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The Effect of Velocity-Based Strength Training

Controlling for resistance exercise volume

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Abstract

Introduction: Velocity-Based Strength training (VBST) is based on measuring bar velocity. This allows for an objective prescription of relative load through the load-velocity relationship and level of effort through the magnitude of relative velocity loss within a training set. Previous studies that employed the squat have investigated the difference between low- (0%/10%/15%/20%) and high (30/40%) velocity losses with an equal amount of sets. These investigations have revealed that low and high velocity losses promote equal strength gains. Furthermore, high velocity losses are superior for hypertrophy and low velocity loss are superior for the development of jumping ability. However, the application of low- and high velocity losses have given rise to unequal resistance exercise volumes. Because resistance exercise volume is an important determinant for training adaptation, the purpose of this investigation was to equalize resistance exercise volume and investigate if this would promote greater strength increases for low velocity losses. Additionally, would similar resistance exercise volume equalize hypertrophy regardless of low or high velocity losses?

Methods: 22 participants were randomized and allocated into either a high velocity loss group (HVLG; 40% [squat] and 60% [bench-press]), or a low velocity loss group (LVLG; 20% [squat] and 30% [bench-press]) in the squat and bench-press. The LVLG completed additional sets to match the resistance exercise volume of the HVLG. The participants trained with a frequency of three times per week for six weeks. Of the 22 subjects that were recruited 16 completed the entire intervention. Pre-tests for strength, hypertrophy and jumping performance tests were conducted before initiation and 72 hours after the training period. Additionally, V1 – load (the weight that can be moved at 1 m/s) maximal effort strength tests were completed prior to every training session. Hypertrophy was assessed using ultrasound thickness measurement of the m. vastus lateralis and m. triceps brachii lateral head, and a DXA scan for full body assessment. Magnitude Based Statistics was employed to investigate the statistical and practical significance of the results, with and without co-variables.

Results: Both groups had a small clear increase in strength for all variables, with the exception of a clear trivial increase in bench-press 1RM for the LVLG. Meanwhile all DXA variables showed clear trivial changes in lean mass for both groups. Ultrasound showed clear trivial changes in thickness for m. triceps brachii lateral head and m. vastus lateralis for the LVLG, while the HVLG showed clear small increases for both muscles investigated. There were clear trivial differences for both strength and DXA measured lean mass between the groups. However, when statistically controlling for resistance exercise volume the 1RM squat results changed from trivial and clear to small and clear in favor of the LVLG. Furthermore, there was a small clear difference between the groups in thickness for the m. vastus lateralis in favor of HVLG, but only a trivial clear difference for the m. triceps brachii lateral head.

Discussion and conclusion: The purpose of this study was to investigate the effect of low velocity losses vs. high velocity losses in promoting strength gains and hypertrophy, when resistance exercise volume is controlled for. The reason we did not see superior increases in strength for the LVLG may be that the dose-response relationship of strength to resistance exercise volume may require each set to be carried out with a certain level of effort that the LVLG did not reach. However, the results show that when statistically controlling for resistance exercise volume the LVLG would have exceeded the HVLG, possibly indicating that the resistance exercise volume was not adequately equalized. Furthermore, we speculate that the metabolic stress associated with the high velocity losses in combination with the mechanical loading created a hypertrophy stimulus for the HVLG that exceeded the LVLG. Peculiarly, high velocity losses did not promote superior hypertrophy for the m. triceps brachii lateral head. This may be explained by the differences of the pattern of velocity loss between the squat and the bench-press. We conclude that low velocity losses provide no additional strength gain over high velocity losses. Furthermore, if hypertrophy is desired high velocity losses are superior to low velocity losses.

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Abbreviations

MVT – Minimum velocity threshold

1RM – one repetition maximum

nRM – number repetition maximum

VBST – velocity-based strength training

HVLG – High Velocity Loss Group

LVLG – Low Velocity loss Group

RPE – Rate of perceived exertion

RIR – Repetitions in reserve

LVR – Load Velocity Relationship

DXA – Dual X-ray Absorptiometry

V1 – load | The load that can be moved at 1 m/s

RFD – Rate of Force Development

RSR – Relative Strength Ratio

MBD – Magnitude Based Difference test

SJ – Squat Jump

ROS – Reactive Oxygen Species

Level of effort – used to describe the proximity to failure when the load is moved at the highest possible velocity

Preface

First and foremost I want to thank my supervisor Gøran Paulsen for exceptional guidance. You expertise was irreplaceable whenever I lacked the resources to resolve any issues with the completion of the masters. Your phone was nearly always available and your insights were truly helpful for a bewildered masters student. Thank you for all the help and knowledge you have contributed!

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1.0 Introduction

Adaptations to resistance exercise is the response to the cumulative stimuli of several key resistance exercise components (programming) (Grgic et al. 2018; Kraemer and Ratamess 2004; Schoenfeld 2010). The key resistance exercise components include, but are not limited to, intensity (also called relative load), training volume and level of effort (the proximity to failure and contraction velocity). (Grgic et al. 2018; Kraemer and Ratamess 2004; Schoenfeld 2010). Manipulating these variables can considerably affect the acute physiological responses, as well as the subsequent physiological adaptations following long-term exposure (Grgic et al. 2018; Kraemer and Ratamess 2004; Schoenfeld 2010). Therefore, monitoring the training load is important to ensure a process of systematic and gradual increase of stress placed on the body i.e. progressive overload (Clarke and Skiba 2013; Kraemer, Ratamess, and French 2002; Schoenfeld 2010). Through the quantification of load and level of effort.

Traditionally, the key resistance exercise components have been a result of the assessment of the one repetition maximum (1RM), by prescribing training load through percentages of the 1RM and the repetitions possible at the corresponding percentages (Schoenfeld 2010). Therefore, percentage based training (PBT) prescription relies heavily on accurate assessment of 1RM. There are several shortcoming of using PBT. First, the potential inaccuracies in determining 1RM before training, and failing to adapt to the stimulus of training during the training period. Because 1RM is not stable in novice populations the assessment could be reflective of an abnormal performance either positive or negative. The subsequent training load will then be either heavier or lighter than intended. Furthermore, during a period of resistance exercise participants of all levels experience daily fluctuation in performance and readiness. In addition, adaptation can occur on differing timelines between individuals. These daily fluctuations can change the daily obtainable 1RM value, also changing the load that corresponds to the percentage prescribed through PBT. Therefore, daily readiness fluctuations and the possibility of abnormal 1RM assessment will cause the training load to rarely match the intended relative load.

Secondly, PBT has no objective method to quantify level of effort. PBT has somewhat successfully implemented subjective measurement through RIR and RPE that may be beneficial for strength progression; however, the use of RIR and RPE may vary between populations which does not allow of accurate global application (Helms et al. 2016, 2018). As level of effort is an important variable to consider for a magnitude of important aspects of resistance exercise, it can be detrimental to ignore (Pareja-Blanco, Rodríguez-Rosell, et al. 2020; Sánchez-Medina and González-Badillo 2011; Schoenfeld 2010). Other attempts at customizing the training load include the implementation of nRM. This approach requires the subject to always train to failure. Training to failure is not an approach to training that necessarily leads to superior results compared to non-failure training, as well as causing significant amounts of fatigue, making the approach equally suboptimal for prescription of training load (Fernando Pareja-Blanco, Rodríguez-Rosell, et al. 2017; Pareja-Blanco, Rodríguez-Rosell, et al. 2020; Sánchez-Medina and González-Badillo 2011).

Velocity-Based Strength Training (VBST) attempts to resolve the shortcomings of different approaches to traditional resistance exercise through the quantification of the training stimulus by velocity (Sánchez-Medina et al. 2017; Sánchez-Medina and González-Badillo 2011; Sanchez-Medina, Perez, and Gonzalez-Badillo 2010). When implementing VBST, the concentric velocity of all repetitions within a training set is measured. This allows for autoregulation through identification of relative load and monitoring of level of effort within the training set. Identification of relative load is possible because of the intrinsic relationship between velocity and relative load. Thus, changes in the obtainable velocity against a given load can indicate changes in maximal strength capacity. VBST allows us to monitor the level of effort because of the relationship that exists between the percentage velocity loss in the set, and the repetitions completed relative to the amount of repetitions possible within a training set. A major prerequisite of VBST is that each subject needs to move the weight at the highest possible velocity. If the participants does not attempt to move the external load at the highest possible velocity, the velocity attained against the external load will not reflect the capacity of the muscle, making velocity unable to quantify the resistance exercise stimuli.

Velocity has been used to prescribe relative load and velocity loss in long-term resistance exercise in past investigations (Dorrell, Smith, and Gee 2020; Fernando Pareja-Blanco, Sánchez-Medina, et al. 2017; F. Pareja-Blanco et al. 2017; Pareja-Blanco, Alcazar, et al. 2020; Pareja-Blanco et al. 2020; Pérez-Castilla et al. 2018). The investigations looked into the effect of different velocity loss threshold on gains in strength, jumping performance and hypertrophy. Previous velocity losses implemented include 20% vs. 40%, 15% vs. 30%, 10% vs. 20% and 0% vs. 10% vs. 20% vs. 40% (Dorrell et al. 2020; Fernando Pareja-Blanco, Sánchez-Medina, et al. 2017; F. Pareja-Blanco et al. 2017; Pareja-Blanco, Alcazar, et al. 2020; Pareja-Blanco et al. 2020; Pérez-Castilla et al. 2018). The only exercise investigated through VBST in an intervention was the squat prior to this investigation. Collectively the current evidence supports that lower velocity losses are more effective for gains in jumping performance, higher velocity losses increases hypertrophy to a greater degree and both types of training are equal for maximal strength gains (Dorrell et al. 2020; Fernando Pareja-Blanco, Sánchez-Medina, et al. 2017; F. Pareja-Blanco et al. 2017; Pareja-Blanco, Alcazar, et al. 2020; Pareja-Blanco et al. 2020; Pérez-Castilla et al. 2018). However, certain shortcoming of these investigations’ approaches have become apparent. The most obvious one, that remains unresolved, are the volume differences arising from VBST. When two individuals partake in VBST, training to an equal velocity loss at an equal relative load, does not guarantee that the total repetitions completed between those individuals will be equal. This leads to differing resistance exercise volumes when velocity losses are equal. However, because the velocity losses differed between the groups in the past, the resulting resistance exercise volume differences became very large. Limiting the velocity loss within a training set affects the amount of repetitions completed relative to the amount possible when training with different velocity losses; furthermore, because the variability between two individuals training to the same velocity loss may be large the differences in resistance exercise volume are exacerbated when training to different velocity losses. Because of the large differences to such a central key component of resistance exercise, it is not possible to distinguish between the effects of resistance exercise volume and velocity loss on neuromuscular adaptations in previous investigations. The present investigation intends to equalize the resistance exercise volume to isolate the effect of training with differing velocity losses on resistance exercise outcomes.

1.1 Research question

Based on the available literature on VBST presented in the introduction, the following research questions were formulated:

1) What is the effect of training with low velocity losses (20% [squat] and 30% [bench press]) compared the high velocity losses (40% [squat] and 60% [bench press]) on strength when the resistance exercise volume is equalized?

2) What is the effect of high velocity losses (40 and 60%) on gains in muscle growth compared to low velocity loss (20 and 30%) when the resistance exercise volume is equalized?

2.0 Theory

2.1 Relative load and velocity

The existing intrinsic relationship between the highest attainable absolute velocity against an external load and relative load has been investigated in several different exercises such as the full- and half squat, leg- and bench-press and the prone pullup as (Bazuelo-Ruiz et al. 2015; Conceição et al. 2016; González-Badillo and Sánchez-Medina 2010; Muñoz-López et al. 2017; Ruf, Chéry, and Taylor 2018; Sánchez-Medina et al. 2017; Sánchez-Medina and González-Badillo 2011; Sanchez-Medina et al. 2010). All these investigations have confirmed the strength of the load-velocity relationship (LVR) (R^2 = < .94). The fact that the relation remains strong despite the diversity of exercises likely means that it is applicable outside of the investigated exercises (Conceição et al. 2016; Muñoz-López et al. 2017; Sanchez-Medina et al. 2010). The LVR, however, is not identical between exercises. This means that an identical relative load would not result in the same absolute velocity between two exercises. Nor would the velocity change at the same rate between two exercises with the same relative or absolute increase in load (Conceição et al. 2016; Izquierdo et al. 2006; Sánchez-Medina et al. 2017)**.**

Because of the evidence supporting the LVR, it has been proposed that it can be used to predict 1RM, and thus replace the traditional 1RM testing procedures. However, Mitter (2018) argues against the use of VBST to predict 1RM because it is inaccurate. However, despite its potential inaccuracy for 1RM predictions, VBST still exceeds at determination of relative load. VBST allows for real time monitoring of progression or regression of force-generating capacity through the changes in velocity against a given load (Conceição et al. 2016; González-Badillo and Sánchez-Medina 2010; Sanchez-Medina et al. 2010). In fact, the velocity attained against a given relative load does not change after long-term resistance exercise and an increase of 0.06-0.09 m/s against the same absolute load between sessions would indicate that the load now represents a load ~5% lower in the squat and bench press (Conceição et al. 2016; Sanchez-Medina et al.

2010). This finding allows coaches and strength and conditioning practitioners to monitor and customize the training load in real time relative to the recovery status of the athlete. Furthermore, a minimum velocity threshold (MVT) that determines the exercise specific lowest velocity before reaching failure has also been identified (Conceição et al. 2016; Sanchez-Medina et al. 2010). The absolute velocity used to monitor relative load changes in relation to the MVT. If the MVT is slower, then the corresponding relative loads will have slower velocities (Conceição et al. 2016; Sanchez-Medina et al. 2010). The absolute velocity of the MVT is likely related to the muscular characteristics as well as the degree of muscle control associated with movement and is an accurate tool to determine when an individual has truly reached muscular failure, and can be used both during training and testing procedures (Sánchez-Medina and González-Badillo 2011). However, the MVT may vary slightly between individuals and therefore needs to be individualized through testing. Once each individuals MVT has been found it does not vary after a period of training and does not need further individualization (González-Badillo and Sánchez-Medina 2010).

