The Faculty of Arts and Education

MASTERS THESIS

Study programme: Idrettsvitenskap - Master	Term: Spring 2023
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Supervisor: Thomas Bjørnsen	
Title of thesis: Muscle Strength and Muscle Size Adaptations in Ice Hockey Athletes in-season: A Comparison Between Moderate and High Velocity Loss Thresholds	
Keywords: Velocity-based strength training, velocity loss, ice hockey, semi-professional athletes, maximal strength, back squat	Pages: 113 Number of attachment/other: 5 Stavanger, 05.31.2023

Acknowledgements

I would like to express my sincere gratitude to my fellow students for the incredible experience we shared during our time at the University of Stavanger. These two years have been truly remarkable, and the friendships we have formed are incredibly meaningful to me.

This master's thesis has been an exceptionally educational and captivating journey. It has presented me with meaningful and exciting challenges, demanding my utmost dedication. I am deeply grateful for the invaluable support and companionship of my colleague Sander Remme throughout this entire year. Our collaboration and camaraderie have played a crucial role in the success of this project. Furthermore, I would like to extend my heartfelt appreciation to my supervisor, Thomas Bjørnsen, for his excellent assistance, guidance, and constructive feedback throughout the research and writing process. His expertise and support have been instrumental in shaping this thesis.

Lastly, I extend my heartfelt appreciation to the subjects who generously participated in this study. Their dedication and effort during the training intervention are deeply valued and greatly contributed to the success of this research.

Sammendrag

Bakgrunn: Teknologisk fremgang har popularisert objektive reguleringsmetoder, som hastighetsstyrt styrketrening (HST) for å regulere sentrale treningsvariabler som intensitet og volum. Til tross, har ikke HST blitt benyttet under konkurransesesong på veltrente idrettsutøvere. **Hensikt:** Denne studien hadde som formål å sammenligne effekten av to grupper med forskjellig hastighetstapterskler (20% og 40%) i knebøy på muskelstyrke og muskelstørrelse hos et ishockeylag under deres konkurransesesong. **Metode:** Et randomisert kontrollert eksperiment ble gjennomført med femten semiprofesjonelle mannlige ishockeyutøvere som gjennomgikk en 8 ukers treningsintervensjon. Utøverne ble tilfeldig fordelt til to grupper, VL20 (trening til 20% hastighetstap) og VL40 (trening til 40% hastighetstap), basert på deres knebøy 1RM. Muskelstyrken i underkropp ble vurdert av 1RM knebøy og maksimal kraft (Fmax) i pneumatisk beinpress. Muskelstørrelse ble evaluert ved bruk av ultralydsmålinger av muskeltykkelse i vastus laterealis og rectus femoris **Resultater:** For muskelstyrke, var (Fmax) i beinpress den eneste variabelen som viste signifikant forskjell (p = 0,01) mellom gruppene. For muskelstørrelse, ble ingen statistisk forskjell oppdaget mellom gruppene for noen av variablene. **Konklusjon:** Resultatene fra denne studien antyder at trening til 40% hastighetstap kan være gunstig for å forbedre muskelstyrken i underkroppen under konkurranseperioden for veltrente utøvere. Imidlertid er utvalgsstørrelsen i denne studien begrenset, noe som kan ha påvirket resultatene.

Nøkkelord: Styrketrening, hastighetsbasert trening, ishockey, maksimal styrke, muskelstørrelse, hastighetstap, knebøy, kraft-hastighetsprofil

Abstract

Background: Technological advancements has popularized objective methods, such as velocity-based strength training (VBT) for regulating key training variables such as intensity and volume within strength training. However, none has utilized VBT during a competitive period for well-trained athletes. **Purpose:** This study aimed to compare the effect of two velocity loss threshold groups (20% and 40%) in back squat on changes in muscle strength and muscle size among an ice hockey team during their competitive season. **Method:** A randomized controlled experiment was conducted with fifteen semi-professional male ice hockey athletes undergoing an 8-week training intervention. The athletes were randomly allocated into two groups, VL20 (training until 20% velocity loss) or VL40 (training until 40% velocity loss), based on their back squat 1RM scores. Their lower body muscle strength was assessed through 1RM back squat and maximal force (Fmax) in Keiser pneumatic leg press. Muscle size was evaluated using ultrasound measurements of muscle thickness in vastus lateralis and rectus femoris. **Results:** For muscle strength, leg press Fmax was the only variable that significantly ($p = 0.01$) differed between group. For muscle size, there were no statistical difference between groups in neither of the variables measuring muscle thickness. **Conclusion:** The findings of this study suggest training until 40% velocity loss might be beneficial for improving muscle strength in lower limbs during a competitive period for well-trained athletes. However, the sample size in this study remains rather small, which might have influenced the results.

Key words: Resistance training, velocity-based training, ice hockey, maximum strength, muscle size, velocity loss, squat, force-velocity profile

Abbreviations

VBT	Velocity-Based strength Training
VL20	The group training until 20% velocity loss
VL40	The group training until 40% velocity loss
RCT	Randomized Controlled Trial
1RM	One-Repetition Maximum
Fmax	Maximal Force, extrapolated from a theoretical force-velocity curve
FV	Force-Velocity
RPE	Rating of Perceived Exertion
RIR	Repetitions in Reserve
PBT	Standardized Percentage-Based Training
CSA	Cross Sectional Area
SD	Standard Deviation
CV	Coefficient of Variation
Kg	Kilograms
mm	Millimeter
NHL	National Hockey League
MPV	Mean Propulsive Velocity
CMJ	Counter Movement Jump
COM	Center of Mass
DCOR	Dynamic Constant External Resistance
SAID	Specific Adaptation to Imposed Demands

Table of Content

Part 1

RESEARCH PAPER

Muscle Strength and Muscle Size Adaptations in Ice Hockey Athletes in-season: A Comparison Between Moderate and High Velocity Loss Thresholds

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

Scandinavian Journal of Medicine & Science in Sports

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University in Stavanger

May 2023

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Introduction

Ice hockey is a common sport with over 1.5 million active players representing 83 associations (International Ice Hockey Federation, 2023). Ice hockey players typically have short shifts of 45-60 seconds followed by 2-5 minutes of rest, with NHL players rarely exceeding 15-20 minutes of active play time per game (Cox et al., 1995; Montgomery, 1988). However, these short shifts are characterized by repeated bursts of high-intensity skating, rapid lateral changes, high-speed collisions, and frequent physical combats (Burr et al., 2008; Cady et al., 2010; Montgomery, 1988; Vigh-Larsen & Mohr, 2022). Due to the nature of the game, ice hockey players require exceptional levels of various physiological components including strength, power, speed, endurance, agility, balance, and lean body mass composition to excel at the highest level (Behm et al., 2005; Burr et al., 2008; Cox et al., 1995; Spiering et al., 2003; Twist & Rhodes, 1993). In particular, strength and power capabilities seems to be vital for ice hockey players, with only the fastest and strongest players being selected for the NHL (Burr et al., 2008). Given the inherent risks involved, ice hockey players face a high potential for injury (Agel et al., 2007; Cady et al., 2010). Therefore, developing muscular strength and size becomes crucial not only for performance, but also for injury prevention (Cox et al., 1995; Montgomery, 1988; Orvanová, 1987; Twist & Rhodes, 1993).

Resistance training is commonly prescribed to enhance muscular strength and size. A common approach employed by trainers is the use of standardized percentage-based training (PBT), where loads are prescribed based on the athlete’s 1RM (Bompa & Buzzichelli, 2015; Weakley et al., 2017). Additionally, athletes are typically assigned a predetermined number of sets and repetitions (Banyard et al., 2019). When the principles of strength training are applied and appropriately periodized according to the athlete’s seasonal phase, PBT has shown to be effective in improving muscular strength and size (Bompa & Buzzichelli, 2015; Raastad et al., 2015; Sheppard & Triplett, 2016). However, there are limitations associated with prescribing PBT, as daily fluctuations in fatigue and readiness can lead to acute changes in 1RM (Greig et al., 2020; Padulo et al., 2012; Zourdos et al., 2015). Subjective methods like RPE and RIR have addressed these challenges by autoregulating training volume (Borg, 1970; Helms et al., 2017; Tuchscherer, 2008). RIR has shown usefulness for experienced powerlifters but has limitations with novice lifters and high repetition sets (Steele et al., 2017; Zourdos et al., 2021). With modern technology, velocity-based training (VBT) has emerged as an objective method for adjusting training intensity and volume, utilizing validated tools to measure movement velocity (Banyard et al., 2017; Banyard et al., 2018; Jovanović & Flanagan, 2014; Larsen et al., 2021). Since there is a relationship between velocity loss and fatigue, an important application of VBT is to use velocity loss thresholds to monitor fatigue and exertion during a set (Jovanović & Flanagan, 2014; Sánchez-Medina & González-Badillo, 2011; Weakley et al., 2021). VBT can also serve as tool to enhance performance and motivation, by giving immediate visual feedback between each repetition or post-set (Mann et al., 2010; Randell et al., 2011; Weakley et al., 2021).

Ice hockey is known for its demanding schedule, involving multiple games and practices per week (McKay et al., 2014; Nightingale, 2014; Nordstrøm et al., 2022). A congested schedule poses challenges in implementing structured training program that maximizes gains while allowing for adequate recovery (Nightingale, 2014). Insufficient workload management in such circumstances can increase the risk of injuries (Drew & Finch, 2016; Eckard et al., 2018). To address this, velocity loss can serve as a guiding factor to determine the number of repetitions or when to determine a set, with 20% velocity loss typically corresponding to 50% of possible repetitions and 40% velocity loss indicating proximity to fatigue (Sánchez-Medina & González-Badillo, 2011). By monitoring velocity loss thresholds, trainers can attempt to objectively prescribe training volume to elicit desired adaptations, irrespective of daily fluctuations in fatigue readiness (Jukic et al., 2023a; Weakley et al., 2021). Previous research have shown that higher velocity loss thresholds such as 40% is likely to be more beneficial for hypertrophy, while moderate thresholds such as 20% are likely to provide greater benefit for power output (Jukic et al., 2023a; Pareja-Blanco et al., 2017a).

