes reaching a wall. The distance between the wall and the iliac crest corresponded to the vertical take-off position of the marker. These measurements were performed at the beginning of the first day of the pre- and post-intervention tests.

Encoder: The Encoder was composed of an encoded wire directly fixed to the bar and winding into a sensor unit fixed to the floor. By measuring the position of the connected cable as a function of time, the software calculates acceleration and velocity (MsucleLab, version 10.5.69.4815). By entering body mass + external load, force and power are calculated from the obtained data. In agreement with the manufacturer´s recommendation, 90 % of body mass + external load was used to calculate force, velocity and power during SJ and CMJ with the encoder.

***Countermovement jump*.**

Force plate: In CMJ, the start of the concentric phase was defined as when the velocity exceeded 0.1 m/s. The end of the concentric phase and average velocity was defined and calculated in the same way as in SJ. F-V parameters in CMJ derived from the contact grid and encoder were obtained in the same way as in SJ.

Keiser leg-press.

The Keiser A300 horizontal leg-press dynamometer uses pneumatic resistance and measured force and velocity across each effort (Colyer et al., 2018). The F-V parameters were calculated by its software.

3.4 Training intervention

After baseline assessments, the participants were instructed to perform two weekly strength training sessions for 10 weeks (13 ± 3 training sessions performed) in addition to their regular handball and ice hockey practice and competitive games. The strength training intervention took place from the middle of September to the end of November, corresponding to beginning and middle part of their handball and ice hockey season. Participants were stratified into three training groups based on their F-V profile derived from Samozino´s simple method (Samozino et al., 2008) in SJ (Jiménez-Reyes, Samozino, Brughelli, et al., 2017). While all three strength training programs were designed to improve jump height, the content was different: either velocity-based, force-based or a balanced approach. Loading focus and exercises are presented in Table 1, a more detailed description of exercises and rep-ranges can be found in appendix I.

Table 1 Loading focus and exercises with training loads for each exercise.

Loading focus/target	Exercises	Training loads
Force-based		
Day 1 (heavy)	Dead lift	1-2 RIR
	Hip-thrust	1-2 RIR
	Bulgarian split squat	5-6 RIR
	Front squat	1-2 RIR
	Squat jump w/ trapbar	70 % of 1RM
Day 2 (Light)	Squat	1-2 RIR
	One-foot dead lift	1-2 RIR
	Bulgarian split squat	5-6 RIR
	Squat jump w/ trapbar	50 % of 1RM
	Calf-raises	5-6 RIR
Velocity-based		
Day 1 (heavy)	Half squad	1-2 RIR
	Squat jump	Negative (rubber band)
	Squat jump w/ trapbar	50% of 1RM
	Step up	10-20 kg
	Hip-thrust	1-2 RIR
	High jumps over broomstick	Bodyweight
Day 2 (light)	Squat jumps	Negative (rubber band)
	Squat jump w/ trapbar	50 % of 1RM
	Box jumps	Bodyweight
	Clean pull	50 % of 1RM
	Stair jumps	Bodyweight
	Single leg stair jumps	Bodyweight
Balanced approach		
Day 1 (heavy)	Dead lift	1-2 RIR
	Front squat	1-2 RIR
	Bulgarian split squat	5-6 RIR
	Hip-thrust	1-2 RIR
	Squat jump w/ trapbar	50 % of 1RM
	Single leg stair jumps	Body weight
Day 2 (light)	Squat jumps	Negative (rubber band)
	Squat jump w/trapbar	50 % of 1RM
	Box jumps	Bodyweight
	Stair jumps	Bodyweight
	Single leg stair jumps	Bodyweight
	Dead lift	1-2 RIR

RIR reps in reserve, *1RM* one-repetition maximum

3.5 Statistical analysis

Mean, % change, coefficient of variation (CV) and intraclass correlation coefficient (ICC) were used to assess reliability between the two baseline measurement days, as well as between the two post-training trials. Average values of both trials at pre and post-intervention were used when examining the agreement between F-V parameters derived from Keiser leg-press, Force plate, Contact grid and Encoder using Pearson's r. Correlations were interpreted categorically with magnitude-based inference using the following scale: 0.1–0.3 small; 0.3–0.5 moderate; > 0.5 large (Hopkins & Batterham, 2018; Hopkins, Marshall, Batterham, & Hanin, 2009). For the purpose of investigating agreement between the different measurement methods, the F-V parameters P_{max} and S_{FV} were calculated relative to body mass. Change scores were log-transformed before analysis to reduce bias arising from nonuniformity error and adjusted for baseline level to correct for the regression towards the mean effect (REF Will). Changes in the F-V parameters and jump height are presented as % mean ± SD and its associated 95% Confidence Interval. Additionally, number of training sessions was included as a moderator of the training-effects in jump height in SJ and CMJ, respectively. The magnitudes of changes from pre- to post-training were assessed as effect size (ES; mean change or mean difference between groups divided by baseline SD of all participants). The thresholds for assessing the observed difference in means were 0.2, 0.6, 1.2 and 2.0 for small, moderate, large and very large, respectively (Hopkins & Batterham, 2018; Hopkins et al., 2009). To make inferences about true values of effects, non-clinical magnitude-based inference was used rather than null-hypothesis significance testing (Hopkins et al., 2009). Magnitudes were evaluated mechanistically: if the confidence interval (CI) overlapped substantial positive and negative values (0.2 and − 0.2), the effect was deemed unclear; otherwise effects were deemed clear and shown with the probability that the true effect was substantial or trivial using the following scale: 25–75%, possibly; 75–95%, likely; 95–99.5%, very likely; > 99.5%, most likely (Hopkins & Batterham, 2018; Hopkins et al., 2009).

4.0 Method discussion

Since this master thesis is a methodological study, the present chapter will primarily discuss aspects not included in the theoretical background-section (Chapter 2.0) or the discussion-section of the paper. A more comprehensive method discussion is found in the paper (Part 2 of the master thesis).

Study design and participants

The purpose of this methodological study was to investigate the reliability and agreement of different measuring methods and equipment frequently used as means to monitor training in the Norwegian Olympic Training Centre. The present study aimed to recruit 36 athletes from sports where explosive performance was of importance. This would allow for three different intervention groups: one force-based group, one velocity-based group and one balanced group (Table 1). Two athletes (one handball- and one ice hockey player) were excluded before baseline-testing due to injuries not related to the study. Therefore, 34 athletes underwent baseline tests. The present study was a rare and great opportunity as scientists rarely get to experiment with national level team athletes training regimes, but it also led to some logistical difficulties regarding the study design. The players had just started their playing season during the initiation of the experimental study, which meant that they had an extremely busy schedule. Therefore, we had to adjust the logistics to their schedule. This led to some challenges that one normally would not face with untrained subjects. We were not able standardize the number of days between baseline 1- baseline 2 and post1-post2, due to the participants´ schedule: the athletes who played the most minutes in games needed more rest, while other athletes also played for the recruitment team on different days. Although some of these challenges were unfortunate for the present study, it was a great opportunity to experience how much strength training it is possible to implement into the national level athletes busy schedule between games and sport-specific practice while managing their total training- and playing load.

Test procedures

F-V parameters were assessed in vertical jumps (SJ and CMJ) as these are important functional movements and the most commonly exercises employed to assess the F-V parameters of the lower limb muscles (Cuk et al., 2014; Jiménez-Reyes et al., 2014; Samozino et al., 2014) in addition to leg-press (Colyer et al., 2018). Three different measuring methods were used to derive F-V parameters during SJ and CMJ (Force plate, Contact grid and Encoder). These are the three methods that the Norwegian Olympic Training Centre use to assess F-V relationships. Note that other methods do exist to assess F-V relationship, such as accelerometers (Giroux et al., 2015) and video (Balsalobre-Fernández, Glaister, & Lockey, 2015). It would have been interesting to investigate the reliability and agreement of training-induced changes in these as well.

Peak (highest) values or average values could have been used to determine the F-V parameter values when investigating agreement between measuring methods of both trials at pre and post-intervention (e.g., if F_0 was 35 N/kg on pre1 and 32 N/kg on pre 2, highest value method would be 35 N/kg, while average value method would be 33.5 N/kg). Both methods were investigated, and average values showed higher Person´s r values. Thus, average values were used to investigate the agreement between measuring methods in the present study.