To gain benefits from VBST it is important for the participants to intend to move the external load with the greatest possible velocity. Without this prerequisite VBST is not able to accurately quantify the velocity stimuli from resistance exercises. Large motor units consisting of faster and more fatiguing muscle fibers are usually reserved for infrequent tasks that require high intensity, high velocity and high forces (Hodson-Tole and Wakeling 2009). The advantages of intentionally moving the external load at the greatest possible velocity for quantifying the training stimulus is apparent through larger motor neurons and larger amounts of muscle mass being activated, in accordance with the size principle (Henneman, Somjen, and Carpenter 1965; Hodson-Tole and Wakeling 2009). Activating all muscle units is preferred because higher threshold motor units consists of both a larger amount of muscle fibers and specifically fast-twitch muscle fibers, which also has a larger growth potential (Henneman et al. 1965; Hodson-Tole and Wakeling 2009; Spiering et al. 2008). Intentionally moving an external load at maximal velocity increases lactate production and fatigue accumulation (González-Badillo et al. 2014; Zając et al. 2015). Such increase is likely the result of increased activation of fast-twitch muscle fibers because of their greater glycolytic power and susceptibility to fatigue (González-Badillo et al. 2014; Morrissey et al. 1998; Padulo et al. 2012; Zając et al. 2015). Furthermore, moving the external load at the highest possible velocity also allows for more accurate determination of fatigue. Not moving the external load at the maximal intended velocity might reserve the fast-twitch units for maintenance of velocity when the task becomes increasingly difficult, obscuring the reduction in force generating capacity that would be present when moving the load at the highest possible velocity (Sánchez-Medina and González-Badillo 2011).

2.2 Measuring Velocity

When measuring velocity, it is important to choose the most valid and reliable measurement variable available. To meet this end the reliability of different velocity variables has been investigated. The following variables related to the concentric phase have all proven valid and reliable for relative load identification: mean velocity (MV), mean power (MP), mean propulsive velocity (MPV), mean propulsive power (MPP) and peak power (PP) (Conceição et al. 2016; Muñoz-López et al. 2017; Sánchez-Medina et al. 2017; Sanchez-Medina et al. 2010)**.** The propulsive phase is defined as *the period of the concentric phase where the acceleration onto the bar due to gravity is lower than the acceleration onto the bar due to the neuromuscular system*. The propulsive phase is synonymous with the acceleration phase, while the period of the concentric phase that is not propulsive will be referred to as the braking phase. Furthermore, the mean propulsive velocity variables consistently outperform the velocity variables related to the entire concentric phase (Conceição et al. 2016; Sánchez-Medina et al. 2017; Sanchez-Medina et al. 2010)**.**

Using the variables related to the propulsive phase is generally recommended because they at all times avoid underestimating the true neuromuscular potential of the individual (Conceição et al. 2016; Sánchez-Medina et al. 2017; Sanchez-Medina et al. 2010). This is especially evident when examining light relative loads, because the braking phase of the lift accounts for a larger part of the concentric phase, the lighter the relative load the larger the braking phase (Conceição et al. 2016; Sánchez-Medina et al. 2017; Sanchez-Medina et al. 2010). Therefore, when stronger and weaker athletes both lift at an identical absolute load, but different relative loads, it will cause the stronger individual to experience a larger braking phase than the weaker individual because they reach a higher peak velocity (Sanchez-Medina et al. 2010). As a result, the difference in strength capacity between the individuals is largely masked by the size of the braking phase when using the variables relating to the entire concentric phase. However, when using the variables relating to the propulsive phase the difference increases in proportion to the difference in strength capacity. Sanchez-Medina et al. (2010) exemplified this through a comparison between two subjects of differing strength levels. In their example, the difference between the mean powers obtained against the same light absolute load was only 40W when the entire concentric phase was used but increased to 305W when only the propulsive phase was used.

It is apparent that when using light loads the propulsive values gives a clearer picture of the difference in strength capacity between individuals. However, because the braking phase is progressively reduced as the external load approaches 1RM, concentric variables are also reliable when using external loads that are close to 1RM. The accuracy will also vary with exercise, as the rate of decreased braking phase with increased load is not equal among exercises. This is obvious when comparing the squat and the bench press, where the bench press is entirely propulsive from approximately 75% of 1RM, while the squat does not become entirely propulsive before 95 % 1RM is reached (Sánchez-Medina et al. 2017; Sanchez-Medina et al. 2010). However, using the concentric variables is still accurate considering that at 70% 1RM only seven percent of the entire concentric phase of the squat is used for braking (Sánchez-Medina et al. 2017). Furthermore, previous investigations have found that the velocity does not differ substantially for heavier loads when using either propulsive variables or concentric variables related to the entire concentric phase (Mitter 2018)

2.3 Fatigue

In addition to monitoring and customizing the training load, VBST also allows for the quantification of fatigue through velocity loss (González-Badillo et al. 2017; Sánchez-Medina and González-Badillo 2011). This is possible because fatigue leads to a transient reduction in force-generating capacity by mainly reducing each muscle fibers capacity for maximal force generation (Allen, Lamb, and Westerblad 2008; Enoka and Duchateau 2008). Furthermore, fatigue can also reduce the muscle fibers maximum shortening velocity and increase its relaxation time (Allen et al. 2008). Interestingly, the mechanisms underlying reductions in maximal shortening velocity and maximal force production seem to differ (Allen et al. 2008). The degree of effort increases as fatigue accumulates in order to maintain the task of moving the external load (Hodson-Tole and Wakeling 2009; Kraemer and Ratamess 2004). The increased effort allows the task to continue, but the velocity of each repetition progressively declines until failure occurs (Sánchez-Medina and González-Badillo 2011). Reduced force-generating capacity and maximum shortening velocity leads to a reduction in power production (Allen et al. 2008; Enoka and Duchateau 2008). Thus, it seems that fatigue facilitates a reduction in force, velocity or power. A change of either of these variables will be measurable by the decline in velocity of movement.

VBST monitors the magnitude of velocity loss between the fastest repetition (first, second or third repetition) and the slowest repetition within each set to quantify the extent of within set fatigue accumulation and level of effort through velocity loss. Additionally, fatigue can be reliably measured as an accumulation from the entire session, against a standardized load tested before and after training (Sánchez-Medina and González-Badillo 2011). This load is most commonly a load moved at 1 m/s (V1 – load), and has been proven valid and reliable for assessment of both velocity loss and the resulting fatigue (González-Badillo et al. 2015; Fernando Pareja-Blanco, Rodríguez-Rosell, et al. 2017; Pareja-Blanco, Rodríguez-Rosell, et al. 2020; Sánchez-Medina and González-Badillo 2011).

When quantifying within set velocity loss one can use either the slowest repetition of each set, in relation to the fastest repetition of all sets, or the fastest and slowest repetition of each set. The use of velocity loss against the fastest repetition of all sets and the slowest repetition of each set is recommended because incurred fatigue might reduce the velocity of the fastest repetition each set. Thus, using the velocity of the fastest repetition of all sets avoids changing the absolute velocity where training terminates. Keeping all repetitions above a predetermined absolute velocity may have beneficial effects during training (Morrissey et al. 1998; F. Pareja-Blanco et al. 2017). Moreover, there has been observed a close relationship between the percentage repetitions completed relative to the amount of repetitions possible and the percentage velocity loss in an exercise. During a resistance exercise set approximately half the repetitions possible has been completed when the velocity is reduced by 30% and 20% from the first and fastest repetition for the bench-press and squat, respectively (Izquierdo et al. 2006; Sánchez-Medina and González-Badillo 2011). When the velocity loss is reduced by 60% and 40% from the first and fastest repetition, the participants has reached failure or very close to failure for the bench-press and squat, respectively (Izquierdo et al. 2006; Sánchez-Medina and González-Badillo 2011). Furthermore, the pattern of velocity decline within each training set differs between exercises (Izquierdo et al. 2006; Sánchez-Medina and González-Badillo 2011). The velocity significantly starts to decline differentially between exercises dependent of how many repetitions they have completed relative to the total amount possible. This information may give implications to what velocity loss that is sensible for specific purposes.

2.4 Long-term Resistance Exercise and Velocity Monitoring

Applying VBST to identify relative load and monitor velocity loss can be used to autoregulate progression in external load while quantifying fatigue accumulation within a training set when coupled in a training program (Jovanović and Flanagan 2014; Sánchez-Medina and González-Badillo 2011). More practically applied this means that VBST will use velocity to determine the external load and allow the amount of repetitions completed within each set to vary depending on the recovery status of the athlete, which will maintain a more standardized stimuli during training. Monitoring and quantifying the amount of stress placed on the body through resistance exercise is important to avoid plateaus and other unwanted consequences of excessive training (Clarke and Skiba 2013; Kreher and Schwartz 2012; Myrick 2015, 2015; Schoenfeld 2010). Correspondingly, the level of effort is an important variable to account for when specific resistance training outcomes are desired (González-Badillo et al. 2015; Fernando Pareja-Blanco, Rodríguez-Rosell, et al. 2017; F. Pareja-Blanco et al. 2017; Pareja-Blanco, Alcazar, et al. 2020).

Intentionally monitoring the level of effort is important for specifically desired gains in resistance exercise. Previous studies have shown that training protocols including training sets with high velocity losses causes larger metabolic and mechanical stresses, increased hormonal responses and muscle damage leading to increased recovery times (González-Badillo et al. 2015; Morán-Navarro et al. 2017; Fernando Pareja-Blanco, Rodríguez-Rosell, et al. 2017; Pareja-Blanco, Rodríguez-Rosell, et al. 2020; Sánchez-Medina and González-Badillo 2011). All of these responses have been postulated to be precursors of muscle growth (Schoenfeld 2010). Additionally, training protocols with high velocity losses have shown to induce a shift from IIX to IIA single muscle phenotype, which is indirectly corroborated by the inferior jumping performance reported after long-term exposure to high velocity losses (Fernando Pareja-Blanco, Sánchez-Medina, et al. 2017; F. Pareja-Blanco et al. 2017; Pareja-Blanco, Alcazar, et al. 2020). Certainly, these results indicate that training with a high velocity loss could be beneficial for muscle growth. On the other hand, executing VBST with lower velocity losses may be beneficial for shorter recovery times, early rate of force development and jumping performance (Morán-Navarro et al. 2017; F. Pareja-Blanco et al. 2017; Pareja-Blanco, Alcazar, et al. 2020; Pareja-Blanco, Rodríguez-Rosell, et al. 2020). The ability of low velocity losses for promoting superior early rate of force development and jumping performances is likely because low velocity losses facilitates training at a higher average lifting velocity, which is also what seems preferential for maintenance of IIX single muscle fiber phenotype (F. Pareja-Blanco et al. 2017; Pareja-Blanco, Alcazar, et al. 2020). Moreover, there is no clear difference between high- and low velocity losses for strength gains (Fernando Pareja-Blanco, Sánchez-Medina, et al. 2017; F. Pareja-Blanco et al. 2017; Pareja-Blanco, Alcazar, et al. 2020).

These findings indicates that training with high- and low velocity losses promote differential neuromuscular adaptations. Therefore, it is important to be intentional about choosing the velocity loss that is most effective for improving the qualities that are desired. The studies implementing VBST into resistance exercise are quite clear that the resulting strength increases are equal, rapid force development and short recovery times favors low velocity losses, while muscle growth favors high velocity losses (Fernando Pareja-Blanco, Sánchez-Medina, et al. 2017; F. Pareja-Blanco et al. 2017; Pareja-Blanco, Alcazar, et al. 2020; Pareja-Blanco et al. 2020). The uncertainty of the existing literature in determining the benefit of high- or low velocity losses to acquire specific neuromuscular adaptations lies in the fact that previous investigations trained to different magnitudes of velocity loss without equating training volume. Training volume is an important variable for strength increases and muscle growth, and it may function as a confounding variable on the results (Grgic et al. 2018; Schoenfeld, Ogborn, and Krieger 2017; Spiering et al. 2008). There has been no attempt to equalize the resistance exercise volume in an intervention between the high velocity loss group (HVLG) and the low velocity loss group (LVLG). However, there are findings indicating that equal volumes, but different proximities to failure from a single training session acutely induces different recovery times (Morán-Navarro et al. 2017; Pareja-Blanco, Rodríguez-Rosell, et al. 2020). Giving rise to speculations about the implications of equal volumes for long-term resistance exercise; however, the findings can only be extrapolated to the acute effects of resistance training and the relative load investigated. It does not say anything about the possibility of fatigue accumulating between sessions.

Taken together, the sum of the present research has clear practical implications for concurrent athletes. Knowing that a drastically lower training volume without training near failure produce superior rapid force development increases and equal strength increases, they can reap the benefits of resistance exercise without the excessive fatigue that may follow training with a high velocity loss. Combined with reduced recovery times this could produce training sessions within their respective sports that contain higher quality practice in the absence of the negative influence if fatigue. Additionally, the strength benefits of resistance exercise would be equally large (Morán-Navarro et al. 2017; Fernando Pareja-Blanco, Sánchez-Medina, et al. 2017; F. Pareja-Blanco et al. 2017; Pareja-Blanco, Alcazar, et al. 2020).

For a strength-trained population the practical implications are less obvious. There may exist a period of neural maturation for athletes competing in strength focused sports (powerlifting, weightlifting, strongman, etc.) (Brechue and Abe 2002). Once this neural maturation has taken place further strength improvements may rely progressively less on neurological adaptations and progressively more on the gradual increase of muscle mass (Brechue and Abe 2002; Taber et al. 2019). It is at least clear that in the long-term, hypertrophy leads to increases in strength and this is clearer in strength-trained individuals (Taber et al. 2019). Based on the findings of Taber et al. (2019) one could speculate that the group that trains with high velocity losses will produce larger strength gains over a longer period of time because of their superior muscle mass accumulation. The possible explanation that previous research has not shown that high velocity losses promote strength better may be because of a too short duration to distinguish the effect of increased hypertrophy on the outcome. As a result, it is possible that it is advantageous for experienced resistance trained athletes to focus on maintaining the neurological adaptations while maximizing the hypertrophic adaptations following neural maturation (Brechue and Abe 2002; Taber et al. 2019).