Different velocity loss thresholds are therefore suggested to be advantageous at different stages of an athlete's season, with higher velocity loss thresholds (> 20%) in off-season periods aimed at adaptions like muscle hypertrophy and conditioning lean body mass (Jukic et al., 2023a; Pareja-Blanco et al., 2017a). On the other hand, during in-season low-moderate (10-20%) thresholds may be beneficial to keep fatigue low and maintaining athletic performance (Weakley et al., 2020b; Weakley et al., 2020c; Włodarczyk et al., 2021). However, to our knowledge, no previous study has investigated high vs low velocity loss thresholds in any team sports during the in-season competition period. Therefore, this study compared 20% and 40% velocity loss thresholds in young well-trained semi-professional ice hockey male players during their competitive season.

Materials and subjects

Subjects

One team with 21 male and one team with 22 female semi-professional ice hockey players were recruited to participate into the study. However, the female team withdrew from the intervention in week 5, after a series of consecutive losses whilst also reporting fatigue and "heavy legs". Therefore, the female's team intervention duration was considered insufficient to be included into the data analysis. Additionally, one male withdrew before the intervention started because of illness, while four male subjects dropped out during the intervention due to sustained injury or personal reasons. Finally, one male was excluded from the data analysis because of insufficient adherence (< 75%).

15 male (17.5 ± 0.64 years, 180.5 ± 6.5cm, 78.4 ± 9.9 kg) semi-professional ice hockey players were included into the data analysis. The subjects had at least one year experience with systematic resistance training program designed by a physical coach. This training program included a wide variety of compound and isolation exercises for upper and lower body (i.e., back squats, pull ups, and dumbbell bench press), a periodization of macro and micro cycles, and a manipulation of key training variables such as intensity and volume. All participants provided written and verbal informed consent, and the study received approval from the ethical board of the University of Agder's Faculty of Health and Sports Science (appendix 1) and the Norwegian Centre for Research Data (appendix 2). The study was conducted in adherence to the principles outlined in the Declaration of Helsinki.

Experimental design

This study was conducted as a randomised controlled experiment in which the subjects were allocated into two velocity loss thresholds groups, stratified upon back squat 1RM by randomizer.org. One grouped trained until 20% velocity loss (VL20 n = 7, 17.6 ± 0.8 years, 82.3 ± 12.1 kg, 181.8 ± 8.4cm) and one group trained until 40% velocity loss (VL40 n = 8, 17.4 ± 0.5 years, 77.4 ± 7.9 kg, 180.4 ± 3.8cm). The intervention consisted of 16 training sessions spanning over an 8-week period, performing two sessions per week. Additionally, the intervention took part during the team's in-season. The team played an average of two games per weekend during the intervention, in addition to having 5-6 on-ice sessions and one upper body strength session per week.

The subjects were assessed twice, pre and post intervention. The testing was divided into three sessions, with each session completed < 24 hours apart from each other. First test session consisted of: sprint 30m off ice with 10m split interval, countermovement jump (CMJ) and 1RM back squat. Second session included ultrasound measurement and keiser leg press, while third session consisted solely of sprint 30m on ice with 10 split time interval. The same testing procedure was performed on both occasions, following the same order of test sessions and the same order of tests per test session.

Training intervention

The subjects performed three sets of back squats twice a week, with an intensity of 70% 1RM in one session, and 80% 1RM in the other. To familiarize the subjects with the training protocol, all subjects trained until 20% velocity loss were achieved the first week. For the remaining duration of the intervention, the subjects trained until reaching their assigned velocity loss threshold. In Week 5, a miniscule deload week was introduced (reducing the number of sets for back squats to two), to minimize fatigue for the female group during a congested fixture list. Consequently, the same adjustment was necessary for the male group too.

Back squats were incorporated into the subject’s training program as the primary exercise, always prioritized as the first exercise, while subsequently followed by 3-4 additional exercises. The following exercises alternated and were compiled by compound and isolation exercises targeting plyometrics, hypertrophy, power, and strength. To facilitate strength development in back squats, a progressive overload was implemented in week 5 and week 7, increasing the external load by 2.5 kg (table 1)

Table 1 Back squat training regime

Session 1	**Session 2**	**Session 3**	**Session 4**
3 sets at 80% 1RM	3 sets at 70% 1RM	3 sets at 80% 1RM	3 sets at 70% 1RM

Session 5	Session 6	Session 7	Session 8
3 sets at 80% 1RM	3 sets at 70% 1RM	3 sets at 80% 1RM	3 sets at 70% 1RM
Session 9	**Session 10**	**Session 11**	**Session 12**
2 sets as 80% 1RM + 2.5kg	2 sets at 70% 1RM + 2.5kg	3 sets at 80% 1RM + 2.5kg	3 sets at 70% 1RM + 2.5kg
Session 13	**Session 14**	**Session 15**	**Session 16**
3 sets at 80% 1RM + 5.0kg	3 sets at 70% 1RM + 5.0kg	3 sets at 80% 1RM + 5.0kg	3 sets at 70% 1RM + 5.0kg

Tab. 1 Overview of back squat training regime during the 8-week VBT- intervention, showcasing and progressive overload introduced at session 9 by 2.5 kg which was kept until session 12, increasing the weight by an additional 2.5kg at session 13 which was kept until the remaining duration of the intervention. Abbreviations: VBT = velocity-based training. 1RM = one repetition maximum.

Prior to each training session, each subject underwent a 20-minute warm up routine, starting with 5-10 minutes indoor-cycling, followed by dynamic mobility and flexibility drill, and a gradual increase in external load in back squat leading up to the working load was reached. Back squats were performed with a controlled eccentric phase until 90 degrees knee angle was reached, followed by an explosive concentric phase. To ensure maximum effort and velocity during the concentric phase, the practitioners provided strong verbal encouragement during each repetition every set. Back squats were performed on a force feedback platform provided by Alphatek which measured movement velocity from the center of mass.

The Alphatek PWR platform displays mean propulsive velocity (MPV) and squat depth on a large screen placed in front of the subject. The screen provided the subjects with objective feedback, which the subjects were trained to utilize to enhance the training effort whilst keeping an acceptable squat depth. Furthermore, the screen also presented the subjects with intra-set velocity loss. Each repetition was measured and compared to the one with the highest movement velocity, ultimately providing the subjects with live information of their current velocity loss. The screen used a traffic light model, which stayed green when the movement velocity in a repetition was approximate to the fastest repetition, then turning yellow when the movement velocity decreased (velocity loss), and ultimately turning the red when subject reached their allocated velocity loss threshold (20% or 40%). The inter-set rest interval for back squats was standardized to < 3 minutes for all sessions.

Measurements

To assess the subject's muscle strength and muscle size, back squat 1RM and leg press Fmax provided measurements of muscle strength, while ultrasound imaging provided measurements of muscle thickness in vastus lateralis and rectus femoris.

Back squat 1RM

A progressive 1RM back squat test was conducted as the final the measurement on test session 1. Prior to 1RM back squat test, the subjects had already with gone a 5-10 dynamic warm up, performed a sprint and CMJ test. The subjects began with a load 50% of self-estimated 1RM, performing no more than 6 repetitions. The load was then gradually increased with 10kg per set, concurrently with a decrease in repetitions performed leading up to the projected 1RM. At the final sets approaching 1RM, the load increased with smaller increments (2.5-5.0 kg), performing no more than 1-2 repetition(s). When a subject was positive the current weight was approximately 1RM, an official 1RM test was conducted with a practitioner observing the repetition was performed correctly.

The subject performed the repetition by standing flat on the floor, with the spine in an upright position, the hip and knees fully extended, and the barbell firmly placed on back of the shoulder at the level of the acromion. The opening of the feet was preferable, but usually at shoulders-width. The subject was then instructed to descend in a continuous motion until the desired squat depth was reached (femur parallel with the floor) before the practitioners gave verbal permission and encouragement to ascend back to the starting position. If the repetition was successfully completed, the load would increase with 2.5kg per set until a heavier load was deemed not possible. A similar load adjustment would also occur if the repetition was unsuccessful, with the load decreasing with a minimum of 2.5 kg until a successful repetition was performed.

Leg press Fmax

Force-Velocity relationship of the lower body was measured with the Keiser A300 leg press device (Model 2531, Keiser Corporation, Fresno, California, USA). FV-values were extracted from its Keiser A420 software using the standard 10-step test with incremental loads. The heaviest load during the 10-step test was determined by adding the subject's back squat 1RM score and bodyweight score together. Using average force and velocity measures, a linear regression was applied to estimate the theoretical maximal force (Fmax). The subject performed 5-6 warm up repetitions, using light-moderate loads. For the 10-step test, the subject was re-seated into the device with the heals firmly placed at the bottom of the plate, with their femur placed vertically at an 80-90-degree angle. The test started by performing two practice attempts with the lightest load (15% of 1RM). When the 10-step test initiated, the subject was verbally encouraged to extend both legs with maximum effort on each repetition. The subject performed 10 repetitions across the FV-curve (15% - 100% 1RM), with the resistance increasing by 20-30 kg per repetition. The subject received 10-20s rest between each repetition for the initial five repetition, while the rest-interval increased to 20-40s for the next four repetitions. After the 10th repetition, the test was completed using no more than a total of 5-10 minutes per subject.

Muscle size

One practitioner performed all ultrasound imaging during this current study and had prior to the study an > 10 hours of practicing a standardized ultrasonography on two subjects (one male and one female). Muscle size was measured by measuring muscle thickness in the axial plane of vastus lateralis and rectus femoris, performing ultrasonography with the equipment LogicScan 128 CEXT-1Z REV;B, Telemed, Vilnius, LT, Lithuania). A 40mm width linear probe with 9hz exication frequency was coated with water soluble ultrasound transmission gel (Aquasonic 100), and placed at approximately 50% of the distance from the hip socket to the top of the knee cap. All subjects lay in a supine position on an examination bench with both knees fully extended, while measurements were recorded from the right leg.

Location of vastus lateralis and rectus femoris were marked with two bars using a waterproof eye liner (name), when a satisfying image were displayed in the Echo Wave II 4.1.0 program on a laptop next to the researcher. A transparent sheet was then allocated on the subject's right leg used to record the probe's relative position to identification marks (moles, scars, birthmarks etc.), allowing for swiftly locating in the post-test procedure. Lastly before imaging, the researcher would also mark the subject’s experiment number on the sheet. Imaging of vastus lateralis was always recorded first, followed by rectus femoris.