Peak or average values could be used to calculate F and V from the Force plate in SJ and CMJ (García-Ramos et al., 2017). Garcia-Ramos et al. (2017) reported that peak values may be the most reliable method, most likely because maximum values are less influenced by arbitrary decisions about how to determine the start and the end of the concentric phase (García-Ramos et al., 2016). F-V parameters derived from a Contact grid can only estimate average F and V, and therefore, it was decided that data derived from the Force plate should also use average values to make the two methods comparable when investigating agreement in training-induced changes.

Training intervention

The thought was initially to divide the athletes into the training programs (force-based, velocity-based or a balanced approach) based on the direction and magnitude of their F-V imbalance as in the study of Jimenez-Reyes et al (2017). Due to the poor reliability in F-V slope at baseline, this caused great concerns. The different measuring methods classified different athletes as force or velocity dominated. Further, even within the same measuring method was some athletes categorized as velocity-dominated at baseline 1 and force-dominated at baseline 2. Lastly, only two athletes where categorized as force dominated (i.e., they would focus on the velocity aspect) at baseline when using samozino´s simple method with the Contact grid (Samozino et al., 2012). Therefore, within each training group, some athletes trained their "weakness", some trained their "strength" and others trained with "optimal profile" (Table 1).

Statistical analysis

Change in the mean, typical error of measurement and re-test correlation were used to assess reliability in measuring methods between the two baseline measurement days, as well as between the two post-training trials. These are the three main types of statistics used when investigating reliability (Hopkins, 2000). Although the raw typical error is probably a more used measure of reliability in other fields of sport science, I decided to use CV as this is the standard form of typical error of measurement used in most other studies investigating reliability of the F-V relationship. When using CV, changes should be presentet as % change (Hopkins, 2000). Training-induced changes in jump height and F-V parameters were analyzed by non-clinical magnitude-based inference rather than null-hypothesis testing (Hopkins & Batterham, 2018; Hopkins et al., 2009), although the use of MBI versus null-hypothesis testing is a highly debated topic within the field of sport science in recent years (Batterham & Hopkins, 2019; Sainani, 2018).

Due to the magnitude of the present methodological study, Pearon´s r was used to investigate the agreement between measuring methods in training-induced changes (Helland et al., 2019). This is a limitation of the present master thesis, as correlation coefficient may not directly assess agreement but rather association (Altman & Bland, 2017). Agreement is usually assessed by a graphical method to compare two measuring methods, referred to as the Bland-Altman plot. The differences or the ratios between the two measuring methods are plotted against the averages of the two methods (Bland & Altman, 1986). If one of the two methods is a "gold standard" (i.e., dual-energy x-ray absorptiometry in body composition measures), the differences can be plotted against the gold standard (Krouwer, 2008). When using this graphical method to assess agreement, are horizontal lines drawn at the mean difference, and at the limits of agreement, which are defined as the mean difference ± 1.96 times the standard deviation of the differences (Bland & Altman, 1986).

Ethical considerations

The present study was performed on healthy highly-trained handball- and ice hockey players competing at a national level. All players were informed about the study by a verbal presentation and a written information document (Appendix II). The potential risks, and the possibilities of any discomfort during the tests and training intervention was explained. Research clearance, data storage and ethical approval for the present Force-Velocity study was obtained from the Norwegian Center for Research data (NSD) (Appendix III) and by The Faculty's Ethics Committee of the University of Agder (Faculty for Health and Sport Science) (Appendix IV) in the summer of 2018. The players provided written consent before the initiation of baseline-testing and were informed that they could withdraw from the study at any point without any explanation needed (see Appendix II for more details about the consent form). All participants were non-identified by use of subject ID, data were anonymized and stored in password protected files locally on computers.

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Part 2:

Research paper

Large Variability Between and Within Methods to Assess Lower Limb Force-Velocity Relationship

This paper is written to the standards of the following journal:

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Figure legends will be moved to the end of the document at submission, and figures and tables will be submitted in separate files, but all are included within the main text in this thesis.

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“Large Variability Between and Within Methods to Assess Lower Limb Force-Velocity Relationship”

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The present article is written as part of a master thesis in sport science by the corresponding author.

Running title: Precision of Force-Velocity Profile Measures

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ABSTRACT

PURPOSE:

We aimed to explore the reliability of lower limb Force-Velocity (F-V) parameters (theoretical maximal force [F_0], velocity [V_0] and power [P_{max}], and the F-V slope [S_{FV}]) when obtained from Force plate, Linear position transducer and Optical infrared contact grid in both squat jump (SJ) and countermovement jump (CMJ), and from Keiser leg-press. Furthermore, we investigated the agreement between these methods, both on cross-sectional measures before and after the intervention, and of training-induced changes.

METHODS:

Twenty-seven national level team athletes underwent a 10-week power-training intervention. SJ and CMJ with five loading conditions (0.1, 20, 40, 60, 80kg), and an incremental F-V test in Keiser leg-press, were assessed two times before and two times after the intervention.

RESULTS:

The different measuring methods displayed a large variability in the four F-V parameters: F_0: change in the mean (CIM)= -3.2-15.7%; coefficient of variation (CV)= 6.0-11.2%; intraclass correlation coefficient (ICC)= 0.31-0.92, V_0: CIM= -2.4-10.3%; CV= 6.3-22.1%; ICC= 0.23-0.79, P_{max}: CIM= -2.0-25.1%; CV= 4.2-14.2%; ICC= 0.33-0.92, S_{FV}: CIM= -6.7-7.1%; CV= 12.4-31.9%; ICC= 0.19-0.94.

CONCLUSION:

The results of the present study indicate that Keiser leg-press and the Encoder in CMJ were the most reliable measuring methods to assess the F-V relationship in highly-trained national team athletes. The poor agreements to detect training-induced changes between methods indicate that they should not be used interchangeably. Due to the moderate-to-poor reliability in F-V slope (S_{FV}), one should be careful to use it as a monitoring tool in athletes.

KEYWORDS:

squat jump, countermovement jump, leg-press, reliability, highly-trained athletes

Introduction

The explosiveness of movements is highly related to athletic performance and is essential in the vast majority of sports[1,2]. In an applied sports and exercise science perspective, explosiveness is the ability to generate high power over a short period of time. Power (P) is expressed as force times velocity, where force (F) is the amount of newton produced during a muscle contraction, whereas velocity (V) is the speed of the muscle contraction[3,4]. The muscles intrinsic properties which enable them to produce high levels of F, V and P have previously been assessed under a single load[5,6]. However, the single-load values of these variables do not represent the maximum capacity of the muscles to develop F, V and P[7]. For instance, if an athlete develops more F, the acceleration will be higher, which will subsequently lead to a higher V. Therefore, the single load approach does not allow to distinguish whether the athlete´s improvement in F or V produced is a consequence of enhanced F capacity, maximal contraction V, or both[8].

The limitations of the single-load approach can be solved by obtaining parameters from the linear Force-Velocity (F-V) relationship to identify the theoretical maximal mechanical capacities of the muscles involved to generate F, V and P[7,9]. The F and V data are most commonly obtained under 4-6 loading conditions, although recent studies have investigated the use of only two loads referred to as the 2-point method[10]. The multiple-load method allow us to determine the F-V relationship parameters by applying the following regression model: ($F[V] = F_0 - S_{FV}V$), where F_0 represents the F intercept (i.e., theoretical maximal force at null velocity), V_0 is the V intercept (i.e., theoretical maximal velocity the limbs can extend during 1 extension under zero load) and S_{FV} is the slope that corresponds to F_0/V_0. Due to the F-V relationship´s linearity, the maximum power output (P_{max}) can be calculated as (F_0 x V_0)/4. The multiple-load approach can be used to determine selective gains in maximum F, V and P outputs since F_0 and V_0 are independent of each other (i.e., a change in F_0 can be observed without a change in V_0 and vice versa)[7].