For now, this means that for a strength-trained population, using a training approach with a larger magnitude of velocity loss seems theoretically beneficial regardless of increased recovery times if it means maximizing accrual of muscle mass. However, knowing that training volume plays a large role in the progression of strength athletes, the current research does not allow us to distinguish between the role of velocity loss or training volume on the results. Therefore, we are unable to draw clear inferences for strength athletes. Hence, the purpose of this investigation is to attempt to isolate the effect of velocity loss through VBST when equalizing resistance exercise volume on a strength-trained population.

2.5 Resistance Exercise Volume

Previous investigations have assessed the contribution of resistance exercise volume to gains in strength and hypertrophy and found it to be substantial (Figueiredo, de Salles, and Trajano 2018; Grgic et al. 2018; Krieger 2009; Ralston et al. 2017; Schoenfeld et al. 2017; Wernbom, Augustsson, and Thome?? 2007). To exemplify the importance of training volume there are studies examining and finding a benefit of the manipulation of other key resistance exercise variables. However, when resistance exercise volume is accounted for the benefits of those manipulations seem to disappear (Figueiredo et al. 2018; Grgic et al. 2018). Moreover, in strength and hypertrophy there exists a dose-response relationship to resistance exercise volume, meaning that an increase in training volume will result in increased hypertrophy and strength. However, excessively high resistance exercise volumes may be equally counterproductive to insufficiently low training volumes. Because resistance exercise volumes that are both too low and too high are equally suboptimal for increases in resistance exercise outcomes the shape of the graded dose-response relationship is proposed to follow a reversed U shape (Figueiredo et al. 2018; Krieger 2009; Wernbom et al. 2007). This means that progressive increases in resistance exercise volume will lead to superior strength and hypertrophy until reaching a plateau where further increases in resistance exercise volume will no longer have beneficial effects. The mechanisms responsible for the superior resistance exercise acquired strength is likely a product of neural and hypertrophic adaptations (Figueiredo et al. 2018; Krieger 2009; Taber et al. 2019). Findings in strength-trained populations support the notion that hypertrophy contributes to strength in the long-term (Taber et al. 2019). Moreover, studies investigating the cellular response to resistance exercise volume support that the muscle protein synthetic response increases more and lasts longer with higher training volumes (Burd et al. 2010; Figueiredo et al. 2018; Ogasawara et al. 2017). Therefore, larger resistance exercise volumes also increases hypertrophy to a greater degree, which might lead to an increased strength capacity of the muscle, that could manifest itself in spite of no change in neural adaptations (Kraemer and Ratamess 2004; Schoenfeld et al. 2017; Taber et al. 2019).

3.0 Methods

3.1 Study design

The current thesis is part of a larger study. The protocol was designed to investigate the effect of resistance exercise volume equated Velocity-Based Strength Training (VBST) on strength, rate of force development and body composition while distinguishing between high- and low velocity losses. This paper will focus on the effects of the training on strength and hypertrophy. During the description of the timeline all test will be included, but only the tests that are essential for the outcome of this thesis will be described in detail. Furthermore, the level of effort was strictly controlled through the velocity loss within each training set. Participation involved a six-week (eighteen training sessions) training period where all other systematic resistance exercise for the involved muscle groups was prohibited. In addition, the test period before and after the intervention lasted a total of two weeks and required physical attendance at four sessions. All tests and training sessions were carried out in the facilities at the Norwegian School of Sports Science.

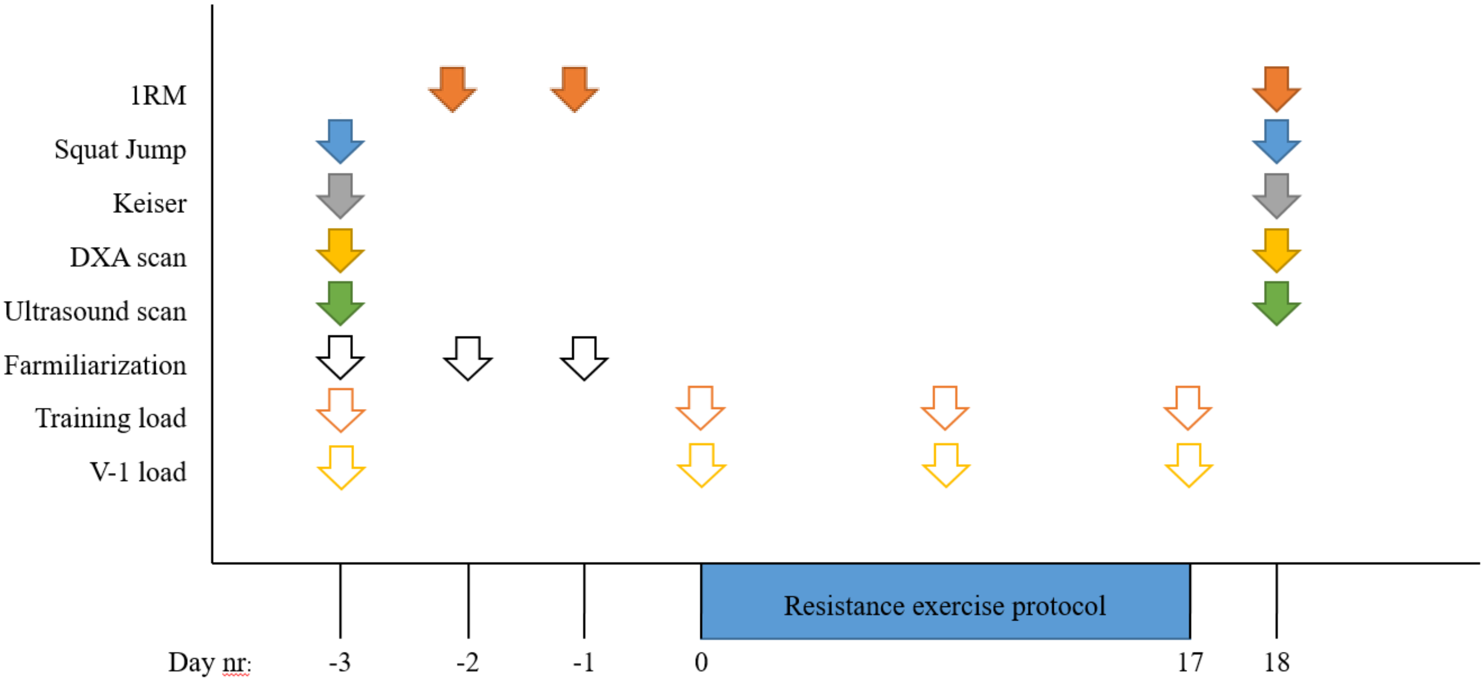

Figure 1: Timeline for testing and training during the intervention. Pre-tests, Post-tests and training sessions

Leading up to the start of the training intervention the participants completed a baseline week consisting of two familiarization sessions and one pre-test session. During day -3 participants met up between 06 AM and 11 AM in a twelve-hour fasted state. To account for the circadian rhythm the initial arrival time for day -3 was recreated for the post-test. Immediately upon arrival weight and height was measured followed by a DXA scan. Once the DXA scan was completed, the subjects were allowed to eat a self-determined meal before they completed muscle thickness measurement images by ultrasound of both the m. triceps brachii lateral head and vastus lateralis. Next, a five minute standardized stationary cycling warm-up that maintained a minimum of eighty watts was performed before force platform jump height measurements and 1RM tests. The last physical test was the progressive loading test on a Keiser leg press (see Figure 2). The 1RM testing procedures were repeated during day -2 and -1. The subjects were only required to complete one true 1RM attempt during the three familiarization sessions. They were allowed to determine if this occurred during day -2 or -1 (see Figure 2). On the days where no true 1RM was attempted, weight increase was terminated when the velocity reached a specified velocity limit. During the day of the true 1RM, the participants were required to continue the 1RM procedures until the MVT was reached or failure to complete the last repetition occurred. The procedures for day -3 was repeated on day 18 for post-testing. After post-testing, a stratified randomization was applied. Individuals were matched based on their strength levels and they were randomly allocated to divergent groups.

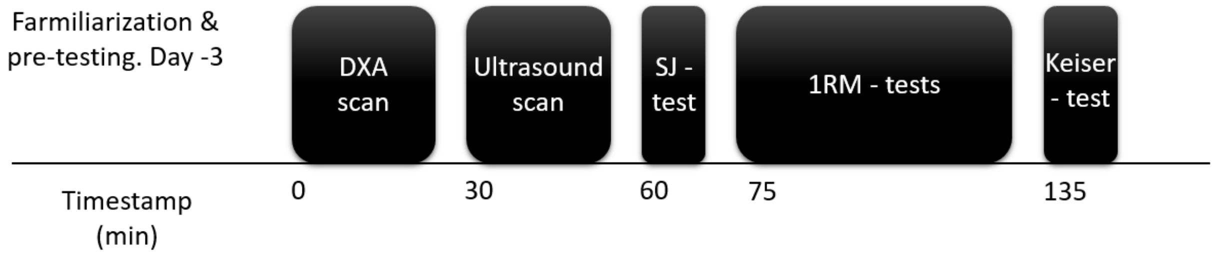

Figure 2: Test day -3. Attendance was fasted and the 1RM-test was repeated for day -2 and -1. Timepoints indicate the pre-planned sequence of tests.

During the intervention the V1 – load was determined before every training session began and re-tested at the end of the session. Determination of training load through velocity followed determination of V1 – load. Other variables registered either at the start of each session or between each training set were: 1) RIR, 2) RPE after each set ($_{\text{set}}$RPE), 3) RPE after the entire session ($_{\text{session}}$RPE), 3) PRS, 4) sleep, 5) total training duration, 6) inter-set break time, 7) training volume (reps x sets).

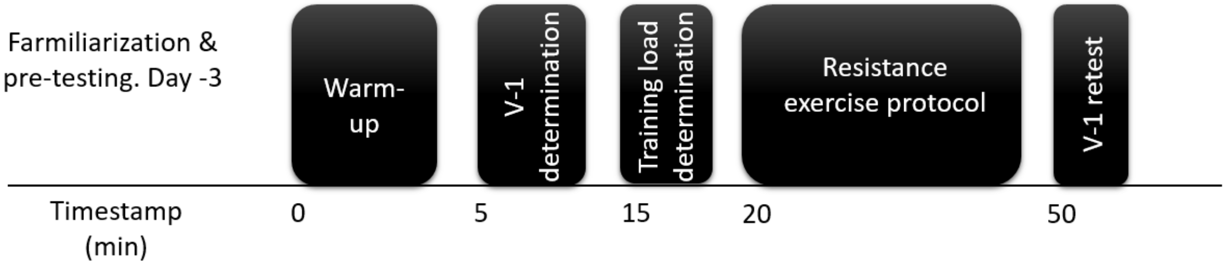

Figure 3: Resistance exercise session protocol. Timepoints indicate the pre-planned sequence of events.

3.2 Recruitment and Inclusion Criteria

The recruitment occurred mainly through posters at notice boards throughout the Norwegian School of Sports Science and local gyms in Oslo. The same poster was published at the Norwegian School of Sports Science website, shared through the school's official social media channels, as well as through the researchers' private social media channels. In addition, the study was presented during lectures at the Norwegian School of Sports Science.

Participants were required to meet the following inclusion criteria: 1) males and females 18-35 years of age, 2) a background of continuous systematic resistance exercise of minimum one year, 3) the opportunity to physically attend three supervised sessions a week, 4) no accompanying musculoskeletal disorders, 5) no planned systematic caloric deficit alongside the training program, 6) lastly, no history with performance-enhancing drugs.

All participants signed an informed consent before the initiation of the familiarization and testing. The local ethical committee at the Norwegian School of Sports Science approved the study, and the project complied with the Declaration of Helsinki.

3.3 Dropout and compliance.

The number of participants who approach us for participation, declined participation, failed to meet inclusion criteria, dropped out during and completed the intervention is described in Figure 1. 16 participants completed the entire intervention and 14 completed all of the post-test. As a result of logistical challenges two of the 16 participants had to complete post-test for the ultrasound, keiser and SJ at a later date, but were rendered unable to show up to the scheduled test due to quarantine following coronavirus symptoms. Hence, their results in the ultrasound and SJ were lost.

The average compliance to the training program was 17.9 (99%) sessions. Out of the 288 planned sessions across all participants, only three training sessions were not completed.

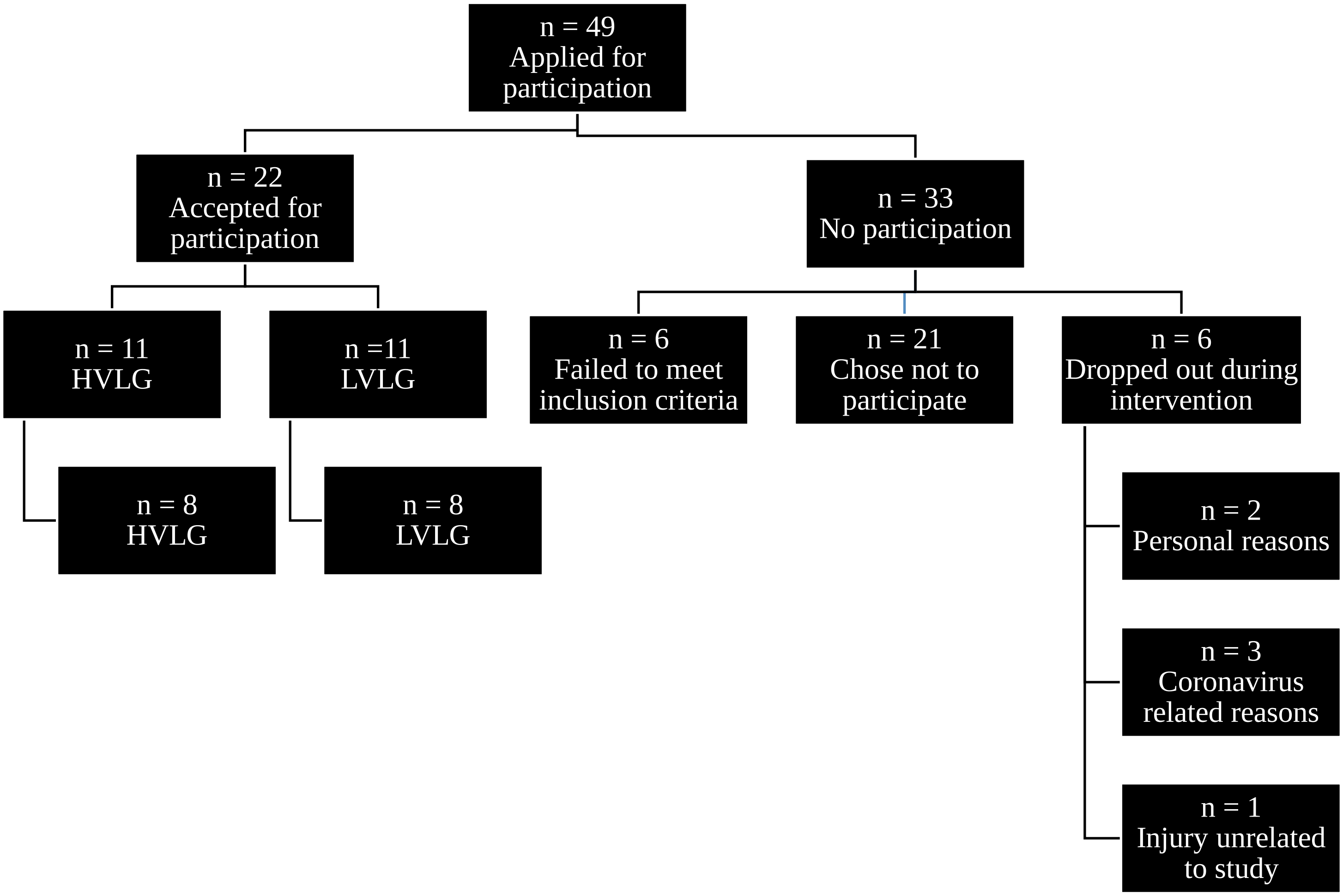

Figure 4: Flowchart describing the course of recruitment

3.4 Subjects

A total of 22 subjects were recruited and started the training protocol. Six subjects dropped out during the training period, but not for reasons related to the exercise involved in the training study (see Figure 4).