Prior to conducting the post-test procedure, the researcher would create small cuts into the transparent sheets at the location marks for vastus lateralis and rectus femoris. During post-test procedure, the researched placed the transparent sheet onto the subject’s right leg matching the position of identification marks. Bars were then drawn onto the subject’s right leg where the cuts in the sheet was created. To further ensure similar placement between tests, an additional laptop was prepared for post-test procedure, showcasing the pre-test image next to the laptop displaying live image in the Echo Wave II 4.1.0 program. Analyses of muscle thickness was conducted with the ImageJ 2.0 Fiji Software using a standardized prescription.

Data Analysis

Baseline characteristics of the subjects were described using mean and standard deviation as descriptive statistics. Data distribution was examined by analysing mean, median, skewness, and kurtosis, indicating a normal distribution. Between-group changes were assessed using an independent sample t-test, presenting percentage mean difference, p-value, and percentage change statistics. Within-group pre to post changes were analysed using a paired sample t-test. Results were reported as percentage mean, standard deviation, and p-value. Statistical analyses were performed using Microsoft Excel with a significance level set at <0.05 and confidence limits at 95%.

Results

Training volume and velocity loss

At baseline, no significant differences between groups were detected in any of the variables analysed. Adherence to training demonstrated no statistical difference between VL20 (88.3 ± 11.3%) and VL40 (92.0 ± 9.4%, $p = 0.508$). However, there was a significant difference ($p = 0.012$) between VL40 (8.8 ± 1.3) and VL20 (6.9 ± 1.2) in the average number of completed repetitions per set (Figure 1). A statistical difference between also detected across all three sets, with VL40 performing significantly more repetitions than VL20 in set 1 ($p = 0.007$), set 2 ($p = 0.025$) and set 3 ($p = 0.043$) (Figure 1). At the end of each set there was also significant ($p < 0.001$) difference in experienced velocity loss between VL20 (25.3 ± 1.8%) and VL40 (47.2 ± 4.8%)

Figure 1 A comparison of back squat training volume between both training groups

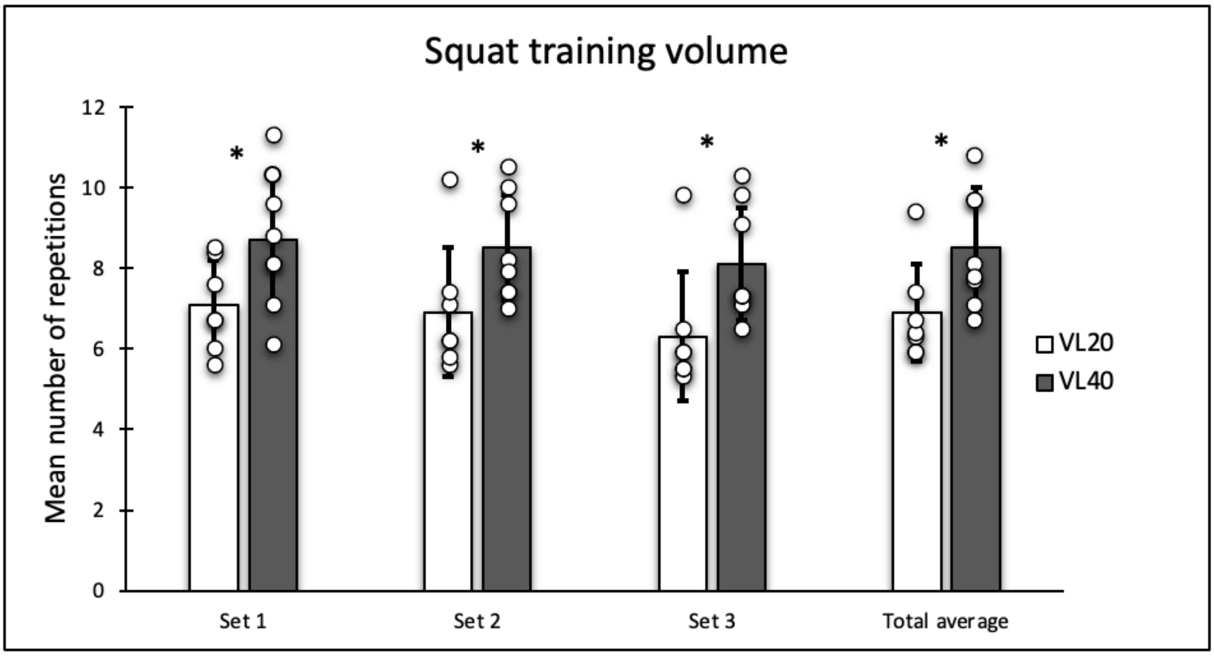

Fig. 1 Data are expressed as mean (± SD) completed number of repetitions per set and total mean in both groups during an 8-week VBT-intervention. (*) indicates a significant difference between groups ($p < 0.05$). Abbreviations: SD = standard deviation. VBT = velocity-based training. VL20 = training until 20% velocity loss. VL40 = training until 40% velocity loss.

Muscle strength

No significant difference was observed in neither of the variables measuring muscle strength between groups at baseline. However, leg press Fmax demonstrated a statistical (p = 0.01) difference between groups at post-test. VL40 (4.4 ± 5.3%) significantly (p = 0.024) increased their leg press Fmax from baseline, while VL20 (-2.0 ± 2.6%) demonstrated no significant change (p = 0.068) (Figure 2). Back squat 1RM demonstrated no statistical difference between groups at post-test (p = 0.136). Nonetheless, only VL40 (10.3 ± 7.0%) significantly (p = 0.001) increased their back squat 1RM compared to baseline, while VL20 (4.4 ± 6.8%) demonstrated no significant change (p = 0.111) (Table 2). Descriptive statistics of both groups for muscle strength is shown in table 2, while mean changes for both group is demonstrated in figure 2.

Table 2 Descriptive statistics muscle strength variables back squat 1RM and leg press Fmax

Measurement	**VL20**				**VL40**				**Group x time interaction**
Back squat 1RM	**Pre (kg)**	**Post (kg)**	**Change (%)**	**Baseline comparison p-value**	**Pre (kg)**	**Post (kg)**	**Change (%)**	**Baseline comparison p-value**	**P-value**
	131.6 ± 12.3	138.2 ± 15.0	4.4 ± 6.8	0.111	127.9 ± 16.5	140.4 ± 13.6	10.3 ± 7.0	**0.001**	0.136
Leg press Fmax	**Pre (N)**	**Post (N)**	**Change (%)**	**Baseline comparison p-value**	**Pre (N)**	**Post (N)**	**Change (%)**	**Baseline comparison p-value**	**P-value**
	357.3 ± 57.4	349.6 ± 52.8	-2.0 ± 2.6	0.068	328.7 ± 25.5	342.9 ± 26.9	4.4 ± 5.3	**0.024**	**0.01**

Tab. 2 An overview of pre and post test scores, % change and p-value for VL20 and VL40, and group x time interaction for the muscle strength variables 1RM and Fmax. Data are expressed as mean and

(± SD) for relative pre and post-test score. Changes from pre-to-post are expressed as percentage (± SD) change. Only Fmax significantly differed between groups (p = < 0.05). Abbreviations: 1RM = one repetition maximum. Fmax = Theoretical maximum force. Kg = Kilogram. N = Newton. VL20 = Training until 20% velocity loss. VL40 = Training until 40% velocity loss.

Figure 2 A comparison of mean (± SD) changes in both groups for muscle strength variables

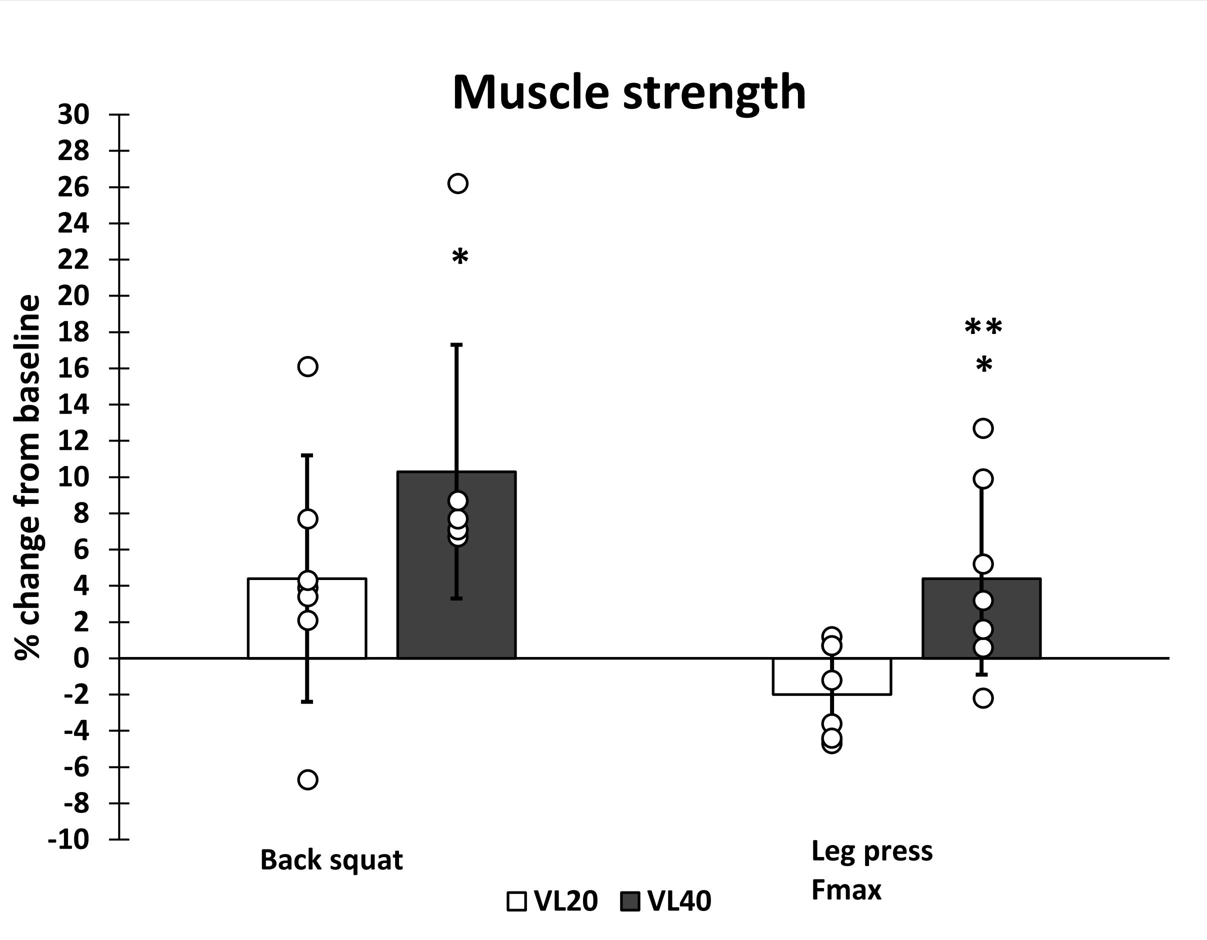

Fig. 2 Data are expressed as mean (± SD) relative change in muscle strength from pre-test following an 8-week VBT-intervention. (*) indicates a significant change from pre-test ($p < 0.05$). (**) indicates a significant change between groups ($p < 0.05$). Fmax significantly differed between groups ($p < 0.05$). VL40 significantly increased back squat 1RM and leg press Fmax, while VL20 demonstrated no significant change in both variables ($p < 0.05$). Abbreviations: SD = standard deviation. VBT = velocity-based training. 1RM = one repetition maximum. Fmax = theoretical maximum force derived from an FV-curve. VL20 = subjects training until 20% velocity loss. VL40 = subjects training until 40% velocity loss.