Within strength and conditioning the F-V parameters (F_0, V_0, P_{max} and S_{FV}) have received increasing recognition as means to monitor training adaptations[11-13], and to determine the optimal balance between the maximal F and V capacities of the lower limbs neuromuscular system based on the S_{FV} parameter[9,13,14]. However, earlier studies have reported large variability in the reliability of the F–V parameters in various exercises such as vertical jumps[8,15-18], the bench press[12,19], the leg-press[20,21] and during sprints[22]. The large variability can make it difficult fort sport practitioners to separate the signal from the noise in F-V parameters, especially on an individual level[13]. Furthermore, the most precise measuring method is not known, as validity and agreement in methods to detect training-induced changes is not well known.

Vertical jumps, such as squat jump (SJ)[14,23] and countermovement jump (CMJ)[23,24], are important functional movements and the most commonly exercises employed to assess the F-V parameters of the lower limb muscles, in addition to leg-press[11]. Furthermore, Force plate and more recent developed devices (e.g., Linear position transducer, Optical infrared contact grid) can be used to assess F-V parameters in SJ and CMJ. Giroux and colleagues[16] have previously investigated the reliability of these three measurement methods, but only in SJ and by using average values of F, V and P, not the entire F-V spectrum´s parameters (F_0, V_0, P_{max} and S_{FV}). Furthermore, to the authors knowledge, no study has investigated the reliability of F-V parameters in a pneumatic leg-press apparatus. Lastly, the agreement of training-induced changes between different measuring methods in SJ, CMJ and leg-press is not known.

To investigate the mentioned limitations, we designed a study to comprehensively explore the F-V relationship of lower limb muscles during vertical jumps and leg-press. The aims were to investigate the reliability of leg muscles F-V parameters when obtained from (a) Force plate, (b) Linear position transducer (Encoder) and (c) Optical infrared contact grid (Contact grid) in both SJ and CMJ, and (d) from Keiser leg-press. Furthermore, we investigated the agreement between measuring methods, both on (a) cross-sectional measures before and after the intervention, and (b) of training-induced changes.

Methods

Participants

Thirty-four athletes volunteered to participate and completed the baseline measurements. Six athletes (two handball players and four ice hockey players) dropped out immediately prior to or during the training intervention due to injury or illness not related to the study. Furthermore, one participant was excluded due to major problems with jump coordination that led to highly inconsistent data. Thus, post-training data from 14 national level handball players and 13 Under-20 national level ice hockey players (n=27, 20 ± 5 years, 182 ± 8 cm, 76 ± 14 kg) formed basis for this methodological study. All players had a strength-training background ranging from 1- to more than 3 years and were highly trained. Written informed consent was obtained from each player prior to participation. The study was reviewed by the Internal Ethical Committee (University of Agder), approved by the Norwegian Centre for Research Data and performed in agreement with the Declaration of Helsinki.

Study design

The F-V relationship was assessed using a Force plate, Infrared optical contact grid (Contact grid) and a Linear position transducer (Encoder) (MuscleLab, Ergotest AS, Porsgrunn, Norway) in both SJ and CMJ, in addition to a Keiser A300 horizontal leg-press dynamometer (Keiser Sport, Fresno, CA). All players were instructed to prepare for the test-days as they would for a regular match in terms of nutrition, hydration, sleep and handball/ice hockey conditioning. The jump tests and leg-press were performed indoors with identical conditions for all tests. They were also instructed to use identical footwear and kit for each of the tests. Body mass was assessed with footwear and kit included prior to testing and tests were performed in the same order on each test day. A standardized 15 min warm-up procedure was carried out after the body mass measurements. It consisted of jogging, local muscle warm-up (hamstring- and hip mobility), running drills (high knees, skipping, butt-kicks, explosive lunges) and four body weight squat jumps. After the warm-up, participants performed loaded SJ, followed by loaded CMJ and finally Keiser leg-press.

Participants were stratified into three training groups based on their F-V profile derived from Samozino´s simple method[15] in SJ[13]. While all three strength training programs were designed to improve jump height, the content was different: either velocity-based, force-based or a balanced approach (training programs are found in the appendix). Then all participants were instructed to perform two weekly strength training sessions over 10 weeks (13 ± 3 sessions) in addition to their regular handball and ice hockey practice and competitive games. The strength training intervention took place from the middle of September to the end of November, corresponding to beginning and middle part of their handball and ice hockey season. To assess changes in jump height in SJ and CMJ, an infrared optical contact grid was used as measurement method.

Squat Jump. After the warm-up, participants´ anthropometrics were assessed to standardize the starting position in SJ[15]. The participants then performed SJ with five external loads ranging from 0.1-80 kg (0.1, 20, 40, 60 and 80 kg). In order to make the test as reliable as possible, participants were asked to maintain their individual starting position (∼90◦ knee angle) for about 2 seconds and then apply force as fast as possible and jump for maximum height before landing with ankles in extended position. Countermovement was verbally forbidden and carefully checked visually from the output. If all these requirements were not met, the trial was repeated. Two valid trials were performed with each load. The recovery time between each attempt was 2-3 min.

Force plate: F-V parameters derived from the Force plate were analysed using a customized Microsoft Excel spreadsheet (Microsoft Office Professional Plus 2018, version 16.23). In SJ, the start of the concentric phase was defined as when force exceeded 20N from the body mass + external load. The end of the concentric phase was defined as when the participant left the Force plate (i.e., take off). Average velocity was derived by using the following equation: $\overline{v} = \sqrt{\frac{gh}{2}}$ where g is gravitational acceleration and h is jump height[15].

Contact grid: Data derived from the Contact grid was based on Samozino´s simple method and Newton´s second law of motion, where mean force, velocity and power can be calculated during a vertical jump movement from the jump height and position measurements in SJ and CMJ[15,18]. Average force ($\overline{F}$) and average velocity ($\overline{v}$) were calculated using two equations considering only simple input variables: body mass, jump height and push-off distance.

$$\overline{F} = mg\left(\frac{h}{h_{PO}} + 1\right)$$

$$\overline{v} = \frac{h_{PO}}{t_{PO}}$$

In these equations m is body mass (kg), g is the gravitational acceleration ($m \cdot s^{-2}$), h is the jump height (m), *hpo* is the vertical push-off distance (m), and *tpo* is the push-off phase duration (s). Anterior iliac crest was selected as anatomical marker to calculate the vertical push-off distance (h_{PO}). The vertical push-off distance corresponded to the displacement of the marker between the starting position and the moment of take-off. The vertical position of the marker was determined with two stadiometers and a rubber band in the starting position. For deciding take-off moment position, the participants were lying on their back, ankles in maximal extension with tip of toes reaching a wall. The distance between the wall and the iliac crest corresponded to the vertical take-off position of the marker. These measurements were performed at the beginning of the first day of the pre- and post-intervention tests.

Encoder: Force, velocity and power were also derived using a linear position transducer (Encoder) which is shown to be a valid and reliable measuring instrument in different weightlifting and jump exercises[25,26]. The transducer was composed of an encoded wire directly fixed to the bar and winding into a sensor unit fixed to the floor. By measuring the position of the connected cable as a function of time, the software calculates acceleration and velocity (MuscleLab, version 10.5.69.4815). By entering body mass + external load, force and power are calculated from the obtained data. In agreement with the manufacturer´s recommendation, 90 % of body mass + external load was used to calculate force, velocity and power during SJ and CMJ with the Encoder.

Countermovement jump. While the handball players performed the CMJ test with the same loads as SJ, the ice hockey players only performed CMJ with external loads of 20 and 80 kg due to time limitations. Although 4-6 loads are preferred, the 2-point method, with one point close to the force intercept (heavy load) and the other close to the velocity intercept (light load), is recently shown to be a reliable method to assess the F-V relationship in multiple-joint movements[10].

Force plate: In CMJ, the start of the concentric phase was defined as when the velocity exceeded 0.1 m/s. The end of the concentric phase and average velocity was defined and calculated in the same way as in SJ. F-V parameters in CMJ derived from the Contact grid and Encoder were obtained in the same way as in SJ.