Table 1 | Subject characteristics prior to the intervention

	Females	Males	Total
	Mean ± SD	Mean ± SD	Mean ± SD
Age (years)	27.4 ± 4.8	26.3 ± 3.1	26.8 ± 3.8
Height (cm)	170.3 ± 7.1	177.7 ± 6.9	174.5 ± 7.7
Bodyweight (kg)	66.8 ± 9.0	81.5 ± 5.3	75.5 ± 10.1
Squat 1RM pre (kg)	86.9 ± 21.5	144.0 ± 16.6	119.0 ± 34.5
Bench press 1RM pre (kg)	55.0 ± 7.7	112.6 ± 12.1	87.4 ± 31.2
Squat RSI pre (1RM/bw)	1.3 ± 0.2	1.8 ± 0.1	1.6 ± 0.3
Bench press RSI pre (1RM/bw)	0.8 ± 0.1	1.4 ± 0.2	1.1 ± 0.3
Subjects (N)	6	10	16

3.5 Intervention

The training intervention consisted of three exercises; squat, bench press and deadlift. The squat and bench press was trained three times per week while the deadlift was trained once per week. However, the deadlift is not included in this investigation. The training program consisted of an undulating weekly periodization.

The absolute weights for each session was determined by velocity allowing for an individualized progression. The training velocity for the squat was 0.6, 0.49 and 0.7 m/s for day one, day two and day three on each training week, respectively. For the bench-press the training velocity was 0.45, 0.38 and 0.53 for day one, day two and day three each training week, respectively. A 0.03

m/s deviation from the planned training velocity was allowed. The percentage velocity losses were identical with earlier VBST training interventions for the squat (F. Pareja-Blanco et al. 2017; Pareja-Blanco, Alcazar, et al. 2020). LVLG would train to a 20% velocity loss and HVLG to a 40% velocity loss. However, during the planning of this intervention there had not been any previous VBST interventions involving the bench press. Thus, the results of a pilot study designed to ascertain the target velocity loss in the bench press revealed that in accordance with previous cross-sectional studies the percent velocity loss that was equivalent to failure or very close to failure was 60% (Sánchez-Medina and González-Badillo 2011). The velocity loss corresponding to completion of half of the possible repetitions was 30% of the highest velocity. Therefore, the chosen velocity losses was decided to be 60% and 30% for HVLG and LVLG, respectively. The only controlled progressive overload that occurred during the training period, not determined by any velocity variable for HVLG, was amount of sets completed each session. To familiarize the subjects into the training regiment, the first week started with two sets in each exercise for HVLG. During week two, three and four the amount of sets was increased to three sets per session. Lastly, for week five and six HVLG completed four sets.

To account for the different training volumes equal sets and different velocity losses leads to, a training intervention equating for training volume was created. Because the amount of reps completed within each training set differs between individuals regardless of similar velocity loss, it was impossible to predict what the training volumes would look like beforehand. To overcome this problem the HVLG had to complete one week of training before LVLG was allowed to start, because HVLG were expected to do a higher amount of repetitions per set. After the first week the amount of reps for each session was summated (reps x sets) and a rep goal per session was created for LVLG. This meant that while maintaining half the percentage velocity loss of HVLG, LVLG would have to complete a higher amount of sets consisting of fewer repetitions to match the training volume.

At the beginning of each training session the participants were asked to assess how well recovered they were through a perceived recovery status scale (PRS) (Matthew and Matt. 2011) and an additional subjective rating from one to ten of how well they had slept. Immediately following the cessation of every training set the participants rated their perceived exertion (RPE) on a 0.5-10 Borg scale, and how many repetitions they had in reserve (RIR) (Borg 1982). They were specifically told to not use the common RIR-RPE to assess RPE (Helms et al. 2016), but rather a feeling of how hard the training set was perceived in accordance with Borg (1982). A visual chart was created and available for guidance (Borg 1982). The inter-set test periods were registered as the time from the subject put the bar down after a set until they picked it back up for the next set. At the end of the session the subjects were asked to rate how hard the entire session was perceived with the same Borgs scale. After the session, the subjects were given a protein feeding in the form of a salty peanut butter caramel protein bar (Star Nutrition, Sweden), consisting of 18.5g of protein, and the total time for the entire session was registered.

During the intervention, the subjects were not allowed to start any new unfamiliar activities or to commence any additional systematic resistance exercise. However, they were encouraged to continue their regular everyday activities. Regarding conditioning training, they were allowed no more than two session per week consisting of short duration and high intensity (for example 4x4 minutes of running or biking) if they desired. This was allowed because high intensity, low volume and infrequent endurance training are thought to not negatively impact resistance exercise outcomes (Methenitis 2018).

3.6 Tests

The following tests were completed during the entire period: 1RM test for the squat, bench press and deadlift, full body Dual X-ray absorptiometry (DXA) scan, ultrasound measurements of the m. vastus lateralis and m triceps brachii lateral head, force development measurements in the squat jump, a standardized progressive loading trial in the Keiser leg press, a test to determine the heaviest weight that could be moved at 1 m/s (V1 – load) and a test to determine the training weight to be used for each session (V-training).

3.6.1. Strength tests - 1RM

After the standardized warm-up, 1RM strength tests following the same protocol for both exercises (squat & bench press) was completed. The stationary biking warm-up executed on a Keiser M3i Lite (Keiser Sport, Fresno, CA, USA) preceded all the physical tests. A specific shoulder warm-up was performed before starting the bench press protocol. It required the completion of two sets consisting of twelve repetitions of two external rotation exercises and the "dislocator" while holding on to a rubber band of their choosing. As opposed to previous investigations, the squat and the bench press were completed with free weights (and not a Smith machine). Furthermore, each repetition was instructed to be executed with a controlled descent during the eccentric phase, the intention to move the weight at the highest possible velocity during the concentric phase, and to have consistent rests between each rep within the sets for all measured repetitions. The velocity of each repetition was measured with a linear encoder (Musclelab, Ergotest, Porsgrunn, Norway) connected to a computer through a single data interface. The position of the linear encoder on the ground was standardized using a custom-made 3D printed holder, while the position of the encoder on the bar was placed on the measurement lines on the bar. The position of the encoder on the ground relative to the subject was strictly monitored and recreated for both pre-test, post-test and training. During day -3 the subjects were instructed to squat down to the maximal depth they could reach without breaking down their technique during the familiarization tests. However, this depth was required to be deeper than the depth corresponding to the femur being parallel to the ground because it is easier to recreated for the participants and to visually monitor for the test leaders. To standardize the squat depth, the muscle lab encoder measured the eccentric distance during the descent, and the average depth for all attempts during day -3 was used to create a depth the subjects had to recreate. To increase internal validation, it was required that this depth did not change significantly between repetitions as the weights increased during the first progressive loading trial. If this occurred, the inconsistent measurements were excluded from the average depth. A 10% positive and negative variation in depth was allowed from the average depth value attained for each subject (for example a subject with a depth of 55 cm could squat within the range of 49.5 cm and 60.5 cm. The strength tests were executed using Eleiko Performance Powerlifting Bar, Eleiko IWF Weightlifting Training Plates (0.5-25 kg plates) and an Eleiko XF 80 Half Rack Hybrid (Eleiko International, Halmstad, Sweden).

The 1RM protocol itself consisted of a self-determined warm-up with weights between 20kg up to 40% of 1RM. Once loading passed 40% of 1RM the subjects were required to complete ten, seven and three repetitions with 50%, 65% and 80% of 1RM, respectively. The weights used for the standardized warm-up were determined based off each subject's self-reported 1RM prior to testing. After 80%, the following sets consisted of one repetition, each at self-determined increments until reaching MVT or failure occurred. The rest between each set lasted no longer than two minutes before the subject reached sets consisting of one repetition. Once participants had reached sets consisting of one repetition the rest was extended to a maximum of five minutes. During the familiarization days, the subjects rarely passed 80%. The parameter that dictated when to end familiarization was when the subject was unable to maintain an absolute velocity of more than 0.45 m/s and 0,30 m/s in the squat and bench press, respectively. It was required that each subject was able to achieve the highest velocity during the first, second or third repetition. Additionally, they needed to achieve a descending velocity profile within each set during the familiarization. This was required to ensure that they were indeed able to consistently activate maximally during each rep before moving on to the 1RM test and training.

3.6.2. Dual X-ray absorptiometry scan (DXA)

In preparation for the DXA scan each subject was required to refrain from strenuous exercise for 48 hours and any type of exercise 24 hours prior to the scan. The participants were instructed to eat and drink regularly leading up to the beginning of the twelve-hour fasting period. The DXA was carried out on a Lunar Prodigy densiometer (Prodigy Advance PA+302147, Lunar, San Francisco, Ca, USA). Prior to testing, height and bodyweight was measured. During the scan, the subjects were required to wear preferably only cotton underwear and to remove all metal from their body, which was recreated for the post-test. The scan itself lasted approximately ten minutes and the subjects were instructed to lie still in the supine position during the entire scan. The subject’s position on the scanner was located using the standardization lines, while the positions of the limbs were standardized using custom-made styrofoam blocks between the arm and the torso and between the hand and the hip. Straps were used to keep the legs in a standardized position. To assure that the standardization tools did not interfere with the measurements a pilot test was executed to assess their contribution. It involved scanning an individual twice in succession, once with and once without the standardization tools. Based on the pilot test the standardization tools did not interfere with the measurements of lean mass. However, it did consistently increase the fat-mass, slightly. The body was divided into total lean mass for the arms, legs and the entire body for subsequent analysis.

3.6.3. Ultrasound

A B-mode ultrasound (50mm, 5-12MhZ, HD11XE, Philips, Bothell, Washington, USA) was used to measure the m. vastus lateralis and the m. triceps brachii lateral head. The right arm and leg was the subject of measurement on every research subject.

For the m. vastus lateralis the subject was placed in a supine position before the acquisition of panoramic and CSA pictures commenced. The positioning of the legs was standardized using a styrofoam block between the knees. The muscle thickness pictures were collected with the probe placed perpendicular to the muscle at the thickest part of the muscle belly. To locate the area of interest the distance between Trochanter Major and the Lateral Epicondyle of the femur was measured and the distance that corresponded to halfway between the locations was used as a landmark. From here, the probe was moved medially or laterally on the perpendicular halfway line until the thickest part of the muscle belly was located and the pictures were taken. Using the halfway reference point found during the thickness measurement a distance of two probe-lengths (one proximally and one distally of the line) running parallel along the muscle fibers was marked as a reference point for the line the probe was meant to pass through during the panoramic scan. While the scan was underway the pressure, speed, tilting and rotation of the probe was inspected to ensure the picture maintained the highest quality attainable.

Regarding the m triceps brachii lateral head measurements the authors were unable to find any previous studies that described a good protocol to take valid and reliable pictures of the muscle during the creation of the protocol. Therefore, the present protocol started by placing the probe laterally and distally on the humerus. The probe was consistently moved proximally following both the m. triceps brachii lateral head and the radial- and ulnar arteries until the arteries came into contact with each other and the humerus. The location was chosen when the thickest part of the muscle belly was located and the ulnar- and radial arteries were visually in contact with each other and the humerus. During the re-testing a monitor with the pictures from the pre-test was available for a more easily replicated picture.

3.6.4. V-1 & training velocity

Before each training session the V1 – load was determined for the squat and the bench-press (the load that can be moved at 1 m/s with maximal effort). For the first session a load that was moved faster than 1 m/s based on the load and velocity measures from the pre-tests was chosen. The weights were increased until a maximal deviation of 0.03 m/s from the V1 – load was reached. Hence, the V1 – load was the weight that could be moved at a range of 0.97 – 1.03 m/s. For the following sessions the same weight as the prior session was used and adjusted up or down depending on how the velocity achieved changed between sessions. Because the fastest repetition is usually found between repetition one and three, each test set consisted of three reps with the intention to move the weight at the fastest possible velocity. The subjects were instructed to hold on to the bar so that it did not leave their shoulders, nor were they allowed to lift their feet off ground. This was done do distinguish between the different phases of the lift rather than allowing their body and bar to become a projectile when the feet leave the ground or the back leaves the bench. Between attempts, the load was incrementally increased until the last series no longer reached within the specified deviation, and thus the previous weight was determined as the V1 – load. The smallest possible increase between the attempts was 1 kg. Immediately after the cessation of resistance exercise V1 – load was retested to quantify the velocity loss due to the within-session accumulated fatigue

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When the V1 – load determination at the beginning of the session was completed the subjects increased the weight until it matched the velocity intended for that training session, described in section 4.6 allowing an identical maximal deviation as for the V1 – load.