Muscle size

No statistical difference was observed in neither of the variables measuring muscle thickness between groups at baseline. There was also no statistical difference in relative change in muscle thickness between groups for vastus lateralis and rectus femoris. Only VL20 (2.0 ± 1.4%) significantly (p = 0.003) increased their muscle thickness of vastus lateralis, while VL40 (2.6 ± 3.7%) demonstrated no significant difference (Figure 3). Rectus femoris remained unaltered in both groups. Descriptive statistics of both groups for muscle size is shown in table 3, while mean changes for both group is demonstrated in figure 3.

Table 3 Descriptive statistics of muscle size variables vastus lateralis and rectus femoris

Measurement	**VL20**				**VL40**				**Group x time interaction**
Vastus lateralis	**Pre (kg)|**	**Post (kg)**	**Change (%)**	**Baseline comparison (p-value)**	**Pre (kg)|**	**Post (kg)**	**Change (%)**	**Baseline comparison (p-value)**	**P-value**
	30.1 ± 3.9	30.7 ± 3.8	2.0 ± 1.4	**0.003**	29.6 ± 3.7	30.4 ± 3.9	2.6 ± 3.7	0.052	0.696
Rectus femoris	**Pre (kg)|**	**Post (kg)**	**Change (%)**	**Baseline comparison (p-value)**	**Pre (kg)|**	**Post (kg)**	**Change (%)**	**Baseline comparison (p-value)**	**P-value**
	27.0 ± 2.7	26.7 ± 2.7	-0.9 ± 1.9	0.245	24.1 ± 3.0	24.2 ± 2.9	0.5 ± 5.3	0.771	0.492

Tab. 3 An overview of pre and post test scores, % change and p-value for VL20 and VL40, and group x time interaction for the muscle size variables vastus lateralis and rectus femoris. Data are expressed as mean and (± SD) for relative pre and post-test score. Changes from pre-to-post are expressed as percentage (± SD) change. No significant differences were observed between groups in both muscle size variables ($p < 0.05$) Abbreviations: SD = standard

deviation kg = kilogram. mm = millimetre. VL20 = subjects training until 20% velocity loss. VL40 = subjects training until 40% velocity loss.

Figure 3 A comparison of mean (± SD) changes in both groups for muscle size variables

Fig. 3 Data are expressed as mean (± SD) relative change from pre-test in muscle thickness of vastus lateralis and rectus femoris following an 8-week VBT-intervention. (*) indicates a significant change from pre-test ($p < 0.05$). VL20 significantly increasing the muscle thickness of vastus lateralis is the only significant change relative to pre-test ($p < 0.05$) Abbreviations: SD = standard deviation. VBT = velocity-based training. VL20 = subjects training until 20% velocity loss. VL40 = subjects training until 40% velocity loss.

Discussion

This study aimed to investigate the effect of incorporating velocity-based training (VBT) into a resistance program on muscle strength and muscle size in young male semi-professional ice hockey players during their competitive season. Two velocity loss thresholds, 20% and 40%, were implemented in the back squat training to compare their effects on strength measurements, including back squat 1RM and leg press Fmax, as well as muscle thickness measurements of vastus lateralis and rectus femoris. Muscle strength comparison demonstrated that leg press Fmax was the only variable that statistically differed between VL20 and VL40. For muscle size, there was no statistical difference between groups observed for either variable.

Muscle strength

Only leg press Fmax significantly differed between VL20 (-2.0 ± 2.6%) and VL40 (3.9% ± 5.1%). However, there are indications of greater improvement in back squat 1RM for VL40 (10.3 ± 7.0%) compared to VL20 (4.4 ± 6.8%). These findings suggest that employing 40% velocity loss thresholds may be more effective in eliciting maximum strength gains in well-trained athletes during the in-season phase. To the author’s knowledge, no current study has investigated velocity loss thresholds application during the in-season for athletes. Nonetheless, the results from this study differ from findings in recently conducted VBT-studies with similar characteristics. Several studies found no significant difference in muscle strength between 20% and 40% velocity loss thresholds over an 8-week intervention (Pareja-Blanco et al., 2020b; Pareja-Blanco et al., 2017a; Rissanen et al., 2022).

Several systematic reviews have examined the effects of different velocity loss thresholds or non-failure vs failure training on muscle strength (Grgic et al., 2022; Hickmott et al., 2022; Jukic et al., 2023a; Zhang et al., 2023). A systematic review by Jukic, Castilla et al. (2023a) found no significant difference between low vs high velocity loss, while another review by Hickmott et al. (2022), observed a favor for low-moderate (< 25%) velocity loss contra moderate-high (> 25%) velocity loss for strength gains. However, Grgic et al. (2022) reported no significant benefit in training to proximate failure vs non-failure in eliciting strength gains. Finally, a meta-analysis by Zhang et al. (2023) exploring the dose-response relationship between velocity loss, reported no statistical difference between low and high velocity loss thresholds.

Nonetheless, the dose-response relationship analysis by Zhang et al. (2023) detected a significant non-linear reverse U-shaped relationship between velocity loss and muscle strength (1RM). The 1RM gain increased until a moderate velocity loss was reached, with highest effect size reported for 25% velocity loss, followed by a decline when exceeding 25% velocity loss. This notion is consistent with findings in Hickmott et al. (2022), favoring < 25% velocity loss, but also with sub-analysis in Grgic (2022); Jukic, Castilla et al. (2023a). When equating effect sizes, When analyzing non-volume equated studies, Jukic, Castilla et al. (2023a) found a slight advantage for not exceeding 25% velocity loss in promoting strength gains. Similarly, in non-volume equated studies, Grgic et al. (2022) found a significant favor for non-failure training in contrast to training to failure in eliciting strength gains.

Therefore, the findings of this study somewhat collide with notion observed in several systematic review which suggests that exceeding 25% velocity loss may not be optimal for maximizing strength gains (Grgic et al., 2022; Hickmott et al., 2022; Jukic et al., 2023a; Zhang et al., 2023). Additionally, several similar 8-week interventions studies utilizing VBT have found no significant difference between 20% and 40% velocity loss in term of strength development (Martinez-Canton et al., 2021; Pareja-Blanco et al., 2020a; Pareja-Blanco et al., 2020b; Pareja-Blanco et al., 2017a; Rissanen et al., 2022).

However, the subjects in this study are well trained athletes who likely possess a higher training status compared to subjects in similar VBT-studies. This is evident from their average back squat 1RM (130.2 kg) at baseline, which exceeds the average scores reported in other similar studies, with no studies reporting > 111.8kg RM in back squat (Pareja-Blanco et al., 2017a; Rissanen et al., 2022; Rodríguez-Rosell et al., 2021). The different is also evident when comparing with professional soccer players (130.2kg vs 100.8kg) (Pareja-Blanco et al., 2017b). This suggest as a subject approaches their genetic ceiling for muscular adaption, a higher intensity of effort may be necessary to continue eliciting strength gains (Grgic et al., 2022). Furthermore, Grgic et al. (2022) also reported that training to proximate failure does not seem to have detrimental effects on strength gains, which is evident observing effect sizes in Zhang et al. (2023) for VL40 compared to VL25, which achieved the highest effect size for > 1 year experienced lifters.

Muscle size

Ultrasound imaging demonstrated no significant difference between groups in muscle thickness of neither variable. Vastus lateralis increased significantly for VL20 (2.0 ± 1.4%), while VL40 (2.6 ± 3.7%) showed a near tendency of change (p = 0.052). Rectus femoris remained unaltered in both groups. With regards to muscle size, the findings of this study are not as clear as the previous literature (Jukic et al., 2023a). Although VL40 showed a greater change in percentage, it is important to note that there were greater individual variations as indicated by the standard deviation. Furthermore, due to the small sample size and potential influence of extraneous factors (i.e., games, practice sessions, outside events, or maturation), this study may have been limited in demonstrating a significant group difference (Hollon, 2015; Pareja-Blanco et al., 2020b).

According to Raastad et al. (2015), the biggest predictor of force production probability is muscle size. Additionally, athletes and pro-bodybuilders utilize high training volume and moderate intensity (50-80% 1RM), with sets performed proximately to neuromuscular failure to induce hypertrophy adaptations (Alves et al., 2020; Gjerset et al., 2015; McArdle et al., 2015). The only intervention-induced difference between VL20 and VL40 was the amount of velocity loss, which ultimately lead to higher training volume for VL40 by performing 21% more repetitions per set. High velocity loss thresholds (> 40%) has shown to be superior for inducing hypertrophy adaptions (Jukic et al., 2023a; Pareja-Blanco et al., 2017a). A reason for that might be that velocity losses of high magnitude (i.e., 40%) induces higher metabolic and mechanical stress compared to moderate (i.e., 20%), resulting in greater neuromuscular fatigue (Nájera-Ferrer et al., 2021; Sánchez-Medina & González-Badillo, 2011). A hypothesis was therefore that the indications of muscle strength differences was a result of group difference in muscle size detected at post-test. However, the absence of greater muscle size change for VL40 than VL20 presents an interesting observation, especially considering VL40 experienced significantly higher velocity loss (47.2 ± 4.8% vs 25.3 ± 1.8%) and performed significantly more repetitions per set (8.2 ± 1.5 vs 6.5 ± 1.5) than VL20.