Keiser leg press. In addition to the three measurement methods in SJ and CMJ, the F-V relationship was assessed using a leg-press test. The Keiser A300 horizontal leg-press dynamometer uses pneumatic resistance and measures force and velocity across each effort[11]. Keiser leg-press was performed as a 6-repetition 1RM test followed by a 10-repetition F-V test with incremental loads based on each players 1RM leg-press[11]. Seating position was adjusted for each participant (~90º knee angle) and feet placed with heals at the bottom end of the platform. Participants were asked to extend both legs with maximum velocity during the 10-repetition F-V test.

Statistics

Mean, % change, coefficient of variation (CV) and intraclass correlation coefficient (ICC) were used to assess reliability between the two baseline measurement days, as well as between the two post-training trials. Average values of both trials at pre and post-intervention were used when examining the agreement between F-V parameters derived from Keiser leg-press, Force plate, Contact grid and Encoder using Pearson’s r. Correlations were interpreted categorically with magnitude-based inference using the following scale: 0.1–0.3 small; 0.3–0.5 moderate; > 0.5 large [27,28]. For the purpose of investigating agreement between the different measurement methods, the F-V parameters P_{max} and S_{FV} were calculated relative to body mass. Change scores were log-transformed before analysis to reduce bias arising from nonuniformity error and adjusted for baseline level to correct for the regression towards the mean effect (REF Will). Changes in the F-V parameters and jump height are presented as % mean ± SD and its associated 95% Confidence Interval. Additionally, number of training sessions was included as a moderator of the training-effects in jump height in SJ and CMJ, respectively. The magnitudes of changes from pre- to post-training were assessed as effect size (ES; mean change or mean difference between groups divided by baseline SD of all participants). The thresholds for assessing the observed difference in means were 0.2, 0.6, 1.2 and 2.0 for small, moderate, large and very large, respectively[27,28]. To make inferences about true values of effects, non-clinical magnitude-based inference was used rather than null-hypothesis significance testing[27]. Magnitudes were evaluated mechanistically: if the confidence interval (CI) overlapped substantial positive and negative values (0.2 and − 0.2), the effect was deemed unclear; otherwise effects were deemed clear and shown with the probability that the true effect was substantial or trivial using the following scale: 25–75%, possibly; 75–95%, likely; 95–99.5%, very likely; > 99.5%, most likely[27,28].

Results

All F-V profiles showed a linear relationship with individual R^2 values ranging from 0.95 to 1.00. F_0 (CV: 3.5-11.2%; ICC: 0.31-0.96) and P_{max} (CV: 4.2-14.2%; ICC: 0.33-0.92) exhibited the highest reliability of the four F-V parameters. V_0 (CV: 5.0-18.5%; ICC: 0.07-0.81) showed lower reliability compared to F_0 and P_{max} but higher compared to S_{FV} (CV: 7.3-31.9%; ICC: 0.19-0.98). Overall, the different measurement methods in SJ and CMJ, and the Keiser leg-press exhibited higher reliability at post-intervention trials compared to baseline.

Squat jump reliability. Reliability of the F-V parameters (F_0, V_0, P_{max} and S_{FV}) in squat jump assessed at two consecutive baseline trials and two post-intervention trials is presented in Table 1. Overall, the Force plate and Contact grid showed similar and higher reliability at baseline compared to the Encoder in F_0 and P_{max}, while the Encoder showed higher reliability in V_0 and S_{FV}. Encoder exhibited higher reliability in F-V parameters compared to Force plate and Contact grid at post-tests.

Countermovement reliability. The Encoder exhibited the highest reliability in all four F-V parameters compared to the Force plate and Contact grid (Table 2), both at baseline and post-intervention trials in CMJ. The Contact grid exhibited higher reliability compared to the Force plate at both cross-sectional measures.

Keiser leg-press reliability. F-V parameters derived from the Keiser-leg press (CV: 3.5-12.4%; ICC: 0.79-0.98) showed the highest reliability compared to the three measurement methods in both SJ and CMJ (Table 2).

Jump height reliability. Jump height derived from the Contact grid in SJ (Table 1) and CMJ (Table 2) exhibited similar reliability at baseline (CV: 4.7-5.5%; ICC: 0.79-0.82) and at post-intervention trials (CV: 3.4-3.8%; ICC: 0.86-0.88).

Table 1 Test–retest reliability of F-V parameters in squat jump

	Mean Pre1	% Δ Pre	CV% Pre	ICC Pre	Mean Post1	% Δ Post	CV% Post	ICC Post
SJ Force Plate								
F_0 (N kg^{-1})	34.9	15.7	7.6	0.31	33.1	-5.5	6.9	0.67
V_0 (m s^{-1})	2.6	10.3	12.6	0.43	2.7	13.9	14.0	0.56
$P_{\max}$ (W kg^{-1})	23.3	25.1	7.0	0.76	22.3	7.7	7.6	0.69
S_{FV} (N s^{-1}m^{-1}kg^{-1})	-13.3	7.0	21.5	0.19	-12.7	-17.0	21.5	0.57
SJ Contact Grid								
F_0 (N kg^{-1})	33.6	0.2	7.5	0.65	33.2	-5.4	6.8	0.67
V_0 (m s^{-1})	2.8	-1.0	16.3	0.39	3.0	12.7	16.3	0.51
$P_{\max}$ (W kg^{-1})	23.0	-0.7	9.4	0.63	24.0	6.6	9.8	0.67
S_{FV} (N s^{-1}m^{-1}kg^{-1})	-12.6	1.3	24.5	0.42	-12.1	-16.0	23.8	0.52
SJ Encoder								
F_0 (N kg^{-1})	31.1	-0.4	11.2	0.53	28.8	-2.9	7.6	0.65
V_0 (m s^{-1})	2.6	1.8	12.3	0.66	2.8	6.8	10.5	0.59
$P_{\max}$ (W kg^{-1})	19.8	1.4	13.0	0.46	19.6	3.7	5.3	0.72
S_{FV} (N s^{-1}m^{-1}kg^{-1})	-12.7	-2.2	20.5	0.65	-10,8	-9.1	18.3	0.60
SJ								
Jump height	35.8	-1.6	5.5	0.78	37.0	4.0	3.4	0.88

Mean Absolute values baseline 1 (pre 1) and post1, Δ *%* change in the mean between baseline 1 and 2, and post 1 and 2, *CV* Coefficient of variation, *ICC* Intraclass correlation, F_0 Theoretical maximal vertical force, V_0 Theoretical maximal velocity, P_{max} Maximal vertical power, S_{Fv} Force–velocity slope

Table 2 Test–retest reliability of F-V parameters in countermovement jump and Keiser leg-press

	Mean Pre1	% Δ Pre	CV% Pre	ICC Pre	Mean Post1	% Δ Post	CV% Post	ICC Post
CMJ Force Plate								
F_0 (N kg^{-1})	35.6	-2.1	8.9	0.57	32.9	1.0	8.1	0.55
V_0 (m s^{-1})	3.1	5.0	22.1	0.23	3.4	-2.1	18.5	0.07
P_{max} (W kg^{-1})	27.1	2.8	14.2	0.33	27.6	-1.1	11.6	0.27
S_{FV} (N s^{-1}m^{-1}kg^{-1})	-12.3	-6.7	31.9	0.31	-10.0	3.2	27.2	0.20
CMJ Contact Grid								
F_0 (N kg^{-1})	32.6	0.4	9.4	0.51	31.5	0.0	7.1	0.70
V_0 (m s^{-1})	3.2	-2.4	16.0	0.52	3.4	4.6	15.2	0.51
P_{max} (W kg^{-1})	26.0	-2.0	8.5	0.72	26.5	4.6	9.4	0.56
S_{FV} (N s^{-1}m^{-1}kg^{-1})	-10.6	2.9	26.0	0.47	-9.6	-4.4	22.6	0.56
CMJ Encoder								
F_0 (N kg^{-1})	33.7	-3.2	6.5	0.79	30.7	-0.7	5.6	0.66
V_0 (m s^{-1})	2.8	4.2	9.4	0.65	3.0	0.9	5.7	0.74
P_{max} (W kg^{-1})	22.9	0.9	4.5	0.58	22.7	0.2	3.2	0.81
S_{FV} (N s^{-1}m^{-1}kg^{-1})	-12.6	7.1	16.0	0.72	-10.5	1.7	11.1	0.69
CMJ								
Jump height	37.9	-1.3	4.7	0.82	39.5	2.8	3.8	0.86
Keiser Leg press								
F_0 (N kg^{-1})	19.2	-2.0	6.0	0.92	18.5	2.6	3.5	0.96
V_0 (m s^{-1})	2.1	4.5	6.3	0.79	2.2	-1.5	5.0	0.81
P_{max} (W kg^{-1})	9.8	2.5	4.2	0.92	10.1	1.1	4.6	0.87
S_{FV} (N s^{-1}m^{-1}kg^{-1})	-19.7	-4.3	12.4	0.94	-19.5	-4.0	7.3	0.98