3.7. Statistics

The data were log-transformed and analyzed using excel spreadsheets customized for analyzing within-group changes and between-group differences through t-tests, with the possibility to adjust for up to 2 variables (Hopkins 2017; Hopkins et al. 2009). Therefore, the spreadsheets let us make adjustments for baseline- and predictor variables allowing us to make inferences about possible mechanisms underlying the effects, and to control for regression to the mean effect.

The results were evaluated for clinical significance using Magnitude-Based Differences (MBD; Hopkins 2007; 2017). The use of MBD in this study was an attempt to gouge the actual real-world effect of the intervention, as well as it being a method appropriate for smaller sample sizes.

First, standardized effects with their following 90% confidence intervals (CI) are calculated (pre-post/baseline SD). To make clinical inferences about the true effect, the changes and differences between groups are evaluated in relation to the smallest worthwhile change with the following scale: trivial, 0.0-0.19; small, 0.2-0.59; medium, 0.60-1.19; large, 1.20-1.99; very large, 2.00-3.99.

In addition to the ES, the CI allows us to make clinical inference about our certainty of the likelihood if the true population effect would be harmful or beneficial. The limits for the likelihood that the effect is harmful or beneficial is "almost certainly not harmful" (<0.5% risk of harm) and "possibly beneficial" (>25% risk of benefit), which corresponds to a minimum ratio of 66 to one for odds of benefit to odds of harm (Hopkins et al. 2009). The qualitative probabilistic statements generated from the MBD spreadsheets can be assigned to the following scale: 0.5%, most unlikely, almost certainly not; 0,5-5%, very unlikely; 5-25%, unlikely, probably not; 25-75%, possibly; 75-95%, likely, probably; 95-99,5%, very likely; >99,5% most likely, almost certainly (Hopkins et al. 2009).

All variables presented in tables or figures are presented separately for each group if not otherwise specified. All results reported are primary outcomes, however, because some variables could act as confounding or explaining variables for the primary outcomes, secondary analysis were undergone to examine causality. The impact of the following variables on 1RM for the squat and bench press, muscle growth, SJ and keiser performance was examined: training volume for the squat and bench press, muscle mass for arms, legs and total body and muscle thickness for the m. vastus lateralis and m. triceps brachii lateral head. During secondary analysis, training volume was the only variable that primarily affected the results; therefore, results adjusted for the influence of the training volume will also be discussed.

4.0 Results

4.1 Baseline

Baseline values for the sixteen participants that completed the intervention are displayed in Table 2. There were no clear differences for any of the baseline variables between the two groups with the exception of bench-press relative strength ratio (RSR) where HVLG possibly had a small beneficial baseline value. Furthermore, there were small to moderate unclear ESs in favor of LVLG for all the DXA scan lean mass and ultrasound muscle thickness measurements.

Table 2 | Baseline variables for each training group

	HVLG	LVLG	Difference	Beneficial - Trivial - harmful
	Mean ± SD	Mean ± SD	ES; ± CI	
Bodyweight (kg)	75 ± 12	76 ± 8	0.17 ± 0.66	47 - 36 - 17
Squat 1RM (kg)	119 ± 41	120 ± 30	0.10 ± 0.67	39 - 38 - 22
Bench press 1RM (kg)	85 ± 35	89 ± 29	0.15 ± 0.71	46 - 35 – 20
Squat RSR (1RM / bw)	1.55 ± 0.33	1.55 ± 0.26	0.03 ± 0.69	33 - 38 - 28
Bench press RSR (1RM / bw)	1.18 ± 0.34	1.10 ± 0.30	-0.32* ± 0.79	13 - 27 - 60
DXA total lean mass (kg)	54.61 ± 11.44	59.29 ± 9.84	0.36 ± 0.70	66 - 25 - 9
DXA arms lean mass (kg)	6.50 ± 2.13	6.96 ± 1.90	0.22 ± 0.71	52 - 32 - 19
DXA legs lean mass (kg)	18.55 ± 3.79	20.50 ± 3.25	0.46 ± 0.70	74 - 20 - 6
UL VL muscle thickness (cm)	4.95 ± 0.71	5.53 ± 0.66	0.68 ± 0.73	87 - 10 - 3
UL TL muscle thickness (cm)	4.90 ± 1.34	5.17 ± 0.98	0.27 ± 0.66	58 - 31 - 11
Subjects (N)	**8**	**8**	**16**	

*Values are group means ± group standard deviation, with the associated standardized effect size; ±90% confidence interval and probability percentages (beneficial – trivial – harmful): the mean group effect is calculated by subtracting the HVLG effect from the LVLG effect. The results are adjusted for baseline. Effect sizes are considered trivial, 0.0-0.19; small, 0.2-0.59; medium, 0.60-1.19; large, 1.20-1.99; very large, 2.00-3.99. 1RM (one repetition maximum); DXA (dual X-ray absorptiometry); RSR (relative strength ration); UL (ultrasound); VL (vastus lateralis); TL (triceps lateralis).. Significance is marked: * Possibly; ** likely; *** very likely.*

4.2. Outcome variables

4.2.1. Primary analyses - Group changes

Table 3 | Main outcome variables; percentage change within HVLG.

	HVLG		
	%Δ ± SD	**ES; ± CI**	**Beneficial - Trivial - harmful**
Bodyweight	2.5 ± 0.9	0.12** ± 0.06	2 - 98 - 0
Squat 1RM	10.8 ± 4.2	0.23* ± 0.12	65 - 35 - 0
Bench Press 1RM	10.8 ± 3.8	0.21* ± 0.11	53 - 47 - 0
Squat V1	30.1 ± 10.2	0.47*** ± 0.25	96 - 4 - 0
Bench press V1	24.1 ± 10.6	0.44** ± 0.25	94 - 6 - 0
DXA total muscle mass	2.2 ± 0.6	0.09*** ± 0.05	0 - 100 - 0
DXA arms muscle mass	1.8 ± 4.4	0.05*** ± 0.08	0 - 100 - 0
DXA legs muscle mass	3.4 ± 2.3	0.14** ± 0.09	14 - 86 - 0
UL VL muscle thickness	7.5 ± 5.2	0.44** ± 0.28	92 - 8 - 0
UL TL muscle thickness	7.1 ± 10.7	0.21* ± 0.22	52 - 48 - 0
Participants		**8**	

*Values are group means ± group standard deviation, with the associated standardized effect size; ±90% confidence interval and probability percentages (beneficial – trivial – harmful). The results are adjusted for baseline and the qualitative probabilistic statements are assigned to the following scale: 0.5%, most unlikely, almost certainly not; 0,5-5%, very unlikely; 5-25%, unlikely, probably not; 25-75%, possibly; 75-95%, likely, probably; 95-99,5%, very likely; >99,5% most likely, almost certainly. Effect sizes are considered trivial, 0.0-0.19; small, 0.2-0.59; medium, 0.60-1.19; large, 1.20-1.99; very large, 2.00-3.99. 1RM (one repetition maximum); DXA (dual X-ray absorptiometry); RSR (relative strength ration); UL (ultrasound); VL (vastus lateralis); TL (triceps lateralis). Bodyweight, squat 1RM, bench-press 1RM, DXA total lean mass, DXA arms lean mass, DXA legs lean mass are all reported in kilograms; squat and bench-press RSR are reported as 1RM divided by bodyweight; ultrasound VL and TL muscle thickness is reported as MM (millimeter). Significance is marked: * Possibly; ** likely; *** very likely.*

Table 4 | Main outcome variables; percentage change within LVLG

	LVLG		
	%Δ ± SD	**ES; ± CI**	**Beneficial - Trivial - harmful**
Bodyweight	1.7 ± 2.9	0.13** ± 0.16	23 - 77 - 0
Squat 1RM	10.4 ± 6.2	0.34** ± 0.21	87 - 13 - 0
Bench Press 1RM	7.2 ± 5.0	0.18* ± 0.12	37 - 63 - 0
Squat V1	22.2 ± 7.0	0.45*** ± 0.24	95 - 4 - 0
Bench press V1	25.3 ± 15.3	0.52** ± 0.32	95 - 5 - 0
DXA total muscle mass	1.7 ± 2.3	0.09*** ± 0.09	2 - 98 - 0
DXA arms muscle mass	0.4 ± 5.7	0.01*** ± 0.12	1 – 98 - 1
DXA legs muscle mass	2.3 ± 2.7	0.13** ± 0.11	13 - 87 - 0
UL VL muscle thickness	0.8 ± 4.0	0.06** ± 0.23	14 - 83 - 3
UL TL muscle thickness	0.8 ± 8.3	0.04* ± 0.31	16 - 75 - 9
Participants		**8**	

*Values are baseline adjusted percent group mean changes ± standard deviation, with the associated standardized effect size; ±90% confidence interval and probability percentages (beneficial – trivial – harmful). The qualitative probabilistic statements are assigned to the following scale: 0.5%, most unlikely, almost certainly not; 0,5-5%, very unlikely; 5-25%, unlikely, probably not; 25-75%, possibly; 75-95%, likely, probably; 95-99,5%, very likely; >99,5% most likely, almost certainly.. Effect sizes are considered trivial, 0.0-0.19; small, 0.2-0.59; medium, 0.60-1.19; large, 1.20-1.99; very large, 2.00-3.99. 1RM (one repetition maximum); DXA (dual X-ray absorptiometry); RSR (relative strength ration); UL (ultrasound); VL (vastus lateralis); TL (triceps lateralis). Significance is marked: * Possibly; ** likely; *** very likely.*

Both groups had similar changes in most of the measurement variables. Analysis showed clear small to moderate possibly to very likely beneficial changes for Squat 1RM, Bench-press 1RM, Squat V1 – load and bench-press V1 – load for both groups. Increases in bodyweight, DXA total lean mass, DXA arms lean mass and DXA legs lean mass were also similar between groups and resulted in small ESs that were likely, most likely or very likely trivial. The group effects differed between m. vastus lateralis and m. triceps brachii lateral head muscle thickness measurements, where the increases for HVLG was small and likely and possibly beneficial, respectively. In contrast, the LVLG had likely and possibly trivial changes in both thickness measurements.

4.2.2. Primary analyses - Group differences

Table 5 | Main outcome; percentage differences between groups

	% difference ± SD	ES; ± CI	Beneficial - Trivial - harmful
Bodyweight	-0.8 ± 1.5	-0.05*** ± 0.10	5 - 91 - 4
Squat 1RM	-0.1 ± 3.5	0.00*** ± 0.10	0 - 99 – 0
Bench press 1RM	-3.1 ± 4.0	-0.07*** ± 0.10	0 - 98 - 2
Squat V1	-4.1 ± 9.8	-0.09** ± 0.22	2 - 80 - 18
Bench press V1	0.8 ± 14.0	0.02* ± 0.32	16 - 73 - 12
DXA total	-0.7 ± 1.7	-0.03*** ± 0.08	0 - 100 - 0
DXA arms	-1.4 ± 4.6	-0.04*** ± 0.14	1 - 95 - 4
DXA legs	-1.6 ± 2.2	-0.08*** ± 0.11	0 - 95 - 5
UL VL	-5.9 ± 4.6	-0.42** ± 0.34	1 - 11 - 88
UL TL	-4.8 ± 11.3	-0.18* ± 0.43	7 - 46 - 47
Subjects (N)		**16**	

*Values are baseline adjusted percent group differences ± standard deviation, with the associated standardized effect size; ±90% confidence interval and probability percentages (beneficial – trivial – harmful). The statistics is calculated based on the HVLG effect subtracted from the LVLG effect. The qualitative probabilistic statements are assigned to the following scale: 0.5%, most unlikely, almost certainly not; 0,5-5%, very unlikely; 5-25%, unlikely, probably not; 25-75%, possibly; 75-95%, likely, probably; 95-99,5%, very likely; >99,5% most likely, almost certainly. Effect sizes are considered trivial, 0.0-0.19; small, 0.2-0.59; medium, 0.60-1.19; large, 1.20-1.99; very large, 2.00-3.99. 1RM (one repetition maximum); DXA (dual X-ray absorptiometry); RSR (relative strength ration); UL (ultrasound); VL (vastus lateralis); TL (triceps brachii lateral head). Significance is marked: * Possibly; ** likely; *** very likely.*

The only clear group difference was a small likely beneficial effect in favor of HVLG for increase in muscle thickness in the m. vastus lateralis. All other variables indicated clear possibly to very likely trivial effects. Note that most differences, although trivial, were in favor of HVLG.

4.2.3. Secondary analyses - Group differences controlling for training volume

Results showed that resistance exercise volume had likely to very likely trivial effect on bench-press 1RM increases and all DXA lean mass measurements. While the differences in V1 – load for bench-press and squat were trivial, and the differences in muscle thickness for the m. triceps brachii lateral head were small, they were possibly beneficial for higher velocity losses. The variable that seemed to be most affected by resistance exercise volume was squat 1RM. The resistance exercise volume adjusted squat 1RM ES was small and possibly beneficial in favor of LVLG. The analysis indicated that with equal volume, the LVLG would possibly have exceeded the HVLG with 7.8 ± 0.1% in the squat. Furthermore, m. vastus lateralis muscle thickness had a small non-significant ES that was likely beneficial for the HVLG.

4.3. Control variables

4.3.1 Recovery, preparedness & fatigue

There was no clear differences between the groups in terms of preparedness measured as PRS and sleep. Furthermore, both objective and subjective measurements of level of effort within the exercise sets all showed very large clear effects in favor of HVLG. These results indicate that the training program succeeded at subjectively and objectively keeping the level of effort different between the groups. The differences between the groups for resistance exercise volume were unclear. Fatigue measured through velocity loss against the V1 – load was possibly and most likely larger for the HVLG for the squat and bench-press, respectively. Subgroup analysis showed that the large variation in resistance exercise volume was largely attributed the female subpopulation. There was also less variation within the male subpopulation.

Table 6 | Objective and subjective measures of fatigue, preparedness, exertion and training volume.