However, it is worth noting that VL20 performed 79% of the completed repetitions per set compared to VL40. This percentage is relatively high compared to findings reported by Sánchez-Medina & González-Badillo (2011), who stated that a 20% velocity loss threshold would result in approximately 50% of possible repetitions in the back squat, while a 40% velocity loss thresholds would result in reaching or approaching failure. The closer similarity of repetitions per set (volume), might suggest that VL20 experienced greater neuromuscular fatigue than in Sánchez-Medina & González-Badillo (2011), which could explain the similarity in changes observed in the vastus lateralis. However, the results from Sánchez-Medina & González-Badillo may be of limited validity for this study as, they measured back squat performed on a smitch machine rather than free weight back squat. Additionally, movement velocity was measured from the barbell in Sánchez-Medina & González-Badillo (2011, while we measured movement velocity from the center of mass (COM) on a force platform.

Lake et al. (2012) conducted a study comparing power output measurements using the velocity of the center of mass (COM) and the barbell during the squat exercise. Their findings revealed that assessing barbell velocity led to a significant overestimation of velocity and subsequently resulted in an overestimate of power output. This discrepancy can be attributed to the fact that the barbell undergoes greater displacement and moves at a higher velocity compared to the COM during the back squat. Consequently, measuring barbell velocity may not be as accurate in assessing power compared to measuring COM velocity on a force platform, which aligns with the methodology employed in our study.

The findings from Lake et al. (2012) shed light on a concern raised by Jukic, Prnjak et al. (2023b), regarding the individual nature of the relation velocity loss and the percentage of maximum repetitions achievable in a set during free weight back squats. The study conducted by Jukic, Prnjak et al. (2023b) questions the utility of using velocity loss thresholds as a reliable method of prescribing training volume in free weight back squats. This scepticism is primarily based on the poor predictive validity of such thresholds, as evidenced by high variability between subjects (reflected in high standard deviations) and absolute errors exceeding 10% in subsequent testing sessions, irrespective of the load utilized. Importantly, these results do not appear to be influenced by factors such as training status or history (Jukic et al., 2023b).

Nonetheless, the findings from other VBT-studies investigating the relationship between velocity loss thresholds and hypertrophy are not consistent across the board. In a similar study, no significant difference was found between training to 20% and 40% velocity loss for hypertrophy (Rissanen et al., 2022). On the other hand, Pareja-Blanco et al. (2017a) reported that 40% velocity loss led to significantly greater hypertrophy than 20% velocity loss. Furthermore, some studies have suggested that moderate (15-30%) velocity loss equally effective in promoting hypertrophy compared to velocity loss thresholds exceeding 30% (Pareja-Blanco et al., 2020b). The lack of clarity regarding the most effective velocity loss thresholds for eliciting hypertrophy is also echoed in several systematic reviews (Hickmott et al., 2022; Jukic et al., 2023a; Refalo et al., 2023).

One possible explanation for the inconsistent findings regarding velocity loss thresholds and hypertrophy is suggested by Refalo et al. (2023). They propose that higher velocity losses approaching failure (> 25%) may promote hypertrophy, but in a non-linear reverse U-shaped manner, similar to the relationship between velocity loss and muscle strength reported in Zhang et al. (2023). This means that higher hypertrophy responses are observed with increasing velocity losses, but only up to a certain point, with a subsequent decrease in hypertrophy response when furtherly increasing velocity loss (Refalo et al., 2023). In contrast, Jukic Castilla et al. (2023a) observed a somewhat linear increase in hypertrophy with increasing velocity loss. These findings are supported by Hickmott et al. (2022), reporting a sadvantage for exceeding 25% velocity loss compared to those below 25% velocity loss.

However, it is important to consider that as velocity loss increases, training volume tends to increase. Andersen et al. (2021) suggest that it may be volume rather than velocity loss itself that plays a crucial role in eliciting hypertrophy. Indeed, Refalo et al. (2023) also propose that achieving an appropriate proximity to failure, combined with an adequate volume (12-20 sets per week), are key factors for muscle hypertrophy. This is supported by a systematic review conducted by Schoenfeld et al. (2017), which demonstrated a significant dose-response relationship between weekly volume an muscle mass. While it is possible to achieve hypertrophic gains with low-volume protocols (< 4 weekly sets), performing at least 10 sets per muscle group per week appears to be necessary to maximize muscle mass increases (Schoenfeld et al., 2017).

Practical implications

- Interestingly, 40% velocity loss proved to be more effective in eliciting maximum strength gains during in-season for well-trained semi-professional ice hockey players. Therefore, it might be beneficial for coaches to prescribe resistance training proximate to failure to well-trained athletes during the competitive period.

- Conversely 40% velocity loss did not promote additional hypertrophy gains compared to 20% velocity loss, despite being previously preferred. Thus, inducing high volume or high amounts of fatigue might not be necessary if hypertrophy is the desired adaption.

- Concerns have emerged regarding the validity and reliability of utilizing velocity loss thresholds as a reliable method of prescribing training intensity and volume. Substantial individual variability in velocity loss before reaching neuromuscular fatigue, which prompts the question of whether implementing velocity loss thresholds offer any additional advantage over cost-effective traditional training approaches.

- The limited sample size in this study may restrict the generalizability of the findings and the ability to detect significant changes resulting from the intervention. Therefore, it is recommended that future studies with larger sample sizes be conducted to enhance the robustness of the results and facilitate broader generalization.

Conclusion

The findings of this study suggests that training to high (40%) velocity loss thresholds might be beneficial compared to moderate (20%) velocity loss thresholds in developing maximum strength in lower limbs for well-trained athletes during their competitive season. We do not know if this is due to higher volume or higher degree of exhaustion following the velocity loss allocation. However, the sample size is rather small, which means the group results might have been influenced by some individual scores. Nonetheless, the results have shown that improving maximum strength for well-trained athletes during in-season is possible with moderate-high velocity loss thresholds while concurrently receiving objective feedback and autoregulation.

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PART 2

THEORETICAL BACKGROUND AND METHODS

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1.0 Theory

1.1 Ice hockey and physical demands

Ice hockey is a popular sport with 83 nations representing the International Ice Hockey Federation (International Ice Hockey Federation, 2023). The majority of the popularity stems from Northern America, as well as Northern and Eastern Europe (Vigh-Larsen & Mohr, 2022). An ice hockey game consists of two teams with five skaters and one goalkeeper on each team, and is contested on a rink measuring 60x30 meters (International Ice Hockey Federation, 2022). Ice hockey is a highly intense team sport characterized by repeated bursts of fast paced skating, rapid directional changes, high speed collisions and frequent physical combats (Burr et al., 2008; Vigh-Larsen & Mohr, 2022).

Given the intensity and physicality of ice hockey, athletes most possess high levels of several physiological components (Burr et al., 2008; Cox et al., 1995; Nightingale, 2013; Twist & Rhodes, 1993). Strength, power, endurance, agility, balance, and an athletic body composition is necessary in order to be successful at the highest level (Behm et al., 2005; Burr et al., 2008; Spiering et al., 2003; Twist & Rhodes, 1993). According to Burr et al. (2008), only the fastest, strongest and most skilful players are likely to be drafted into the NHL, the best and most prestigious hockey league in the world (Burr et al., 2008; Guérette et al., 2021; Marsh, 2016). During the 1990's and 2000's ice hockey players have become bigger, faster, and stronger, which suggest the physical aspect plays an increasing role for on-ice performance (Quinney et al., 2008; Twist & Rhodes, 1993).

1.2 Muscle strength

Muscle strength refers to the maximum ability an athlete's neuromuscular system can exert in a single voluntary contraction during a specific movement at a pre-defined rate (Knuttgen & Kraemer, 1987; Kumar, 2004). A common procedure to measure muscle strength is the one repetition maximum test (1RM), which refers to the heaviest load an individual can lift one time with proper form (Bompa & Buzzichelli, 2015; McArdle et al., 2015; Raastad et al., 2015). The maximum load lifted by an individual is expressed as 1RM, and considered their maximum strength in a specific exercise, (Bompa & Buzzichelli, 2015; Kumar, 2004; Raastad et al., 2015). By using an equation, a sub-maximum test can also be used to estimate 1RM, by performing several repetitions with a given load which is substantially lower than their 1RM. Sub-maximum tests are considered to have a lower risk of injury compared to 1RM-test (McArdle et al., 2015).

1.2.1 Muscle action

A muscle compromises of multiple muscle fibres, each connected to a motor neuron at the neuromuscular junction (Raastad et al., 2015; Triplett, 2015). The sliding filament theory explains the mechanism of muscle contraction, where neural stimulation at the neuromuscular junction initiates the contractile filaments to generate force output (Bompa & Buzzichelli, 2015; McArdle et al., 2015; Triplett, 2015). Muscle actions can be categorized into three main types: concentric, eccentric and isometric. Concentric muscle action occurs when the force output exceeds resistance, resulting in muscle shortening. Eccentric muscle action occurs when force output is insufficient to overcome resistance, leading to muscle lengthening (Bompa & Buzzichelli, 2015; McArdle et al., 2015; McBride, 2015). Concentric and eccentric muscle actions often occur consecutively in a stretch-shortening cycle (Bompa & Buzzichelli, 2015). Isometric action on the other hand, involves no observable movement and occurs when force application and resistance are balanced (Bompa & Buzzichelli, 2015; McBride, 2015).

1.2.2 Factors that determine muscle strength

Force generation during movement relies on various biomechanical factors in the musculoskeletal and central nervous system (Kumar, 2004; McBride, 2015; Raastad et al., 2015). In the musculoskeletal system, muscle cross-sectional area is a primary determinant of force production (McBride, 2015; Raastad et al., 2015). Therefore, muscle hypertrophy increases the potential for generating higher force rates (Kumar, 2004). Muscle fibre arrangement and length are additional factors influencing muscle strength (McBride, 2015; Raastad et al., 2015). Type II fibres (IIA and IIX) exhibit greater force production and the ability to rapidly generate force than type I fibre, which is crucial for athletic performance in sports where force production availability is time limited (Bompa & Buzzichelli, 2015). In the central nervous system, muscle strength is primarily influenced by the recruitment and firing rate of motor units. The number, size and firing rate of motor units greatly contribute to force output (McBride, 2015; Raastad et al., 2015). Neural control also plays a role in coordination and technique, facilitating synchronization among agonist, antagonist and synergist muscles to enhance force production (Raastad et al., 2015).