Mean Absolute values baseline 1 (pre 1) and post1, Δ *%* change in the mean between baseline 1 and 2, and post 1 and 2, *CV* Coefficient of variation, *ICC* Intraclass correlation, F_0 Theoretical maximal vertical force, V_0 Theoretical maximal velocity, P_{max} Maximal vertical power, S_{Fv} Force–velocity slope

Table 3 Percent training-induced changes in jump height in unloaded SJ and CMJ

n = 27	SJ Δ± SD%; CI95	CMJ Δ± SD%; CI95
All groups	5.1 ± 6.2; 2.5^{1c}	5.4 ± 5.7; 2.3^{1d}
Force group	0.5 ± 1.8; 1.7^{0e}	3.3 ± 3.4; 3.2^{1}
Velocity group	5.5 ± 7.7; 5.7^{1}	5.8 ± 5.4; 4.1^{1c}
Balanced group	8.0 ± 6.8; 5.2^{1c}	6.6 ± 8.0; 6.0^{1}

Changes are average values of both trials at pre and post-intervention trials *SJ* Squat jump, *CMJ* Counter movement jump, Δ change (delta), *SD* Standard deviation, *CI* confidence interval. ^{0}Trivial, ^{1}Small, ^{2}Moderate, ^{3}Large, ^{4}Very large for standardized differences in means.
Likelihood of clear differences from pre- to post-training test: ^{c}Very likely, ^{d}Most likely
Likelihood of clear trivial differences: ^{e}Likely, ^{f}Very Likely

Training-induced changes in F-V parameters and jump height

Overall, the different measurement methods demonstrated a clear decrease in F_0 (-4.1 to -14.3%; small to large; likely to most likely) with the exception of Keiser leg press (-1.8 %; very likely trivial). There was a clear increase in V_0 across all measurement methods (3.9 to 9.4 %; small; likely to very likely) except for CMJ Force plate (3.0%; unclear). SJ Force plate, CMJ Force plate and CMJ Encoder exhibited a clear decrease in P_{max} from pre- to post-training (-1.1 to -12.2%; small to moderate; possibly to most likely) (Figure 1), while CMJ Contact grid likely had a small increase in P_{max} (4.8%). Changes in P_{max} were deemed unclear in Keiser leg-press and likely trivial with SJ Encoder. S_{FV} showed clear small increases in all measurement methods with the exception of a moderate change with SJ Force plate (16.1%; most likely) and a very likely trivial change using Keiser leg press (Figure 1).

There were small clear increases in jump height in both SJ and CMJ (5.1%; very likely and 5.4%; most likely, respectively) (Table 3). When including number of sessions as a moderator of the overall effect, one additional training session performed explained 0.5% and 0.6% of changes in SJ and CMJ, respectively. If baseline value was taken out of the equation (only controlling for number of sessions as a covariate), the effect of one extra session was 1.0% and 1.1%, indicating that more training seemed more beneficial for those with lower baseline values.

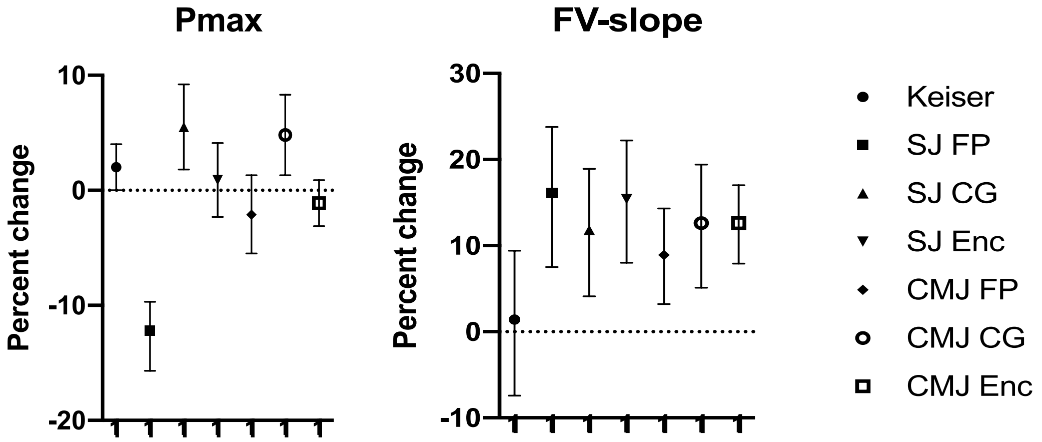

Figure 1 Mean with 95 % CI of percent training-induced change in Pmax (maximal power; W kg^{-1}) and FV-slope (S_{FV}; N s^{-1} m^{-1} kg^{-1}) from different measurement methods. *SJ* squat jump, *CMJ* countermovement jump *CG* Contact grid, *Enc* Encoder, *FP* Force Plate

Agreement in P_{max} and S_{FV} within squat jump

P_{max} had small to large agreements between the three measuring methods on cross-sectional measures (r=.20-.85; possibly to most likely) in SJ (Table 4). Agreement in training-induced changes in P_{max} were only clear between the Force plate and Contact grid (r=.37; likely).

S_{FV} displayed a small to large agreement between the three measuring methods on cross-sectional measures (r=.24-.60; likely to most likely) (Table 5), but trivial between the Contact grid and Encoder on post-tests (r=.02). Agreement in training-induced changes in S_{FV} were only clear between the Force plate and the Contact grid (r=.45: moderate; very likely).

Agreement in P_{max} and S_{FV} within countermovement jump

P_{max} exhibited small to large agreements between the three methods on cross sectional measures (r=.10-.79; possibly to most likely) in CMJ (Table 4). Agreement in training-induced changes in P_{max} were only clear between the Force plate and the Contact grid (r=.42; most likely).

There were small to large agreements in S_{FV} between the three measuring methods on cross-sectional measures (.20-.82; possibly to most likely) (Table 5), but not between the Encoder and Contact grid on post-tests (r=-.06). Agreement in training-induced changes in S_{FV} from pre to post-training were small to moderate between the three methods (r=.21-.49; possibly to likely).

Agreement between different F-V tests (SJ, CMJ and Keiser leg-press) in P_{max} and S_{FV}

Agreements between different measurement methods in P_{max} and S_{FV} are displayed in Table 4 and 5, respectively. Overall, P_{max} exhibited small to large agreement between all the different methods (r=.13-.85; possibly to most likely), but not between SJ Encoder and CMJ Contact grid, on cross-sectional measures. Agreement of training-induced changes in P_{max} were small between SJ Contact grid and CMJ Encoder and moderate between CMJ Encoder and SJ Encoder. Agreement in training-induced changes between different F-V tests in S_{FV} were small between Keiser leg-press and the two jump types using the Encoder, small between SJ Encoder and CMJ Force plate, and large between SJ Encoder and CMJ Encoder.