	HVLG	LVLG		
	Group mean ± SD	**Group mean ± SD**	**% Difference; ± CI**	**Beneficial - Trivial - harmful**
PRS	6 ± 1	6 ± 1	1 ± 10	40 - 30 - 30
Sleep	7 ± 1	7 ± 0	7 ± 9	91 - 4 - 6
sRPE	8 ± 1	7 ± 1	-20^{***} ± 11	1 - 0 - 99
RPE	9 ± 0	7 ± 2	-21^{***} ± 15	2 - 1 - 97
RIR	1 ± 0	3 ± 2	-50^{***} ± 18	0 - 0 - 99
Squat V-loss	40 ± 2	21 ± 1	-47^{***} ± 2	0 - 0 - 100
Bench press V-loss	60 ± 1	31 ± 1	-48^{***} ± 2	0 - 0 - 100
Squat Resistance exercise volume	423 ± 160	353 ± 25	14 ± 31	77 - 6 - 17
Bench-press resistance exercise volume	435 ± 131	361 ± 23	14 ± 24	87 - 4 - 9
Squat V1 loss	-9% ± 3%	-8% ± 2%	-10^{**} ± 14	4 - 28 - 68
Bench press V1 loss	-11% ± 3%	-6% ± 2%	-47^{***} ± 12	0 - 0 - 100
Subjects (N)	**8**	**8**	**16**	

*Values are percent group differences ± standard deviation, with the associated standardized effect size; ±90% confidence interval and probability percentages (beneficial – trivial – harmful). The statistics is calculated based on the HVLG effect subtracted from the LVLG effect. Effect sizes are considered trivial, 0.0-0.19; small, 0.2-0.59; medium, 0.60-1.19; large, 1.20-1.99; very large, 2.00-3.99. PRS (Perceived Recovery Status); sRPE (session Rate of Perceived Exertion); RIR (repetitions in reserve); V-loss (within set average velocity loss); V1 – loss (velocity loss against an external load moved at 1 m/s, tested at the beginning and end of the session). Resistance exercise volume is reported as repetitions x sets, relative load was controlled through velocity. Significance is marked: * Possibly; ** likely; *** very likely.*

5.0 Discussion

The purpose of this investigation was to equalize resistance exercise volume to investigate if lower velocity losses would promote greater resistance exercise gains and equalize hypertrophy. The primary finding of the present investigation was; there existed no benefit of training with low velocity losses (20% [squat] and 30% [bench press]) over high velocity losses (40% [squat] and 60% [bench press]) for gains in maximal strength and hypertrophy. However, secondary results that were statistically controlled for resistance exercise volume indicated that there were small clear benefits of training with low velocity losses for 1RM in the squat, but not the bench-press which was trivial and unclear. There were also tendencies towards superiority for high velocity losses for the load that can be moved at 1 m/s (V1 – load) in both exercises when controlling for resistance exercise volume, but these were of trivial magnitude.

Furthermore, there were small significant benefits of training with high velocity losses over low velocity losses for hypertrophy in the m. vastus lateralis and m. triceps brachii lateral head, but not for changes in body composition and lean mass. Controlling for resistance exercise volume did not change the results of any of the hypertrophy measures.

5.1. Strength

5.1.1. 1RM & V1-load

Earlier VBST studies have investigated the effect of different velocity losses by matching the amount of sets completed between the groups. Unfortunately, this resulted in larger training volumes for HVLG than for LVLG. However, because the strength increases for the LVLG in previous investigations matched the strength increases of the HVLG, it suggested that their resistance exercise volume was on the lower end of the dose-response of strength to resistance exercise volume. Thus, by matching resistance exercise volume, it could be possible to improve the LVLGs strength response to surpass that of the HVLG. While at the same time maintaining a lower velocity loss and acute fatigue. Despite no clear differences in resistance exercise volume in our investigation the LVLG did not increase strength beyond that of the HVLG. Rather the strength increases for both the 1RM and the V1 – load increased to a statistical similar degree for the bench press and the squat. There were trivial non-significant tendencies towards HVLG being superior for the V1 – load for the squat, but not the bench-press. Although the V1 – load is not a maximal strength test as the load is equivalent to 45% 1RM and 60% 1RM for the bench press and squat, respectively, it is a maximum effort test with lower relative load that can indicate how strength progresses. This is because the velocity attained with each relative load does not change during long-term resistance exercise (González-Badillo and Sánchez-Medina 2010). Furthermore, it is a test, which unlike the 1RM, was practiced on two occasions every session. In addition to not being exhaustive and being strictly controlled, its frequency of practice makes it likely to be the most sensitive variable collected to measure progression during the intervention.

Additionally, there was relatively low variation within the test itself. When investigating the variance in the first week of training after acclimatization where we do not expect large changes in performance because it is early in the training period, we saw that the V1 – load test only varied by an average of three and five percent for the bench-press and the squat, respectively. Because the increase in V1 – load was more than fourfold the variance, we can be quite certain that the changes we saw were representative of the actual change. Therefore, V1 – load could be a better measure of the change in strength than 1RM and the tendencies towards larger increases for the squat in the HVLG may be more indicative of the effect of the training program. However, this is speculative. It is worth noting that even though there were no tendencies for the superiority of the HVLG for the V1 – load for the bench-press in the primary analysis, this did change towards the HVLGs favor once secondary analysis were completed. However, they were still of trivial magnitude.

Because there were no clear differences in resistance exercise volume and because the strength gains were equal, our results support the dose-response of strength to resistance exercise volume (Krieger 2009). However, considering the equal strength increases and unequal resistance exercise volumes previously employed, our results indicate that there is either something other than just resistance exercise volume (the sum of repetitions), that accounts for the resulting strength increases or that there was some sort of ceiling effect of resistance exercise volume that was reached for strength. It is possible that the dose-response of strength to resistance exercise volume also require that the sets be carried out at a certain level of effort. If this is true then it could indicate that the rate of the HVLG strength progression would outpace the LVLG in the long-term possibly because of the associated superior hypertrophy of training with a high velocity loss. The superior hypertrophy would aid the strength increases through increasing the force generating capacity of the muscle which is dictated by the amount of muscle mass, specifically the cross-sectional area of the muscle (Fukunaga et al. 2001; Taber et al. 2019). Which could also explain the tendency for superior increases in V1 – load for HVLG. Therefore, it could be that the additional sets completed by the LVLG may have been unnecessary because they were not equally hypertrophically stimulating as the level of effort was not high enough. Generally lower velocity losses do not stimulate hypertrophy as good as higher velocity losses (F. Pareja-Blanco et al. 2017; Pareja-Blanco, Alcazar, et al. 2020; Pareja-Blanco et al. 2020), and our results indicates that doing additional sets to match the resistance exercise volume do not promote hypertrophy further. There may exist an upper limit to the strength response of increasing resistance exercise volume in the absence of higher levels of effort. Furthermore, the inferior hypertrophy for the LVLG seen in this and other investigations would likely undermine the long-term strength increases, as long-term increases in strength are related to hypertrophy (F. Pareja-Blanco et al. 2017; Pareja-Blanco, Alcazar, et al. 2020; Taber et al. 2019).

The secondary analysis that controlled for resistance exercise volume resulted in a small and possibly beneficial effect in favor of LVLG. Therefore, had we been able to perfectly equate the resistance exercise volume our results indicate that the LVLG would have exceeded the HVLG in strength by approximately eight percent. This also means that our initial assumption that LVLG would exceed HVLG with equal training volumes would be correct. However, future investigation need to improve our methods for equalizing resistance exercise volume to prove this confidently.

Furthermore, the previous investigations describing the relationship between resistance exercise volume and strength progression have not done so through equal amount of repetitions completed. They have associated the amount of sets completed with strength progression (Krieger 2009; Ralston et al. 2017). This could support the theory that there is a dose-response of strength in response to the amount of sets at a certain level of effort rather than the sum of maximal voluntary contractions completed. If we were to compare the resistance exercise volume similarly to this, our approach has created different resistance exercise volumes, not equal. However, comparing three sets of three repetitions to three sets of six repetitions would be inaccurate because either relative load or level of effort would not be accounted for.

5.2. Hypertrophy

5.2.1. Hypertrophy as a mechanism?

The ultrasound measurements were very clear that local hypertrophy was small and significantly in favor of HVLG for the m. vastus lateralis, but it was trivial and non-significant for the m. triceps brachii lateral head. These results may be a better indication of the actual hypertrophic effects of the training program because ultrasound has been proposed to be more sensitive to local changes (Schoenfeld et al. 2017). While DXA measurement include tissue that is not skeletal muscle and variance in other tissues may obscure the DXA measurements. Our ultrasound results for the m. vastus lateralis indicate that mechanical loading alone cannot completely explain all the associated hypertrophy. Though we have not measured this directly the increased metabolic stress associated with higher velocity losses was likely responsible for the superior hypertrophy (González-Badillo et al. 2015; Morán-Navarro et al. 2017; Fernando Pareja-Blanco, Rodríguez-Rosell, et al. 2017; Pareja-Blanco, Rodríguez-Rosell, et al. 2020; Sánchez-Medina and González-Badillo 2011; Spiering et al. 2008)**.** However, this seems contradictory to the resulting hypertrophy of the m. triceps brachii lateral head, where there were only trivial non-significant differences between LVLG and HVLG. The explanation for this discrepancy may be manifold. Firstly, it may be a result of the incongruent morphological and biomechanical characteristics of the muscles and movements associated with the squat and the bench-press. Including, but not limited to muscle size, fiber type composition and differences in sticking points (Kompf and Arandjelović 2017; Tillaar, Andersen, and Saeterbakken 2014). What is more, the pattern of velocity loss between the squat and the bench-press differ, this could be one of the main drivers for the equal hypertrophy seen in the bench-press (Izquierdo et al. 2006). Significant velocity reductions in the bench-press occur after approximately a third of the repetitions possible in a single set has been completed (Izquierdo et al. 2006). While in the squat significant reductions in velocity do not occur before half of the possible repetitions have been completed (Izquierdo et al. 2006). This means that a higher degree of incurred fatigue occurs in the bench-press for the same relative amount of repetitions. Hence, this may lead the LVLG to experience a more similar metabolic stress relative to the HVLG in the upper body musculature engaged in the bench-press. Furthermore, some markers of metabolic stress are actually higher following half the possible repetitions in the bench-press relative to the squat, supporting this statement (Sánchez-Medina and González-Badillo 2011).

Metabolic stress has been theorized to mediate muscle hypertrophy through mechanisms including increased fast-twitch fiber recruitment, elevated systemic hormone production, muscle damage, cell swelling and increased production of ROS. All of these mechanisms are thought to mediate muscle protein synthesis directly and/or activate satellite cell proliferation to elicit muscle growth (Pearson and Hussain 2015). Sánchez-Medina and González-Badillo (2011) showed that for the same amount of repetitions completed relative to the amount possible the metabolic response were similar between the squat and the bench-press for most of the variables measured. Some were slightly higher for the bench-press. However, because the squat engages a larger muscle mass this could mean that the musculature of the upper body experiences a larger metabolic stress relative total muscle mass engaged. This may have been enough to decrease the difference in rate of muscle mass accrual between the groups. Thus, making our investigation unable to reveal a difference for the upper body musculature because the metabolic stimuli was likely not different enough to expose divergence in the hypertrophic effects during the time frame of our investigation. For the lower body musculature, it is unlikely that the superior hypertrophy seen for the m. vastus lateralis is due to fast-twitch fiber recruitment, elevated systemic hormonal production, muscle damage or increased production of ROS. This is because when training with loads close to 1RM, specifically 80-85% of 1RM or heavier, muscle fibers are maximally recruited (Kraemer and Ratamess 2004). Therefore, the maximal nature of the loads and the intention to move the load at the highest possible velocity likely maximally activated all motor units. As a result, increased fiber recruitment is likely not the reason for the increased hypertrophy in the m. vastus lateralis.

Exercise induced systemic hormonal responses have shown to play a negligible, however, complementary role in muscle growth through GH, IGF-1 and MGF, by possibly activating muscle protein synthesis through multiple anabolic signaling cascades including mTOR and mitogen activated protein kinase (MAPK) (Duchateau et al. 2021; Pearson and Hussain 2015). MGF may also facilitating activation, proliferation and differentiation of satellite cells (Duchateau et al. 2021; Pearson and Hussain 2015). Furthermore, exercise induced muscle damage is an important stimuli that activates the satellite cell mediated muscle growth and metabolic stress has been postulated to be a mechanisms of primary muscle damage (Duchateau et al. 2021; Owens et al. 2019; Pearson and Hussain 2015). Because muscle damage is postulated to both increase MGF and satellite cell activation and proliferation, muscle damage could have assisted the resistance exercise induced hypertrophy through increased metabolic stress. (Owens et al. 2019). In contrary to this, mechanical loading during exercise is a more likely candidate to impose muscle damage, additionally the repeated bouts effect attenuates the effect of muscle damage during long-term resistance exercise (Duchateau et al. 2021; Owens et al. 2019). Exercise induced muscle damage is therefore unlikely to be the cause of our observed superior hypertrophy for the HVLG (Owens et al. 2019).

Resistance exercise implementing compound movements, in a repetition range above six, conducted to or very close to failure leads to large accumulations of metabolites (Sánchez-Medina and González-Badillo 2011). Increased accumulations of metabolites leads to a pressure gradient within the muscle causing the inflow of water into the muscle fibers' intracellular space causing the cell to swell. The following reposition of water could threaten the structural integrity of the cell, leading to the initiation of intracellular signaling responses that solidifies the cellular ultrastructure (Pearson and Hussain 2015). The resistance exercise sessions planned for the HVLG in the current investigation were intended to be divided between a high (12), medium (8) and low (4) repetition ranges, with load being inversely added relative to repetitions (both dictated by velocity). The LVLG was expected to complete approximately half of the repetitions corresponding to high, medium and low, on average. The high- and medium repetition range training sessions in conjunction with the level of effort corresponds to a situation in which large metabolite accumulation occurs for the HVLG. Because of the low velocity loss in the LVLG none of their session would lead to any large metabolic responses (Sánchez-Medina and González-Badillo 2011). Therefore, our HVLG was very likely exposed to a much larger accumulation of metabolites. These metabolite accumulations could have led to cellular swelling, bolstering the protein synthetic stimuli and consequently leading to superior hypertrophy signaling and increased hypertrophy of the m. vastus lateralis. This phenomenon has been found previously in studies investigating cluster sets. Completing resistance exercise with a short 30 second break halfway through each set reduced the metabolic response and resulted in reduced hypertrophy in comparison to completing each set without a break halfway (Duchateau et al. 2021; Pearson and Hussain 2015). Metabolic stress that causes cellular swelling is therefore our leading theory about the cause of superior hypertrophy. However, Pearson and Hussain (2015) has strongly posited that any definitive statements about the contribution of cellular swelling to hypertrophic adaptation would be premature due to the scarcity of research. Therefore, because we have not directly measured this we cannot definitively conclude that cellular swelling was the sole cause.