1.2.3 Muscle size and hypertrophy

Muscle size refers to the magnitude of a skeletal muscle, typically express by its cross-sectional area, volume or thickness (Triplett, 2015). Muscle size is determined by the number of muscle fibres, their cross-sectional area and fibre architecture(McArdle et al., 2015; Raastad et al., 2015). Resistance training that increases external muscular tension, stimulates muscle growth (hypertrophy) (French, 2016; Kraemer et al., 2016; McArdle et al., 2015). The endocrine system promotes the synthesis of contractile proteins like actin and myosin within the myofibril, as well as proliferation of myofibrils within the muscle fibres (French, 2016; Kraemer et al., 2016; McArdle et al., 2015). Hypertrophy is according to French (2016), positively related to muscle strength. Heavy resistance training presents a potent stimulus for significant increases in lean tissue mass, because motor units are recruited sequentially according to their size, leading to high-force production (French, 2016; Kraemer et al., 2016). Overload training induces hypertrophy by enlarging individual muscle fibres, potentially transitioning fibre type from I to II, and influencing architectural changes such as altering the pennation angle, which impacts force production capacity (French, 2016; McArdle et al., 2015).

1.3 Muscle strength and muscle size's importance for ice hockey performance

Developed muscle strength and size is important for ice hockey because it is a major predictor of athletic performance and physical sturdiness (Behm et al., 2005; Burr et al., 2008; Cox et al., 1995; Häkkukinen et al., 1985; International Ice Hockey Federation, 2022; Montgomery, 1988; Orvanová, 1987; Twist & Rhodes, 1993).

1.3.1 Athletic performance

Improved training methods and increased knowledge of physiological demands of ice hockey, has resulted in search for more agile, stronger, and faster athletes (Montgomery, 2006; Nightingale, 2014). Players rely on muscle strength for agility and balance, but is also a factor for speed (Twist & Rhodes, 1993). Strength enables players to accelerate and maintain strong strides at top speed (Behm et al., 2005; Twist & Rhodes, 1993). As per Bompa & Buzzicehlli (2015), there is a correlation between strength and power, since a stronger muscle can move heavier loads at higher velocities, resulting in increased maximum power. Power provides a meaningful contribution to skating speed (Behm et al., 2005). Furtherly, the ability to generate force quickly relates strongly to dynamic team sports where the required force production is time limited (Bompa & Buzzichelli, 2015; McArdle et al., 2015).

Maximum strength is strongly related to muscle size, as muscle mass is a major predictor of force production capability (Jones et al., 2008; McArdle et al., 2015; Moss et al., 1997). In fact, skeletal muscle generates between 16 and 30 newtons per square centimetre of muscle cross-sectional area (McArdle et al., 2015). An athlete's body index, which is a critical physical component used for drafting players in the NHL, consists of height, lean mass and muscular development (Burr et al., 2008). An increase in lean body mass has shown to have positive relationship with increased muscle strength and power (Häkkukinen et al., 1985).

1.3.2 Physical sturdiness

Due to the nature of the game with high intensity bouts and high-speed collisions, ice hockey players require exceptional muscular strength to withstand challenges from opponents (Cox et al., 1995; Orvanová, 1987; Twist & Rhodes, 1993). According to Burr et al. (2008), in these intense physical challenges muscle size is also crucial, as larger and stronger athletes will be at an advantage. Therefore, the athletes will benefit from possessing adequate muscle mass and muscle strength to become sturdier in bodychecking and one-on-one altercations (Montgomery, 1988; Twist & Rhodes, 1993).

Alongside improving sport performance, appropriate developed muscle strength and muscle mass can also reduce the risk and severity of injury (Nightingale, 2014; Twist & Rhodes, 1993). Absolute strength ensures the athlete is prepared for contact with other players, rigid boards, the ice surface, and the goal (Twist & Rhodes, 1993). The added muscle mass helps with protection of bones and joints during physical altercations (Burr et al., 2008; Twist & Rhodes, 1993). Strength development also helps against muscle injuries that frequently occur during explosive movements. It's also important that the strength is well balanced between muscle groups, as muscle imbalance makes a joint susceptible for injuries (Twist & Rhodes, 1993).

1.4 Strength training

Strength training is exercise that has the goal to develop or maintain the ability to create the highest amount of force possible at a specific type of muscle action (Raastad et al., 2015). A common method of implementing strength training involves the action of raising and lowering an external resistance (e.g., dumbbells and barbells), known as dynamic constant external resistance (DCOR) (McArdle et al., 2015. Athletes utilizes DCOR-training to develop strengh, muscle mass and power (Pareja-Blanco et al., 2014; Suchomel et al., 2018; Suchomel et al., 2016). Coaches usually prescribe external loads relative to an individual's 1RM in a specific exercise (Weakley et al., 2017). Additionally, athletes are commonly assigned to complete a specified number of sets and repetitions (e.g., 5 sets of 10 repetitions) based on the desired goal of the training session or period (Banyard et al., 2019).

Table 4 Recommendations for different forms of strength training for advanced athletes

Type of strength	Load (% of 1RM)	Sets	Repetitions	Rest intervals (min)	Frequency (sessions per week)	Exercises (per muscle group)
Maximum strength	> 80	4-8	1-5	< 3	4-6	1-4
Hypertrophy	70-85	2-4	6-12	2-3 1-2	4-6	2-5
Power	30-50	4-8	1-5	< 3	4-6	1-3
Muscular endurance	20-60	1-3	> 15	0-2	4-6	2-4

Tab.4 An overview of recommendations in key training variables for different types of strength training (Raastad et al., 2015).

Abbreviations: 1RM = one repetition maximum. Min = minutes.

1.4.1 Principles of strength training programming

There are three fundamental principles to consider when designing a strength training program: specificity, overload, and progression (Kraemer & Ratamess, 2004; Raastad et al., 2015; Sheppard & Triplett, 2016). Specificity refers to the approach of tailoring an athlete's training in a targeted manner to elicit specific adaptations or training outcomes. In the context of resistance training, specificity encompasses various factors, such as the muscles involved, movement patterns, and the nature of muscle action, including movement speed and force application. It is important to note that specificity does not necessarily mean replicating the exact movement patterns of the sport. The concept of SAID (Specific Adaptation to Imposed Demands) is highly relevant here, as it suggests that the type of demand placed on the body determines the specific adaptation that will occur. In other words, the body adapts specifically to the demands placed upon it during training. By understanding and applying the principle of specificity, trainers can design training programs that target the specific physiological and performance adaptations desired for a particular sport or activity (Sheppard & Triplett, 2016).

The overload principle in athletic training entails pushing athletes beyond their typical workout intensity to induce a forced adaptation (Kraemer & Ratamess, 2004). This principle recognizes that in order to continue making progress and stimulating improvements, athletes need to continually challenge their bodies beyond what they are accustomed to (Sheppard & Triplett, 2016). Resistance training can increase loads assigned to exercises, but other subtle changes, such as more sessions, added exercises, complex or simple workouts, shorter rest periods, or a mix of these, can also be effective (Kraemer & Ratamess, 2004; Sheppard & Triplett, 2016). The key is to stress the body at a higher level than it's used to, without overtraining. To continue improving performance, training intensity must progressively increase (Kraemer & Ratamess, 2004; Sheppard & Triplett, 2016).

Progression provides a practical application of the overload principle, and forms the basis of most resistance training programs (McArdle et al., 2015). When progression is applied properly, it promotes long term benefits. While resistance is typically the focus of intensity progression, there are other methods of increasing the training intensity, such as adding more exercises, training sessions, and altering the technical demands of an exercise. The key is to customize progression based on the athlete’s training status and to introduce it gradually and systematically (Sheppard & Triplett, 2016).

Training volume, intensity and frequency are considered key variables for strength training (Kraemer & Ratamess, 2004; Raastad et al., 2015). Volume is the total work performed during a session or a period. This refers to the selection and number of exercises, sets, repetitions, and rest intervals (Bompa & Buzzichelli, 2015; Raastad et al., 2015). The number of repetitions performed per set can also refer to degree of exhaustion, which is also considered a training variable (Vieira et al., 2022). Intensity refers to the degree of mobilization or effort, and is typically expressed as a percentage of 1RM (Bompa & Buzzichelli, 2015; Raastad et al., 2015). However, degree of mobilization can also refer to the velocity movement that is utilized (González-Badillo et al., 2011; Vieira et al., 2022). Lastly, training frequency is quite simply how often a session is repeated (Kraemer & Ratamess, 2004; Raastad et al., 2015). In order to create a successful strength training program, these key variables must be appropriately and progressively manipulated (Bompa & Buzzichelli, 2015; McArdle et al., 2015).

1.4.2 Periodization

Coaches uses periodization to manipulate foremostly training volume and intensity to ensure that the athlete's peak performance always coincides with major competition (Bompa & Buzzichelli, 2015; McArdle et al., 2015). Periodization subdivides a specific strength training period, such as 1 year (macrocycle), into smaller phases (mesocycles), and further into condensed segments (microcycles) (McArdle et al., 2015). In essence, the training model progressively decreases training volume and increases intensity as duration of the program progresses to maximize gains in muscular strength and power (Bompa & Buzzichelli, 2015; McArdle et al., 2015). Fractionating the macrocycle into components allows multiple ways of manipulating training intensity, volume, frequency, sets, repetitions, rest intervals, movement velocity and degree of exhaustion to prevent overtraining. Periodization can also ensure variety in the athlete's strength program and reduce negative overtraining or "staleness" (McArdle et al., 2015).

A general design for periodization divides a typical macrocycle into four distinct phases (McArdle et al., 2015) (Table 5). All periodization strength programs begins with a general anatomical adaption phase by incorporating hypertrophy training, which prepares the athlete for the next phases (Bompa & Buzzichelli, 2015). As competition approaches, training volume decreases, while training intensity concurrently increases (McArdle et al., 2015).

Additionally, one of the goals of periodization, is to transfer gains in strength into power and muscular endurance, concurrently with the schedule closing into major competition (Bompa & Buzzichelli, 2015) For the upcoming competition, the athlete repeats the periodization cycle (McArdle et al., 2015).