Table 4 Agreement in maximal power output (P_{max}) in different measurement methods (pre, post and change)

Baseline agreement	1	2	3	4	5	6
1 Keiser Leg Press	…					
2 SJ Contact Grid	.53^{3c}	…				
3 SJ Encoder	.65^{3d}	.20^{1a}	…			
4 SJ Force plate	.72^{3d}	.85^{3d}	.37^{2b}	…		
5 CMJ Force plate	.29^{1b}	.47^{2c}	.12^{1a}	.39^{2b}	…	
6 CMJ Contact Grid	.18^{1a}	.68^{3d}	-.05	.56^{3d}	.79^{3d}	…
7 CMJ Encoder	.74^{3c}	.36^{2b}	.67^{3d}	.47^{2c}	.23^{1a}	.13^{1a}
Post agreement						
1 Keiser Leg Press	…					
2 SJ Contact Grid	.52^{3c}	…				
3 SJ Encoder	.61^{3d}	.41^{2b}	…			
4 SJ Force plate	.72^{3d}	.64^{3d}	.56^{3d}	…		
5 CMJ Force plate	.51^{3c}	.74^{3d}	.56^{3d}	.47^{2c}	…	
6 CMJ Contact Grid	.25^{1b}	.67^{3d}	.12^{1a}	.26^{1b}	.50^{3c}	…
7 CMJ Encoder	.70^{3d}	.43^{2c}	.81^{3d}	.45^{2c}	.58^{3d}	.10^{1b}
Change agreement						
1 Keiser Leg Press	…					
2 SJ Contact Grid	.04	…				
3 SJ Encoder	-.05	.06	…			
4 SJ Force plate	.07	.37$^{\mathbf{2b}}$	-.01	…		
5 CMJ Force plate	-.06	-.42	-.01	-.42	…	
6 CMJ Contact Grid	.01	.01	-.22	.01	.42$^{\mathbf{2d}}$	…
7 CMJ Encoder	-.20	.13$^{\mathbf{1a}}$	.48$^{\mathbf{2c}}$	-.30	.00	-.34

SJ squat jump, *CMJ* countermovement jump, n = 27, ^{1}Small, ^{2}Moderate, ^{3}Large. ^{a}Possibly, ^{b}Likely, ^{c}Very likely, ^{d}Most likely

Table 5 Agreement in Force-Velocity-slope (S_{FV}) in different measurement methods

Baseline agreement	1	2	3	4	5	6
1 Keiser Leg Press	…					
2 SJ Contact Grid	.33^{2b}	…				
3 SJ Encoder	.55^{3c}	.35^{2b}	…			
4 SJ Force plate	.32^{2b}	.56^{3d}	.24^{1b}	…		
5 CMJ Force plate	-.05	.39^{2b}	.27^{1b}	.04	…	
6 CMJ Contact Grid	-.25^{b}	.44^{2c}	-.06	.19^{1a}	.82^{3d}	…
7 CMJ Encoder	.35^{2b}	.42^{2c}	.83^{3d}	.26^{1b}	.53^{3c}	.33^{2b}
Post agreement						
1 Keiser Leg Press	…					
2 SJ Contact Grid	.00	…				
3 SJ Encoder	.66^{3d}	.02	…			
4 SJ Force plate	.33^{1b}	.60^{3d}	.45^{2b}	…		
5 CMJ Force plate	-.09	.51^{3c}	.04	.13^{1a}	…	
6 CMJ Contact Grid	-.23^{a}	.50^{3c}	.04	.14^{1a}	.67^{3d}	…
7 CMJ Encoder	.56^{3d}	.12^{1a}	.60^{3d}	.47^{2c}	.20^{1a}	-.06
Change agreement						
1 Keiser Leg Press	…					
2 SJ Contact Grid	-.08	…				
3 SJ Encoder	.20$^{\mathbf{1a}}$	-.01	…			
4 SJ Force plate	-.50	.45$^{\mathbf{2c}}$	-.10	…		
5 CMJ Force plate	.01	-.35	.17$^{\mathbf{1a}}$	-.31	…	
6 CMJ Contact Grid	-.05	-.01	-.01	.08	.49$^{\mathbf{2c}}$	…
7 CMJ Encoder	.27$^{\mathbf{1b}}$	-.01	.50$^{\mathbf{3c}}$	.00	.39$^{\mathbf{2b}}$	.21$^{\mathbf{1a}}$

SJ squat jump, *CMJ* countermovement jump, *n* = 27, ^{1}Small, ^{2}Moderate, ^{3}Large. ^{a}Possibly, ^{b}Likely, ^{c}Very likely, ^{d}Most likely

Discussion

The present study investigated the reliability and the agreement of the F–V relationship parameters during vertical jumps (SJ and CMJ) assessed by Force plate, linear Encoder and Contact grid, and with Keiser leg-press. In general, individual F–V relationships obtained from the participants in all different methods proved to be strong and linear, while their F-V parameters showed moderate-to-high (F_0 and P_{max}) or low-to-moderate (V_0 and S_{FV}) reliability. The present results are in accordance with previous studies that have indicated that F_0 and P_{max} are more reliable than V_0 and S_{FV} parameters[8,20]. The high reliability observed in P_{max} could be explained by the pattern of the experimental data, since the range of the recorded average F and V data that served for the regression modelling was mainly located in the middle section that reveals the maximal power output[8]. In contrast, F_0, and particularly V_0, are relatively remote extrapolations[8,17]. Additionally, the higher CV observed in V_0 could be a consequence of calculating average V from the force/acceleration signal, or even in terms of velocity-estimations based on flight time from the Contact grid during SJ and CMJ, which may inevitably affect its reliability. Lastly, V_0 may be more influenced by familiarization than F_0, possibly due to higher biological variation in factors affecting maximal velocity of contractions [20].

S_{FV} is the linear regression slope in an F-V profile: the outcome of the theoretical maximal force at null velocity (F_0) and the theoretical maximal velocity the lower limbs can extend during 1 extension under zero load (V_0), which make the reliability of S_{FV} usually inferior to the reliability of P_{max}, F_0 and even V_0 since S_{FV} is affected by both of these extrapolations. S_{FV} have recently been used as the tool to individualize training programs for explosive performance by comparing individual F-V profiles to a theoretical optimal F-V relationship/profile (F-V imbalance)[13]. The poor reliability of S_{FV} observed in the present study are in agreement with a few previous studies[17,20], and causes great concerns for the application of individualized training programs based on the F-V imbalance.

Of the seven methods adopted in the present study the Keiser leg-press displayed the highest reliability in all four F-V parameters (F_0, V_0, P_{max} and S_{FV}). The reliability of Keiser leg-press concur with the study of Alcazar and colleagues[21] (CV: 2.6-10.1 %) but not with the study of Meylan et al[20] (CV: 6.1-23.6 % ICC: .54-.97). The two studies both used a leg-press apparatus with a linear position transducer fixed to the weight plates, while the present study used a Keiser leg-press dynamometer that uses pneumatic resistance and measures force and velocity across each effort. Therefore, the participants in Meylan et al. (adolescent males, 11-15 year) may explain the lower reliability observed compared to Alcazar et al. and the present study rather than the equipment used.

CMJ Encoder exhibited a reliability close to the one found in Keiser leg-press in F_0 and P_{max} in the present study, but slightly less reliable in V_0 and S_{FV}. Hughes et al.[29] showed that test-retest reliability of average velocity derived from a linear position transducer is highest during squats with loads at 60-80% of 1RM (CV: 2.5-4.3%), and lower at 20-40% of 1RM (CV: 6.4-7.2%) and 90-100% of 1RM (CV: 14.2-22.6%). Thus, the reliability of average velocity got progressively worse the further away the attempts were from ~60-80% of 1RM-loads. Therefore, it is possible that the slightly lower reliability in V_0 with CMJ Encoder than with Keiser leg-press in the present study, may be due to the fact that two of the loads used in CMJ were under 20% of the participants´ 1RM in most cases, which then furthermore affects the S_{FV}.

Although similar reliability in SJ Encoder have been reported by Giroux et al[16] as observed in the present study, it was somewhat surprising that SJ Encoder exhibited relatively poor reliability compared with CMJ Encoder in all four F-V parameters and even twice the CV in F_0 and P_{max} at baseline. The poor reliability compared to CMJ Encoder may be due to the exercise itself rather than the equipment, as countermovement jump is a more sport specific exercise, especially for the handball players, and previously used in their training. In contrast, the athletes are less familiarized with the squat jump exercise, including just the concentric phase of the jump. Further, the participants found it difficult to stand completely still for at least 2 seconds in the bottom position in SJ before initiation of the jump, which can lead to more variation in the calculation of average F and V[13]. This limitation is not present to the same degree in the CMJ exercise, since force calculations before the jump are done in an upright position.