Furthermore, within our experimental approach the accrual of lean mass, as assessed by the DXA scan, had only a trivial non-significant difference between the groups, contradicting the theory that metabolic stress was responsible for the superior hypertrophy Rather; it indicates that the increased resistance exercise volume completed by the HVLG caused the superior hypertrophy found in previous investigations. Previous studies and meta-regressions corroborate this with their reports of dose-response relationship between both muscle protein synthesis and hypertrophy to resistance exercise volume (Ogasawara et al. 2017; Schoenfeld et al. 2017). Greater resistance exercise volumes have shown to be capable of larger and more long-lasting increases in muscle protein synthesis, possibly through simultaneous activation by several pathways (Burd et al. 2010; Duchateau et al. 2021; Figueiredo et al. 2018; Pearson and Hussain 2015). It could be speculated that when resistance exercise volume was controlled for the muscle protein synthetic response to each session may have been equalized overall, likely leading to similar DXA measured hypertrophy. Whether the intracellular response is reflective of the remodeling of the muscle is not certain; however, it is obvious that the training volume has an effect on the anabolic response of the muscle (Figueiredo et al. 2018).

5.2.2 Differences between methods

There are discrepancies between the DXA and ultrasound results. However, the assessment of hypertrophy with ultrasound is proposed as a more accurate way of measuring hypertrophy and it might be tempting to trust it over the DXA results. Nonetheless, it must be considered that the resulting hypertrophy may be specific to certain regions of the muscle. Selective regional hypertrophy may be manifested either as a result of training at different muscle lengths or different speeds of contraction (Earp et al. 2015)**.** It seems the muscle has the potential to preferentially increase its cross-sectional area regionally as an adaptational response to optimize the force outputs for specific stimuli (Earp et al. 2015)**.** Specific regions of the muscle can be selectively activated in response to high-velocity contractions, furthermore, the region of the muscle that experiences the greatest muscle activation also experiences the largest training induced increase in cross-sectional area (Earp et al. 2015). Because of this, our findings of increased m. vastus lateralis hypertrophy in the absence of total leg hypertrophy could be confounded by regional changes in cross-sectional area that may occur because of training at different velocities (Earp et al. 2015). If regional hypertrophy resulted from the different velocities where training was terminated, it could possibly explain the discrepancies between the DXA and the ultrasound results on measures of hypertrophy. As a result, the differences between the groups measured by the ultrasound may have been limited by the location of the acquired images. If regional hypertrophy did occur, then we may have compared a region with sufficient hypertrophic response to a region with insufficient hypertrophic response. Furthermore, previous studies have also shown that completing resistance exercise with differing velocity losses can lead to differing hypertrophy responses between muscles within the same muscle group (F. Pareja-Blanco et al. 2017). F. Pareja-Blanco et al (2017) specifically found that the m. rectus femoris muscle mass remained unaltered in both velocity losses (20% and 40%), while the m. rectus intermedius and m. vastus lateralis increased their muscle mass in response to training with a high velocity losses (40%), but not low velocity losses (20%). We cannot exclude the fact that similar adaptations may have occurred here. This may also be the explanation for the equalized hypertrophy measured with the DXA scan. Because we used total leg lean mass for the

DXA measurement this method may not have been sensitive enough to distinguish the local hypertrophy within the m. vastus lateralis. Therefore, it is likely that the ultrasound results are more representative of the long-term effects of training with differing velocity losses in spite of the possibility for regional hypertrophy. Additionally, if this is the case, then training with a higher velocity loss or evenly spacing it into training may be beneficial for long-term strength progression through greater accrual of muscle mass (Taber et al. 2019).

5.3. Training volume

The primary aim of our investigation was to equalize resistance exercise volume to identify the individual contribution of resistance exercise volume and velocity loss. Statistical analysis shows unclear differences in resistance exercise volume. There was an approximate 70 repetition (17%) difference in total training volume over the course of the entire intervention for both exercises. This is a large difference; however, it is still more than 20% lower than previous studies (Fernando Pareja-Blanco, Sánchez-Medina, et al. 2017; F. Pareja-Blanco et al. 2017; Pareja-Blanco, Alcazar, et al. 2020). Moreover, there are two causes for the apparent difference in resistance exercise volume that needs to be addressed. Firstly, two participants completed nearly twice the amount of repetition compared to any other participant in either group. When investigating the results without these outliers, defined as those participants with training volumes one standard deviation away from the pooled mean, the difference in resistance exercise volume drops to six and three percent for the squat and bench-press, respectively. This is equivalent to one repetition extra per session for the squat, and half a repetition extra every session for the bench-press. The differences are considered negligible and the argument can be made that the resistance exercise volume was essentially equal. The second cause, partially to blame for hindering our approach to being able to equalize the volume in spite of these outliers, was the untimely outbreak of the corona virus. The sudden unavailability of facilities affected our recruitment process and our capacity for participants, which resulted in some of our participants randomized into the HVLG to also be recruited last. Incidentally, this was also the outliers. Though their participation increased the average volume for the HVLG, we were unable to adjust the training volume of the LVLG according to the contribution of the outliers; because they were recruited after LVLGs training had commenced.

Additionally, the outliers were only females. When investigating resistance exercise volume in the squat for only the males, the difference fell to two percent, which is the equivalent of five extra repetitions over the course of 18 training sessions. When it came to the bench-press the males resistance exercise volume differed by eleven percent, which is equal to 47 repetitions extra in total (three repetitions extra each session). When it came to the squat for the females there was an astounding one 145 total repetition difference in the squat, and an 84 repetition difference in the bench-press over the course of the entire investigation. This is the equivalent of eight repetitions extra per session for the squat and five repetitions extra each session for the bench-press. From this, it is clear that there was a much smaller variation in the male population compare to the female population. Furthermore, this emphasizes the incredibly high variation in the training experience when employing a VBST program. The outliers mentioned completed close to 700 repetitions in the squat while the average amount of repetitions completed (including the outliers) was just below 400 repetitions. Additionally, there was only one male that completed more than 380 repetitions, while there were six women with 380 repetitions or more. This further highlights the large interindividual differences that can be experienced when training with VBST. Our results indicate that these differences vary between the sexes. However, other possible mechanisms include, but are not limited to training status, fiber type composition, age and capillary density. Our results indicate the possible need for individualization that considers sex when employing VBST.

We regard the volume differences to be impacted drastically by the outliers and despite the seemingly different volumes from the averages, the resistance exercise volume was equal for the majority of our subjects. Nonetheless, when adjusting for resistance exercise volume for the entire groups the outliers were included in the analysis.

5.4. Strengths and limitations

There are several limitations to the findings of this investigation. First, this investigation is not directly comparable to previous VBST investigations. This is because we have employed a much more strength-trained population. Furthermore, approximately half of the population is female which, to the authors knowledge, is a scarcely investigated population within VBST. There are studies investigating women that showed that women possibly have a slightly less steep LVR (Torrejón et al. 2019). Moreover, females have a different fatigability than men (Clark et al. 2005). Because of this, it could be that the training program implemented was suboptimal for females and this may have confounded our results. Specifically, because the training program is made on the discoveries of only a male population. Furthermore, another limitation to our investigation was that we had no control group available to measure progress against, therefore it is unknown if this method of training would be superior to traditional resistance exercise. However, Dorrell et al (2020) has confirmed that VBST interventions has the potential to improve resistance exercise outcomes to a greater degree than traditional resistance exercise. Moreover, it is unknown if the same participant would respond differently to different magnitudes of velocity losses. The original plan was to assess this by implementing a crossover design for this investigation. However, because our capacity was restricted and due to the uncertainty of consistent access to facilities the study design was changed to account for the situation.

The only measurements of velocity available to us during the data acquisition was mean velocity (MV). This limits us from directly comparing our findings to previous studies who have employed mean propulsive velocity (MPV). The differences between MV and MPV diminish the closer to 1RM you get, therefore, the actual resistance exercise is likely not affected by this. However, during fatigue assessment through the V1 – load there could be interference due to the submaximal nature of the load and the large associated breaking phase. An additional limitation that contrasts the majority of other investigations is that our investigation did not implement the use of a smith machine. This could limit the reliability of the measurement due to variation in placement of the encoder relative to the participant or rotation of the bar during the movement. However, the placement of the encoder was strictly monitored and standardized using assistive markers. Due to the possibility of regional adaptations in muscle as a response to the imposed velocity stimuli our ultrasound assessment of only the middle part of the m. vastus lateralis and m. triceps brachii lateral head may inhibit us from assessing the true hypertrophy that has occurred if one of the training forms increases the cross-sectional area in a different part of the muscle. Therefore, we cannot exclude the possibility that a greater degree of hypertrophy occurred at a region that was different from the one we assessed.

Lastly, there were only 16 participants our of the 24 that were recruited that completed the study. Which was low in comparison to an average participant number of 36 in previous VBST interventions. This reduces the statistical weight of our results and has to be taken into consideration before practical application. Moreover, two of the subjects were inhibited from completing the entirety of the test battery due to unforeseen circumstances further reducing the confidence of the ultrasound and keiser test.

However, our investigation has also improved upon previous investigations in many areas. Firstly, this is the first intervention that has attempted to compare two volume-equated VBST forms to isolate the effects of velocity loss from resistance exercise volume. Resistance exercise volume is a key resistance exercise variable that is important to consider, thus, our investigations brings important additional information. Additionally, though it restricts us from directly comparing our selection to previous investigations we have extended the knowledge of VBST onto a more highly strength-trained population than investigated previously. As well as including females into a VBST intervention. This allows the generalization of VBST to cover a larger population. Furthermore, we had strict and frequent testing of V1 – load to both measure acute session fatigue and progression against a submaximal load. The frequency of its implementation and the following familiarity with the test allowed us to monitor the changes in performance very closely, though we admit that it is an indirect measure of strength progression. It also allowed us to monitor the progression in strength closely in relation to the development of acute session fatigue.

5.5 Conclusion

The purpose of this investigation was to equalize resistance exercise volume to investigate if low velocity losses would promote greater resistance exercise gains and equalize hypertrophy. The primary results of the present investigation leads us to conclude that for a population of strength-trained individuals low velocity losses (20/30%) provide no superior strength gains compared to high velocity losses (40/60%). However, there is uncertainty in this statement due to the secondary analysis indicating that statistically controlling for resistance exercise volume would have led to beneficial increases for the low velocity loss group. Furthermore, high velocity losses provide superior hypertrophy gains compared to low velocity losses.

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7.0 Appendix

7.1 Informed consent

Vil du delta i forskningsprosjektet: «Hastighetsstyrt styrketrening»?

Dette er en forespørsel til deg om å delta i et forskningsprosjekt hvor formålet er å undersøke effekten av hastighetsstyrt styrketrening. I dette skrivet gir vi deg informasjon om hensikten med prosjektet og hva deltakelse som forsøksperson vil innebære for deg.

FORMÅL

Hastighetsstyrt styrketrening skiller seg fra tradisjonell styrketrening ved at det er hastigheten på løftet som er styrende, ikke motstanden (antall kg på stanga). Ved hastighetsstyrt styrketrening er det et prinsipp at vektene skal løftes så raskt som mulig i alle repetisjonene; det vil si maksimal mobilisering i løftefasen, men alltid rolig og kontrollert i bremsefasen. Et måleinstrument gir deg feedback på løftehastigheten underveis i treningen. Etter hvert som du løfter vil hastigheten i løftefasen alltid gradvis reduseres, fordi en nevromuskulær tretthet utvikles – du blir sliten og til slutt klarer du ikke flere repetisjoner. I denne studien ønsker vi å teste hvor stort fall i hastighet som er gunstigst for å øke maksimal styrke, eksplosiv styrke og muskelvekst over en treningsperiode. Med andre ord, spørsmålet vi stiller er om det er mest effektivt å gi seg før hastigheten faller betydelig eller om det er best å løfte hver serie til du så vidt får opp vektene på siste repetisjonen.

For å være forsøksperson i denne studien skal du være frisk, kvinne eller mann, i alderen 18-35 år, og du skal ha erfaring med styrketrening (minst ett år med regelmessig styrketrening). Styrketreningserfaringen må omfatte øvelsene knebøy, benkpress og markløft. Om du skal delta i denne studien kan du ikke være idrettsutøver, og du må redusere annen trening til maksimalt to rolige økter per uke.

HVA INNEBÆRER DELTAKELSE I STUDIEN?

Prosjektet innebærer å teste ulike former for maksimal og eksplosiv styrke fem ganger: En tilvenningsrunde, og deretter før og etter en treningsperiode på seks uker, som skal gjennomføres to ganger. Vi vil også måle muskeltykkelse og kroppssammensetningen din i sammenheng med styrketestene. Du vil bedt om å registrere det du spiser i en 24-timersperiode i starten og slutten av hver seksukersperiodene. Totalt vil studien strekke seg over omtrent 17 uker.

I første treningsperiode vil du trene tre økter per uke (ca 60-90 min varighet). I hver styrkeøvelse skal du trene med et hastighetsfall på 15-30% eller 30-60%; det vil typisk si, henholdsvis, ~4-6 og ~8-12 repetisjoner. I den andre treningsperioden vil du også trene tre økter i uken, men hvis du trente med lavt hastighetsfall (15-30%) i første periode skal du trene med stort hastighetsfall (30-60%) i denne perioden. Det vil være tilfeldig hva du gjør først og sist. Dette er en såkalt kryssoverstudie.

FORDELER OG ULEMPER MED DELTAGELSE SOM FORSØKSPERSON

I denne studien vil du få oppfølging og veiledning på alle treningsøktene, og treningsprogrammene er laget for at du skal oppnå økning i maksimal og eksplosiv styrke, samt muskelvekst i trente muskler. Du vil også få innblikk i idrettsforskning og få personlig resultater fra vitenskapelig tester, som normalt ikke er tilgjengelig for deg.