Table 5 General design for a periodization cycle

#	Phase	Emphasize	Volume	Intensity	Other
1	Preparation phase	Modest strength (hypertrophy)	High, 3-5 sets, 8-12 repetitions	Low, 50-80% 1RM	Flexibility and, aerobic and anaerobic training
2	First transition phase (competition preparation)	Strength development (maximum strength and/or power)	Modest, 3-5 sets, 5-6 repetitions	Moderate, 80-90% 1RM	Flexibility and interval aerobic training
3	Competition phase (in season)	Selective strength development (maximum strength and/or power, and/or muscular endurance	Low, 3-5 sets, 2-4 repetitions	High, 90-95% 1RM	Short periods of interval training that emphasize sport-specific movement
4	Second transition phase (active recovery)	Recreational activities	Low	Low	Active recovery by incorporating different activity modes

Tab. 5 An overview of a general design for a periodization cycle showcasing manipulation of key training variables intensity and volume. The cycle is divided into four phases which aligns with the athlete's seasonal phase, and subsequently repeated when completed (Gjerset et al., 2015; McArdle et al., 2015). Abbreviations: 1RM = one repetition maximum.

1.5 Autoregulation

The intensity of a set is usually prescribed based on a pre-determined percentage of the athlete's maximum strength (1RM), commonly known as standardized percentage-based training (PBT) (Bompa & Buzzichelli, 2015; Larsen et al., 2021; Thompson et al., 2020).

There are however numerous limitations with PBT, primarily being acute performance fluctuations and short term chronic physiological adaptions, leading to acute changes in 1RM (Greig et al., 2020; Padulo et al., 2012; Zourdos et al., 2015). Prescribing loads based on a single 1RM can also cause other challenges as its highly individual, or as if abnormal performance or improper administration were present during 1RM testing (Cooke et al., 2019; Helms et al., 2016; Weakley et al., 2021). This can lead to the training stimulus applied for a training program being inappropriate for the intended outcome (Helms et al., 2016).

Based on that fluctuations in performance can occur, different training prescriptions methods referred to as autoregulation has become popular to increase maximum strength (Helms et al., 2017). Autoregulation is a resistance training prescription approach to adjust training variables, based on the daily individual fluctuations in fitness, fatigue and readiness of the athlete (Greig et al., 2020; Larsen et al., 2021; Shattock & Tee, 2022). In general there are two types of autoregulation, subjective and objective autoregulation (Larsen et al., 2021).

1.5.1 Subjective and objective autoregulation

Subjective autoregulation have been utilized in the realm of training since researcher DeLorme (1945) conducted experiments on the rehabilitation of service men after World War II. DeLorme later modified his original program to include three progressive sets of ten repetitions, which he called progressive resistance exercise (Larsen et al., 2021). Furthermore, Borg (1970) introduced the first rating of perceived exertion (RPE), originally intended for endurance training. The Borg RPE could be utilized to train towards an RPE, by subjectively rating intra-effort on a scale from 6-20 to reflect heart rate. Borg (1982), modified the RPE scale for resistance training ranging 1-10 (CR 10 RPE scale). However, the CR10 RPE scale has shown to be unreliable for resistance training as participants reached failure when reporting 6.9-8.1 in intensity (Pritchett et al., 2009; Shimano et al., 2006). The CR10 RPE was therefore adapted by Tuchschere (2008), where the RPE was determined by how many estimated repetitions in reserve (RIR) the participant had left before reaching failure. RIR has demonstrated efficacy among experienced powerlifters (Helms et al., 2017), although its effectiveness may be limited for novice lifters or when assessing high repetition sets (Steele et al., 2017; Zourdos et al., 2021).

Alongside technological advancements, new objective methods such as velocity-based training (VBT) have merged to enhance the accuracy of intensity and volume measurement in training (Banyard et al., 2017; Banyard et al., 2018; Larsen et al., 2021). VBT encompasses various training approaches and utilizes validated measurement tools to track movement velocity during exercises (Jovanović & Flanagan, 2014; Weakley et al., 2021). By accounting for acute performance fluctuations, VBT estimates the daily 1RM, employing intensity and volume adjustments. Successful implementation of VBT require that maximum intensity is performed in the concentric phase, and that each subsequent repetition can be measured (García-Ramos, Torrejón, et al., 2018; González-Badillo et al., 2017; Sánchez-Medina et al., 2017).

1.5.2 Why velocity?

According to Weakley et al. (2021), objective autoregulation utilizes velocity for three primary purposes. Firstly, as external resistance increases, lifting velocity decreases, reaching it lowest point when approaching 1RM (Izquierdo et al., 2006; Weakley et al., 2020a). Secondly, velocity and intensity exhibit a nearly linear relationship across different exercises and submaximal loads (Conceição et al., 2016; García-Ramos, Pestaña-Melero, et al., 2018). Thirdly, as fatigue accumulates, velocity decreases due to reductions in muscle fibre shortening speed and force generation (González-Badillo et al., 2017; Sánchez-Medina & González-Badillo, 2011). Additionally, and in important application of VBT is the monitoring of fatigue and exertion during training through the use of velocity loss thresholds and velocity-exertion profiles(García-Ramos, Pestaña-Melero, et al., 2018; González-Badillo & Sánchez-Medina, 2010; Jovanović & Flanagan, 2014; Sánchez-Medina & González-Badillo, 2011). Velocity loss partly reflects the metabolic fatigue present in a working set, with greater velocity loss observed as sets approaches failure (Sánchez-Medina & González-Badillo, 2011).

1.6 Practical application of VBT

By implementing velocity loss thresholds, training volume can be controlled, and the amount of induced fatigue can be limited based on the training goal (Jovanović & Flanagan, 2014). Another use of VBT is to set specific target velocities or velocity ranges for each repetition, particularly useful for optimizing power output (Loturco et al., 2017; Ramírez et al., 2015).

Maintaining a consistent velocity zone ensures that the athlete works at a consistent intensity level, unlike PBT where percentages can vary day to day (González-Badillo & Sánchez-Medina, 2010). Furthermore, VBT also serves as a feedback tool to enhance performance by promoting competitiveness and motivation (Mann et al., 2010; Randell et al., 2011; Weakley et al., 2021). Immediate feedback from each set allows practitioners to adjust the training load based on daily fluctuations (Włodarczyk et al., 2021). It has been demonstrated that such feedback can improve performance in professionals (Argus et al., 2011; Nagata et al., 2020). Consequently, VBT has been proposed as a more accurate methods for prescribing training loads that enhance both general and specific performance (Włodarczyk et al., 2021). However, the accuracy of some devices used to measure movement velocity is limited (Lake et al., 2019; Lake et al., 2018; Pérez-Castilla et al., 2019; Scott et al., 2016).

1.6.1 Velocity loss

Velocity loss experienced during a set is associated with neuromuscular fatigue (Jukic et al., 2023a; Sánchez-Medina & González-Badillo, 2011; Weakley et al., 2021). By recognizing and monitoring this concept, practitioners can possibly prescribe and control external loads and training volume, regardless of daily fluctuations in fatigue and readiness (Jukic et al., 2023a; Weakley et al., 2021). Additionally, velocity loss thresholds are related to the number of repetitions achievable in a set (González-Badillo et al., 2017; Rodríguez-Rosell et al., 2020b). For example, Sánchez-Medina & González-Badillo (2011) reported that in squats, a 20% velocity loss typically corresponds to 50% of possible repetitions, while a 40-50% velocity loss indicates or close to muscle failure.

Velocity thresholds enable the termination of a set to manage volume and fatigue, facilitating training adaptations (González-Badillo et al., 2017; Jovanović & Flanagan, 2014). High velocity loss thresholds (e.g., 40%) is according to Pareja-Blanco et al. (2017a) more beneficial for muscle hypertrophy, while conversely, low-moderate (< 20%) velocity loss thresholds might benefit power and strength output (Jukic et al., 2023a; Pareja-Blanco et al., 2017a). However, it is important to establish lower and upper limits for velocity loss thresholds to optimize muscle adaptations. Setting thresholds below 10% does not induce sufficient fatigue to ensure muscle adaptations, while exceeding 40% does not seem promote further strength and hypertrophy adaptions (Pareja-Blanco et al., 2020b). During different stages of the season, implementing varying velocity thresholds can be advantageous. Moderate-high (20-40%) can possibly be introduced during off-season to induce hypertrophy adaptations and conditioning of lean body mass (Jukic et al., 2023a) Alternatively, low-moderate (10-20%) thresholds might be beneficial during in-season to help reduce fatigue and maintain athletic performance (Weakley et al., 2020b; Weakley et al., 2020c; Włodarczyk et al., 2021).

2.0 Methodological discussion

2.1 Subjects

The sample size of this current study was initially n = 43, consisting of 22 females and 21 males. Unfortunately, the female group dropped out of the intervention in week 5, while the attrition of six males occurred during the course of the study. As a result, the final sample size (n = 15) for the data analysis was less than half of the originally planned design. Sample size calculation represents a pivotal aspect of RCT’s, which includes a reasonable estimation of expected dropouts (Batterham & Atkinson, 2005; Cramer et al., 2016; Kadam & Bhalerao, 2010). According to Andrade (2020); Kadam & Bhalerao (2010), sample size calculations can be conducted using programs like G*Power or calculation formulas, which was not applied for this study and can therefore be viewed as a limitation (Batterham & Atkinson, 2005).

The small sample size and high dropout, raise concerns regarding the study’s statistical power to effectively address the research question (internal validity), and of the increased risk of false negative results (type 2 error) (Andrade, 2020; Cramer et al., 2016; Friedman et al., 2015). According to Pareja-Blanco et al. (2020b), 12 subjects per allocated group would satisfy alpha (0.05) and power (0.95) assumptions, which highlights the concern of small sample size in each allocated group in this study (VL20 = 8, VL40 = 7). The sample size of each allocated velocity loss group is also smaller than in similar conducted VBST studies, including > 10 participants in each group (Alcazar et al., 2021; Martinez-Canton et al., 2021; Pareja-Blanco et al., 2020b; Pareja-Blanco et al., 2017a; Rissanen et al., 2022).