SJ Force plate, SJ Contact grid and CMJ Contract grid displayed similar reliability, all lower than Keiser leg-press, CMJ Encoder and SJ Encoder. The reliability of F_0 and P_{max} with SJ Force plate in the present study was similar to Feeney et al[17] (CV: 8.4-9.9 %), while the reliability in V_0 and S_{FV} was higher (CV: 17.3-30.2 %). The different methods of loading may explain the differences in reliability, as Feeney and colleagues used a weighted west who adds mass closer to the center of gravity compared with weighted bars added to shoulders. Secondly, none of the participants were active athletes. The reliability of SJ Force plate in the present study was inferior to the findings by Garcia-Ramos et al[8] (CV: 3.8-8.2 %). The main methodological differences between the two studies were the calculation of average velocity. Garcia-Ramos and colleagues used the impulse-momentum approach to calculate the velocity of the system centre-of-mass from the vertical ground reaction force data. The customized excel-spreadsheet used in the present study was not able to correctly calculate average velocity using this method, and it was challenging to find the velocity on each load manually for every individual. Therefore, average velocity was estimated using flight time[15], which may explain the poor reliability of V_0 and subsequently the poor reliability of S_{FV} in SJ Force plate in the present study.

The poor reliability of SJ Contact grid and CMJ Contact grid observed in the present study is contradictory to previous findings[15,16,18], although the reliability reported in these studies was of the average F, V, P values, which have less variability than the extrapolated F_0 and V_0 parameters[16]. Unlike the Encoder and Force plate, which is only partial estimations of F and V, the F-V profile derived from a Contact grid is purely estimations based on jump height, body weight, external load and the push-off distance[15]. Additionally, it is difficult to control the depth in CMJ, even with a rubber band, as the CMJ is supposed to be an explosive eccentric-concentric movement. Countermovement depth might not affect jump performance, but could markedly affect the F and P output[17].

Of the seven methods used to assess the F-V relationship in the present study, the CMJ Force plate seem to be the least reliable option (CV: 8.9-31.9 %), which again is contradictory to the findings of Garcia-Ramos et al[8] (CV: 2.4-8.2 %). In addition to the points discussed with SJ Force plate regarding the calculation method of average velocity, some challenges may have contributed to the poor reliability observed in CMJ Force plate. Due to time-limitations, half of the participants (ice hockey players) performed CMJ with only 2 loads (20 and 80 kg). Although the 2-point method have previously been validated[10], the R^2 values will always be equal to 1 and the deviations of the F-V points from the linear regression equation equal to 0, independently of the participants ability to exert their maximal force and velocity[21]. Hence, the F-V profile is directely affected if the participants do not perform the repetitions at each load as fast and strongly as possible. In addition, the external load of 80 kg may have been sub-optimal or too heavy for some of the young ice hockey players. Although every participant managed to jump with 80 kg, Morin and Samozino[30] have previously discussed if individuals should be able to jump at least 10 cm for it to be a valid attempt. For a few participants the countermovement was so slow that the complete force-impulse was not recorded by the software which made it impossible to calculate average F. The challenges faced in calculating F-V parameters from the Force plate in SJ and CMJ could be solved by using peak values of F and V rather than average values, because maximum values are less influenced by arbitrary decisions about how to determine the start and the end of the concentric phase[25]. Since F-V parameters derived from a Contact grid can only estimate average F and V, we decided to also use average values in the data derived from the Force plate, to make the two methods comparable when investigating agreement in training-induced changes. In both SJ and CMJ the Force plate and Contact grid exhibited a likely moderate agreement in training-induced changes of P_{max}. Note that this may be due to the fact that both methods used the same calculations for average V because of the reasons explained above.

Athletes do not always familiarize properly to F-V profile measurements during SJ, CMJ and Keiser leg-press due to time limitations. Hence, to assess the variability in our F-V profile measurements both with and without familiarization, the first two trials were conducted without familiarization and the second round with proper familiarization after both baseline measurements and a training period that included both the SJ and CMJ exercises. The four F-V parameters in all seven-measurement methods in the present study displayed a higher reliability on post-intervention trials. These observations are in agreement with the findings of Meylan et al.[20], who conducted three test rounds and observed improved reliability for each round. The improvements in reliability in the present study highlight the importance of prioritizing proper familiarization to F-V profile measurements[31], even in highly-trained national level athletes.

Although nearly all the measuring methods displayed an agreement in F-V parameters on cross-sectional measures, the agreement in training-induced changes were small in some cases and trivial in most cases. The Keiser leg-press, CMJ Encoder and SJ Encoder exhibited a small agreement in S_{FV} change, which further support that Keiser leg-press and the Encoder, especially in the CMJ-exercise, seem to be the most reliable and best options for assessing the F-V relationship.

To conclude that there has been real change from pre- to post-intervention, the change should be greater than the test-retest CV[31]. No measurement method displayed a larger clear change in F-V parameters than the test-retest CV. This has practical implications as training-induced changes in the F-V relationship are subtle in highly-trained athletes[16]. The training-induced changes in F-V parameters observed in the present study might be lower than exptected due to the athletes′ hectic schedule during playing season. First, the desired number of training sessions of 18 was not met (13 ± 3). Secondly, the implementation of the training intervention during regular season may have caused a total training load that exceeded the capacity for recovery in the athletes, especially for the participants in the "force-group", who displayed a clear decrease in F_0, and trivial training-induced improvements in jump height. The relatively high CV observed in the present study at baseline can partially be explained by the lack of familiarization and the difficulty to standardize and control for the recovery before baseline tests, as some athletes played substantially more minutes in games than others during this period.

Strengths and limitations

Participants consisted of highly-trained national level athletes, which is one of the strengths in the present study. Further, we analyzed cross-sectional reliability and agreement at two occacions with a strength-training intervention between. To the author knowledge have no other study investigated the agreement in training-induced changes of the entire F-V spectrum (F_0, V_0, P_{max}, S_{FV}) in the seven measuring methods used in the present study. Lastly, the athletes were closely followed-up in their strength-training, as three members of the project were present at all sessions.

Nevertheless, the present study has several limitations. First, the absence of familiarization before baseline was the main limitation when the agreement between measurement methods to detect training-induced changes was investigated, as the variability was relatively high at baseline. Furthermore, due to the athletes´ hectic schedule, it was not possible to standardize the number of days between test-retest. Thus, some athletes were more recovered than others during F-V assessments. Lastly, our statistical power may have been too low to detect moderate effects within the different training groups (i.e., type II statistical errors might have occurred) (Table 3). However, clear effects were detected in F-V parameters by most measuring methods (Figure 1) and in jump height (Table 3) when investigating training-induced changes by the athletes as a collected group.

Conclusion and future perspectives

The present study explored the test-retest reliability and agreement in methods frequently used to assess F-V relationships within the sports and fitness community. The results of the present study indicate that Keiser leg-press and the Encoder in CMJ were the most reliable measuring methods to assess the F-V relationship in highly-trained national team athletes. The poor agreements to detect training-induced changes between methods indicate that they should not be used interchangeably. Due to the moderate-to-poor reliability in F-V slope (S_{FV}), one should be careful to use it as a monitoring tool in athletes. Future research should investigate how training-induced changes in F-V parameters correlates with changes in sport specific tests, as well as how other measurement methods are able to detect training-induced changes in F-V parameters.

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Conflict of interest

The author declares that there is no conflict of interest. The author alone is responsible for the content and writing of the manuscript

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Appendix

Content

Appendix 1: Training programs

Appendix 2: Informed consent to the participants

Appendix 3: Approval from the Norwegian center for research data

Appendix 4: Approval from the local ethics committee

Appendix 1

OLYMPIATOPPEN

SAMMEN OM DE STORE PRESTASJONENE

Navn:
Idrett: Håndball / Ishockey
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	10 x 2	10 x 2	10 x 2	100 %	Kroppsvekt	1-2 min	Hender på hofte
Sum antall set:	13	13	13				

Navn:
Idrett: Håndball / Ishockey
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	10 x 2	10 x 2	10 x 2	100 %	Kroppsvekt	1-2 min	Hender på hofte
Markløft	8 - 10 x 3	5 - 7 x 3	3 - 5 x 3	80 %	1-2 RIR	2-3 min	Konvensjonell, stopp i bunn
Sum antall set:	14	14	14				

OLYMPIATOPPEN

SAMMEN OM DE STORE PRESTASJONENE

Navn:
Idrett: Håndball / Ishockey
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 %	70 % 1RM	3-4 min	Eksplosivt, 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	80 %	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	Antall reps = pr fot
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
Ettbeins tåhev	10 x 2	10 x 2	10 x 2	80 %	5-6 RIR	1-2 min	Smithmaskin / beinpress
Sum antall set:	10	10	10				

Appendix 2

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 18 og 35 år og ha erfaring med å løfte vekter. 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 1) mot å optimalisere kraft-hastighets-forholdet (trener på dine «svakheter»), 2) trener «motsatt» og har som mål å bedre dine «styrker» (enten hastighet eller kraft) eller 3) å bedre begge egenskaper («balansert gruppe», både kraft og hastighet). Det vil være 3 økter per uke i 8 uker. Du vil bli testet igjen etter 4 uker trening (midtveis) og etter 8 uker trening.