Du vil kunne oppleve ulemper ved deltakelsen i denne studien. Deltakelse som forsøksperson vil kreve tid, og både tester og trening kan oppleves som både fysisk og mentalt slitsomt. Du kommer til å bli stiv og støl etter spesielt de første treningsøktene, og det er en risiko for skader under testing og trening med tunge vekter. Vår erfaring er imidlertid at det sjelden oppstår skader i studier som dette. En annen mulig ulempe er at underveis i studien kan du kun trene to treningsøkter utenom det denne studien legger opp til.

HVA SKJER MED INFORMASJONEN OM DEG?

Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket. Alle personopplysninger vil bli avidentifisert. Det betyr at resultatene blir ikke lagret under navn, men med en kode. Navnet ditt blir derfor koblet til en kode som oppbevares i en safe ved Seksjon for fysisk prestasjonsevne ved Norges idrettshøgskole. Det er kun prosjektansvarlig som har tilgang til denne. Etter prosjektslutt skal kodelisten slettes og dermed vil all data være anonymisert. Dine personopplysninger vil ikke kunne identifiseres i publikasjoner.

Prosjektet skal etter planen avsluttes 31.12.2021. Vi er pliktet til å oppbevare data og separat navneliste i 5 år etter sluttdato for etterprøvbarhet og kontroll av resultatene. Etter dette, altså 31.12.2026, vil all data i prosjektet slettes.

Dine rettigheter: Så lenge du kan identifiseres i datamaterialet, har du rett til:

- innsyn i hvilke personopplysninger som er registrert om deg,
- å få rettet personopplysninger om deg,

- få slettet personopplysninger om deg,
- få utlevert en kopi av dine personopplysninger (dataportabilitet), og
- å sende klage til personvernombudet eller Datatilsynet om behandlingen av dine personopplysninger.

Hva gir oss rett til å behandle personopplysninger om deg? Vi behandler opplysninger om deg basert på ditt samtykke. På oppdrag fra Norges idrettshøgskole har NSD – Norsk senter for forskningsdata AS vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

FRIVILLIG DELTAKELSE

Der er frivillig å delta i studien og du kan når som helst trekke deg fra studien uten å oppgi noen grunn. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg.

Dersom du har spørsmål til studien, eller ønsker å benytte deg av dine rettigheter, ta kontakt med prosjektansvarlig Gøran Paulsen (goran.paulsen@nih.no / 93429420) eller de to masterstudentene som skal gjennomføre prosjektet Roger Behrmann Myrholt (rogermyrholt@hotmail.com) eller Henrik Pettersen (henrikmfk@gmail.com), vårt personvernombud Karine Justad (personvernombud@nih.no), eller NSD – norsk senter for forskningsdata AS (personverntjenester@nsd.no / 55582117).

Med vennlig hilsen

Gøran Paulsen

Prosjektansvarlig

SAMTYKKEERKLARING

Jeg har mottatt og forstått informasjon om prosjektet «*Hastighetsstyrt styrketrening*», og har fått anledning til å stille spørsmål. Jeg samtykker til:

- ☐ å delta i studien
- ☐ at mine opplysninger behandles frem til prosjektet er avsluttet (31.12.2026)

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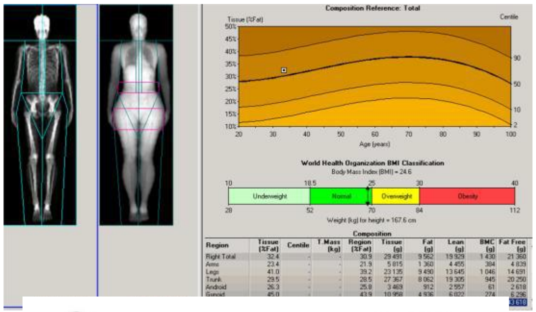
(Dato) (Signatur deltaker)

7.2 DXA guidelines

OLYMPIATOPPEN

Informasjon til deg som skal ta Dual-energy X-ray Absorptiometry



Hva er DXA?

DXA er en hel kroppsskanning som estimerer din kroppssammensetning slik at vi får vite hvor stor andel av kroppen som er fettmasse, muskelmasse (lean body mass) og skjelettmasse (beinmineral tetthet/innhold). Eksponeringen fra røntgen strålingen er meget lav, ca 0,3 mrem for en helkroppsskanning. Til sammenlikning tilsvarer strålingen fra en transkontinental flytur i USA 4-6 mrem, eller vanlig røntgenstråling 25-270 mrem. DXA regnes som en relativt nøyaktig målemetode med en feilmargin på estimering av LBM, fett%, fettmasse og beinmineraltetthet på 0.5-2% (avhengig av type skanner).

Forberedelser til DXA

For at målingen skal bli så nøyaktig som mulig, bør du ta noen forhåndsregler:

- Du skal ikke trene hardt dagen før skanningen
- Sørg for å være i god væskebalanse ved testing, dvs drikk rikelig dagen før scannet.
- Møt fastende (ikke mat og drikke på 12 timer). Du kan drikke ett glass vann på morgenen
- Ha på deg undertøy i bomull (jenter truse og sports-BH)
- Alle smykker og klokke fjernes
- Gi beskjed om du har noen implantater (for eksempel skruer i bein etter brudd).

Prosedyre

Du vil bli veid og målt høyde før du begynner. Selve skanningen tar ca 15 minutter. Du ligger rolig på bordet i undertøyet hele tiden, og du kjenner ingenting.

Viktig!

Til tross for lav stråling anbefales det å utelukke graviditet før skanningen. Det er ditt ansvar å gi informasjon om det er muligheter for at du er gravid.

Kontakt: Anu Koivisto (41900391) eller Christian Helland (90113431)

Veibeskrivelse

1. Benytt NIH inngang som ligger mot OLT/friidrettsbane.
2. Følg korridoren til venstre forbi Servicetorget, toaletttene og leseloungene til du kommer til en heis/trapp på din høyre side (ca 50m).
3. Ta ned trappen til kjeller. DXA rommet er den første til venstre, døren er merket med DXA-skilt.

7.3 Rate of perceived Exertion & Perceived Recovery Status

OLYMPIATOPPEN

SAMMEN OM DE STORE PRESTASJONENE

Hvor restituert og uthvilt er du?

Vurder din opplevelse av hvor restituert og uthvilt du er ved hjelp av skalaen under.

10	Helt restituert og uthvilt Svært energisk/toppform	Forventer å prestere godt
9		
8	Godt restituert og uthvilt Ganske energisk	
7		
6	Over middels restituert og uthvilt	Forventer å prestere på det jevne
5	Tilstrekkelig restituert og uthvilt	
4	Delvis restituert og uthvilt	
3		
2	Ikke særlig restituert Ganske sliten	Forventer å prestere under middels
1		
0	Veldig lite restituert Svært sliten	

Skalaen er en modifisert versjon etter Laurent mfl. (2011; JSCR)

Borg RPE scale	
0	Ingenting
0.5	Veldig, veldig lite slitsomt
1	Veldig lite slitsomt
2	Litt slitsomt
3	moderat slitsom
4	Noe slitsomt
5	Slitsomt
6	
7	Veldig slitsom
8	
9	
10	Veldig, veldig slitsom

Attachment figure 5 | Visual aid for RPE assessment

7.4 Optional nutritional guidelines

NIH NORGES IDRETTSHØGSKOLE

Retningslinjer for ernæring til deg som deltaker ved hastighetstrening

Viktigheten av et godt proteininntak.

Hvor stort tverssnittsareal en muskel har (med andre ord hvor stor den er) avgjør i stor grad muskelen sin kraftgenererende egenskaper (Fukunaga et al. 2001). Musklene våre er i konstant forandring ved at muskelproteiner brytes ned og bygges opp, tilegnelsen av muskelmasse skjer ved hjelp av stimulering til økt muskelproteinsyntesen gjennom styrketrening og inntak av protein (Devries and Phillips 2015; Tang and Phillips 2009). For å maksimere effekten av proteininntaket burde hvert proteininntak være av tilstrekkelig kvalitet, mengde og i et relativt kort tidsrom etter trening (Devries and Phillips 2015; Schoenfeld and Aragon 2018; Tang and Phillips 2009). Dermed vil det være hensiktsmessig å etterfølge enkelte retningslinjer for å legge det beste grunnlaget for muskelmasse akkumulering.

Retninglinjer

Forsøk i så stor grad som mulig å:

- la hvert måltid inneholde en mengde protein som tilsvarer 0.4-0.6 g/kg (jo færre måltider jo mer protein per måltid)
- spis 2-4 måltider om dagen
- innta protein så fort som mulig etter trening maks 2-3 timer
- proteinet bør helst være av god kvalitet (kasein eller whey)
- Underveis i treningsperioden forsøk å begrens alkoholinntak til mindre enn 1 gang i uken.

Eksempler på matvarer som er gode proteinkilder

- Fisk
  - Torsk
  - Laks
  - Makrell
- Egg
- Magre meieriprodukter
  - Skyr
  - Yt
  - Melk
- Kjøtt fra fjærkre
  - Kylling
  - Kalkun
- Kjøtt
  - Okse
  - Svin

7.5 Training program

Attachment table 1 | Squat training program

Uke 1	Dag 1	Dag 2	Dag 3
HVLG	2x VL (40%)	2x VL (40%)	2x VL (40%)
Intensitet	≈ 84%	≈ 89%	≈ 79%
Target MPV (m/s)	0.60	0.49	0.70

Uke 2-4	Dag 1	Dag 2	Dag 3
HVLG	3x VL (40%)	3x VL (40%)	3x VL (40%)
Intensitet	≈ 84%	≈ 89%	≈ 79%
Target MPV (m/s)	0.60	0.49	0.70

Uke 5-6	Dag 1	Dag 2	Dag 3
HVLG	4x VL (40%)	4x VL (40%)	4x VL (40%)
Intensitet	≈ 84%	≈ 89%	≈ 79%
Target MPV (m/s)	0.60	0.49	0.70

Attachment table 2 | Bench-press training program

Uke 1	Dag 1	Dag 2	Dag 3
HVL	2x VL (60%)	2x VL (60%)	2x VL (60%)
Intensitet	≈ 82%	≈ 87%	≈ 77%
Target MPV	0.45	0,38	0.53

Uke 2-4	Dag 1	Dag 2	Dag 3
HVL	3x VL (60%)	3x VL (60%)	3x VL (60%)
Intensitet	≈ 82%	≈ 87%	≈ 77%
Target MPV	0.45	0,38	0.53

Uke 5-6	Dag 1	Dag 2	Dag 3
HVL	4x VL (60%)	4x VL (60%)	4x VL (60%)
Intensitet	≈ 82%	≈ 87%	≈ 77%
Target MPV	0.45	0,38	0.53

Attachment table 3 | Deadlift resistance exercise program

Uke 1	HVLG	LVLG
Reps	12RM	6/12RM
Serier	2	4
Intensitet	70 %	70 %
Uke 2-4	**HVLG**	**LVLG**
Reps	8RM	4/8RM
Serier	3	6
Intensitet	80 %	80 %
Uke 5-6	**HVLG**	**LVLG**
Reps	6RM	3/6RM
Serier	4	6
Intensitet	90 %	90 %

7.6 Overview over all Effect Sizes investigated

	Logtransformerte verider																	
	Primæranalyse				Volum		Muskelmasse DXA - Fullkropp		Muskelmasse DXA - Armer		Muskelmasse DXA - Bein		Fettmasse DXA		Ultralyd VL		Ultralyd TL	
↓	Effekt størrelse ikke justert	±	Effekt størrelse juster for X2	±	Effekt størrelse justert for X1	±	Effekt størrelse justert for X1	±	Effekt størrelse justert for X1	±	Effekt størrelse justert for X1	±	Effekt størrelse justert for X1	±	Effekt størrelse justert for X1	±	Effekt størrelse justert for X1	±
Knebøy 1RM	-0.01	0.09	0.01	0.10	0.22	0.09	-0.01	0.10	0.00	0.10	0.00	0.10			0.00	0.15		
Benkpress 1RM	-0.08	0.09	-0.07	0.10	-0.09	0.14	-0.08	0.10	-0.09	0.14							-0.26	0.46
Knebøy V1	-0.12	0.27	-0.17	0.25	-0.10	0.34												
Benkpress V1	0.02	0.30	0.02	0.32	-0.05	0.45												
DXA fullkropp - Kneb	-0.02	0.09	-0.04	0.09	0.06	0.16												
DXA fullkropp - Benk	-0.02	0.09	-0.04	0.09	-0.04	0.16												
DXA armer	-0.04	0.16	-0.04	0.18	-0.02	0.27												
DXA Bein	-0.04	0.13	-0.08	0.13	0.00	0.24												
Ultralyd VL	-0.45	0.32	-0.42	0.34	-0.46	0.53												
Ultralyd TL	-0.18	0.43	-0.14	0.45	-0.15	0.63												
SJ Høyde	0.09	0.38	0.09	0.28	-0.11	0.76	0.03	0.46			0.07	0.37	0.11	0.44	0.26	0.47		
SJ PW	-0.03	-0.32	-0.03	-0.30	-0.29	0.38	-0.13	0.35			-0.04	0.37	0.03	0.33	-0.03	0.41		
SJ PW/bw	-0.24	0.57	-0.17	-0.51	-0.58	0.92	-0.26	0.72			0.23	0.67	-0.19	0.63	-0.39	0.76		
SJ MW	-0.42	0.58	-0.40	0.48	-0.64	0.62	-0.55	0.70			-0.38	0.65	-0.35	0.63	-0.47	0.73		
SJ MW/bw	-0.69	0.79	-0.50	0.52	-0.960	1.04	-0.75	1.00			-0.61	0.89	-0.67	0.86	-0.87	1.01		
Keiser (MW)	0.10	0.27	0.09	0.30	0.48	0.62	0.10	0.31					0.11	0.32	-0.03	0.45		
Keiser (MW/bw)	0.20	0.47	0.18	0.54	0.70	1.16	0.21	0.55			0.21	0.55			0.00	0.72		
Keiser (N/bw)	0.18	0.46	0.16	0.49	0.71	1.07	0.19	0.53					0.19	0.53	0.01	0.76		