Det bli gjennomført følgende tester:

1) DXA
2) Ultralyd
3) Squat Jump
4) Countermovement jump
5) 30m Sprint
6) 1RM knebøy

7) Keiser leg press
8) Kne-ekstensjon
9) Spørreskjema for opplevd overskudd og 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 99094092) eller Thomas Bjørnsen (Telefon: +47 98619299) 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: 99094092), eller Thomas Bjørnsen, fagansvarlig kraft/styrke Olympiatoppen Sør (thomas.bjornsen@uia.no, tlf: 98619299). 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 (Telefon: +47 99094092, mail: paul.solberg@olympiatoppen.no) eller Thomas Bjørnsen (Telefon: +47 98619299, mail: thomas.bjornsen@uia.no).

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.

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, biobank, økonomi og forsikring.

Samtykkeerklæring følger etter kapittel B

Kapittel A – Utdypende forklaring av hva studien innebærer

Kriterier for deltakelse

- Alder 18-35 år
- Utøver på minimum nasjonalt nivå
- Trener styrke regelmessig
- Ingen betydningsfulle skader, sykdommer eller medisinbruk
- Ikke røyker

Tester, trening og annet den inkluderte må gjennom

Tester gjennomføres 3 ganger over 2 dager under intervensjonsperioden (Før start, midtveis og etter). Følgende tester gjennomføres alle 3 gangene:

- Spenst på kraftplattform: Knebøyhopp og svikthopp med 5 ulike motstander
- 30 meter sprint
- Knebøy – 1RM
- Benpress (Keiser): sittende benpress med 10 motstander
- Kne-ekstensjon: 5 ulike motstander (40-50-60-70-80kg)
- Kroppssammensetningsmåling (Lunar iDXA)
- Ultralyd måling av lårmusklenes tverrsnittsareal og pennasjonsvinkel
- Spørreskjema for opplevd overskudd og motivasjon

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 1) trener spesifikt for å utligne dominansen og dermed øke power (arbeidskapasitet), 2) trener «motsatt» og har som mål å bedre sine «styrker» (enten hastighet eller kraft) eller 3) en «balansert gruppe» som trener mot å bedre begge egenskaper (kraft og hastighet).

De 3 gruppene trener 3 økter per uke i totalt 8 uker, der man enten har fokus på styrkeøkter med typiske baseøvelser og styrketrening (1-12 RM), hastighetsfokus som trener sprint- og spenst-trening 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 var 10 uker inkludert testing.

Eventuell kompensasjon til og dekning av utgifter for deltakere

Det er ingen økonomisk kompensasjon i forbindelse med studien.

Deltakers ansvar

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

Kapittel B – Personvern, biobank, 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 deltakelse i studien

Jeg er villig til å delta i studien

____

(Signert av prosjektdeltaker, dato)

Jeg bekrefter å ha gitt informasjon om studien

____

(Signert, rolle i studien, dato)

Appendix 3

NORSK SENTER FOR FORSKNINGSDATA   Norsk   Thomas Bjørnsen

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

Referanse
631969

Status
Vurdert

Åpne Meldeskjema   Vurdering

Skriv melding her

Send melding

N

NSD Personvern
18.10.2018 10:55

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)

T

Thomas Bjørnsen
17.10.2018 19:44

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

N

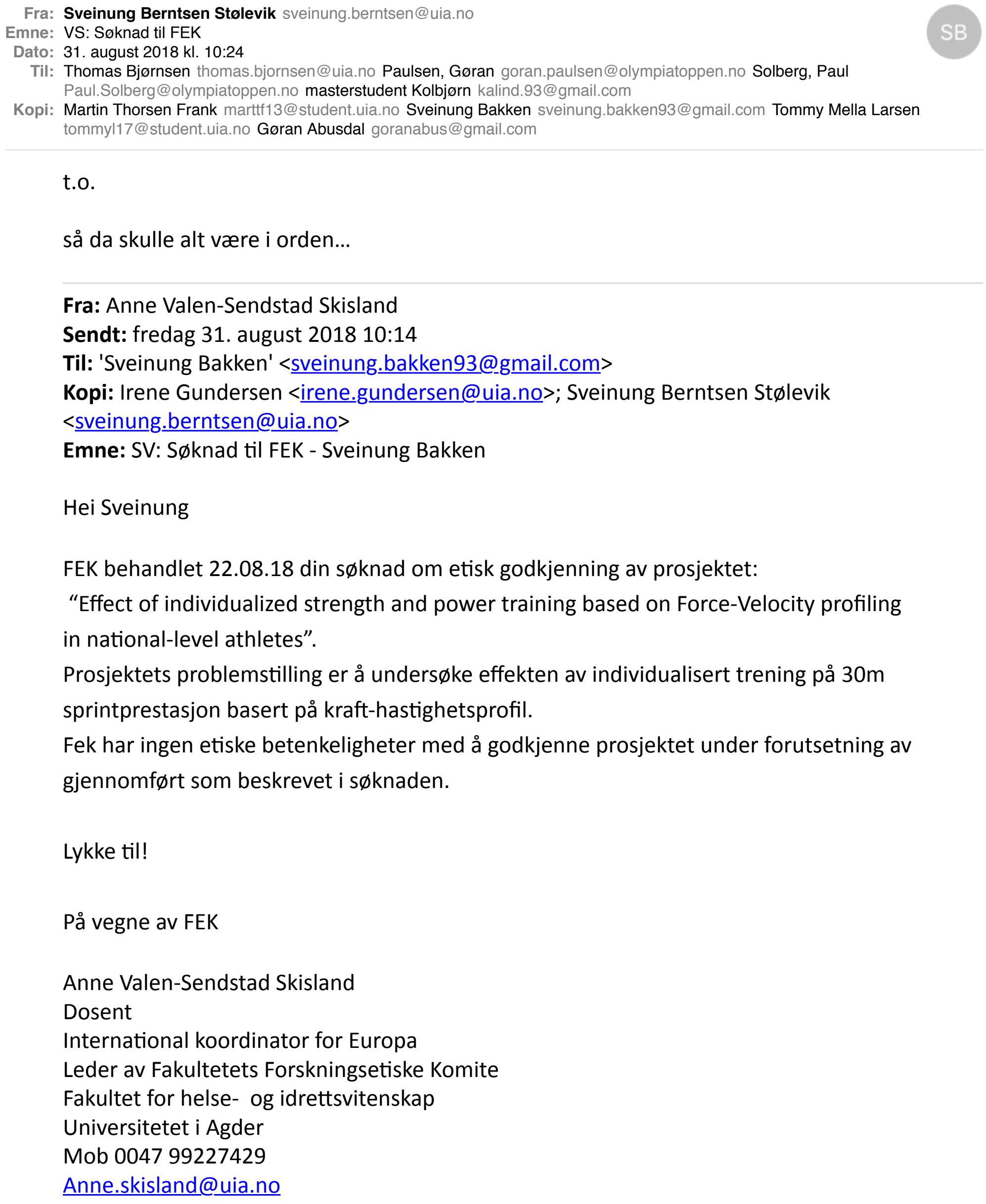
NSD Personvern
17.10.2018 19:43

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

B

Belinda Gloppen Helle
11.10.2018 15:04

Appendix 4



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