The subjects in this study were semi-professional ice hockey players, which represents a small population, making it a narrow target group. Narrow target groups makes the result of a study often difficult to generalize, and in conjunction with the small sample size and high dropout rate, might not add any future benefit to science research (Andrade, 2020; Simon, 2001). However, RCT’s often target narrow groups of the population for improving the efficiency and precision of the study (Simon, 2001). Thus, theoretically increasing the sample size would have been ideal, but might have been challenging to formalize given the small population.

Including the female's group data for gender comparison was not an option as they dropped out and didn't finish the training intervention. To be able to directly compare between genders, it would have required the male group performed a mid-test session (in week 6) given the male's training duration was three weeks longer than the female group. This was not possible to conduct in an already congested competitive schedule. A comparison between the female VL20 group and VL40 could also have been an option, but their training adherence was poorly distributed between subjects, while they also performed post-test in the same week as the male group (week 9), thus many weeks after their last training session.

The dropout of the female group seems to be linked to a combination of training status and match day results. The female group was new to resistance training that induces high amount of fatigue. According to Berlin et al. (2006); Shang et al. (2012), increased amounts of fatigue seems to produce higher rates of dropout, which is also reflected by a comment from their coach, reporting increased fatigue and "heavy legs". In-season game performance is a variable of great importance when it comes to motivation, and in week 5 of the intervention, the female group played three games in three days (Blanchard & Vallerand, 1996; Vallerand & Losier, 1999). Unfortunately, they lost all three games, which was seen as a breaking point for the female group, ultimately removing any motivation for completing the remaining duration of the intervention. Precautions were taken during this week by implementing a miniscule deload, lowering the sets performed from 3 to 2. Further adjustments were suggested, but the female group did not want to continue the study intervention after the three consecutive losses.

2.2 Experimental design

This present study was conducted as a randomized controlled experiment, an experimental variant of randomized controlled trial (Royall, 1991). RCT's are performed under controlled conditions with random allocation of subjects into comparison groups (Bhide et al., 2018; Hollon, 2015). According to Royall (1991) experiment trials is best suited for interventions where there is uncertainty of which assignment is better. RCT's are frequently referred to as the" gold standard" when searching for causal conclusions (Cartwright, 2010; Deaton & Cartwright, 2018; Ginsburg & Smith, 2016; Hariton & Locascio, 2018; Kabisch et al., 2011). Causal conclusion refers to the cause-effect relationship between an intervention and outcome (Bhide et al., 2018; Cartwright, 2010; Hariton & Locascio, 2018). The causality also determines the internal validity, which is the degree which an outcome can be attributed to the experimental treatment rather than extraneous variables (Behi & Nolan, 1996; Campbell & Stanley, 1963; Hollon, 2015).

A study that is internally valid means that the result of study holds a high probability of truth. In fact RCT’s are designed to establish causal conclusion, and if conducted appropriately the design itself ensures that a positive result in the experiment confers a high probability on the causal conclusion (Cartwright, 2010). For RCT’s to provide accurate and dependable assessments of effectiveness, they must be conducted meticulously, including concealing allocation, blinding, and using an adequate sample size (Hariton & Locascio, 2018).

No study is likely to prove causality on its own, but one strength with RCT’s is the randomisation process, which is not possible in any other study design (Hariton & Locascio, 2018; Tarnow-Mordi et al., 2017). The randomisation process reduces much of the bias inherent from other study designs by balancing observed and unobserved subject characteristics in large studies (Ginsburg & Smith, 2016; Hariton & Locascio, 2018; Royall, 1991). Balancing of subject’s characteristics was performed by stratification of their observed squat 1RM value at pre-test. However, randomizing is completely futile if the sample size not adequate compared to the number of variables. Considering the sample size, it’s possible that this current study does not have a balance of variables (D'Agostino & Kwan, 1995; Kunz & Oxman, 1998). Increasing the sample size does not eliminate factors threatening validity, however it will likely make the randomization process more balanced increasing the confidence in making causal conclusions (Deaton & Cartwright, 2018; Hollon, 2015).

Blinding can help eliminate unconscious information bias, by using placebo to hide treatment information to the subjects and researchers (Bhide et al., 2018; Simon, 2001). Blinding is important if the subjects attitude can affair their reliability in participation or training-induced responses (Kabisch et al., 2011). Additionally, when the researchers assessing outcomes are not blinded, there is an increased risk of observer bias (Hróbjartsson et al., 2014). With the available resources and due to the nature of training studies, blinding was not possible and can be viewed as a weakness (Hariton & Locascio, 2018). With further resources it might have been possible to conduct the test with researchers that were blinded for the groups. However, according to Simon (2001) the absence of blinding does not present a fatal flow, with non-blinded outcomes typically favouring experimental design (Hróbjartsson et al., 2014).

Nonetheless, RCT's are not without limitations. Undertaking an RCT can be a complex process that involves several challenges including: devising and conducting the experiment, analysing data, interpreting findings, and construing results (Bhide et al., 2018). The reliability of the data is heavily reliant on the appropriateness of the methodology employed at each stage of the research process, which is crucial to ensure results credibility (Kabisch et al., 2011). Additionally, there are several extraneous factors in the process that might threat the internal validity (Campbell & Stanley, 1963, p. 5; Hollon, 2015).

Changes observed following an intervention is not necessary solely due to the intervention, as it can be a consequence of factors independent from the intervention (Hollon, 2015). Campbell & Stanley (1963) points out several factors that might have influenced the outcomes of this study: History, which refers to outside events that can have intervened during the intervention, or maturation, changes that have taken places as consequence of development. Instrumentation, which refers to the potential sources of measurement error, such as changes in the measurement tools, calibration methods, or the people involved, that can affect the validity and reliability (Campbell & Stanley, 1963, p. 5; Hollon, 2015). Randomization and stratifying on possible confounds does make sure RCT's control for such factors, but it can also be undermined by attrition (differential mortality) (Campbell & Stanley, 1963, p. 5; Hollon, 2015). An experiment is considered internal valid when all possible extraneous variables have been controlled (Behi & Nolan, 1996).. A pretest -posttest experimental-control group design is regarded as the gold standard among experimental design, as it controls for most of the factors threatening internal validity, utilizing a control group (Cahit, 2015). Inclusion of a control group that trained without feedback or didn't train at all would therefore be beneficial to ensure that the outcomes of this intervention is cot caused extraneous factors (Cahit, 2015).

2.3 Training intervention

This study prescribed an 8-week VBT-intervention, which is consistent with the median duration (8 weeks) of 19 longitudinal VBT-interventions systematically reviewed by Jukic et al. (2023a). 8-week duration is commonly employed by several studies covered by Jukic et al.

(2023a) with the same velocity loss thresholds, indicating that an 8-week intervention is sufficient to observe an effect, but also convenient for comparisons with similar studies (Martinez-Canton et al., 2021; Pareja-Blanco et al., 2020b; Pareja-Blanco et al., 2017a; Rissanen et al., 2022). Further investigation of Jukic et al. (2023a) suggests that 16 session distributed over two sessions per week is a common approach employed by VBT-interventions with similar duration using back squats (Martinez-Canton et al., 2021; Pareja-Blanco et al., 2020b; Pareja-Blanco et al., 2017a; Rissanen et al., 2022; Rodríguez-Rosell et al., 2020a). Given an increase in weekly sets might elicit further hypertrophy gains, three rather than two weekly sessions might have been more beneficial for this study (Refalo et al., 2023; Schoenfeld et al., 2017). However, two sessions per week was in align with the ice hockey team's schedule having two lower body sessions per week. Taking into account the high training status of the subjects, a prolonged intervention (i.e. 10-12 weeks) might have be more beneficial, as eliciting further strength gains for athletes become increasingly challenging as they reach their genetic ceiling (Grgic et al., 2022).

Considering additional training sessions was not convenient with the team's schedule, an increase in sets per session (i.e., 4-5) could have been an option to further stimulate strength and hypertrophy gains. The choice of sets (3) is consistent to that of longitudinal VBT-studies, consisting of subjects with > 1 year of recreational resistance training (Jukic et al., 2023a). However, Rissanen et al. (2022) progressively overloaded the subjects by increasing the number of weekly (2 sets week 1-2, 3 sets in week 2-4, and interchanging 4-5 sets from week 4-8). A similar approach could have been utilized in this study rather than only increasing the external load by 2.5kg in week 5 and 7. Intra-set rest interval (< 3 minutes) was shorter than the majority of longitudinal studies in Jukic et al. (2023a), which opted for 4 minutes. The subjects in this current study received shorter time to recover, suggesting that a higher neuromuscular fatigue was induced compared to others. However, rest interval is a variable that could have been manipulated over the course of the study, possible lowering the rest interval, as Raastad et al. (2015) suggests 2-3 minutes rest interval when using 70-85% 1RM load.

The male team was largely familiar with regular resistance training, while the female team was less so, but none of the teams had previous experience with VBT. Therefore, a familiarization process was introduced in week 1 of the intervention, ensuring the subjects were familiarized with VBT by utilizing velocity loss thresholds. Implementing a familiarization process is according to Jukic et al. (2023a) highly recommended, as it reduces the risk of bias. Both velocity loss groups in the male and female team performed back squat until reaching 20% velocity loss, ensuring familiarization to VBT-training utilizing velocity loss thresholds. Furtherly, given the high total training volume the subjects experienced during in-season, it was also important to regulate their training output from back squats. Therefore, autoregulation with two velocity loss thresholds (20%/40%) was prescribed to autoregulate the subject's volume based on daily fluctuations in fitness, readiness, and fatigue (Greig et al., 2020; Larsen et al., 2021; Shattock & Tee, 2022).

However, a distinguishment from other VBT-studies is the usage of free weight back squats, opposed to smith-machine back squats (Jukic et al., 2023a). In another study conducted by (Jukic et al., 2023b), there are raised concerns about the effectiveness of prescribing and regulating training intensity and volume with velocity loss thresholds for free weight back squat. The reasoning behind this is mainly that there is high variability between subjects (high standard deviation) in the number of completed repetitions with free weight back squat when assigned to the same velocity loss threshold (Jukic et al., 2023b). Despite, although 40% assignment would theoretically result in higher volume than 20% assignment, the number of completed repetitions might be highly individual and vary across training sessions, suggesting the experienced fatigue during a set largely comes down to individual physiology than the velocity loss threshold itself (González-Badillo et al., 2017; Jukic et al., 2023b; Sánchez-Medina & González-Badillo, 2011).

Finally, the findings of Jukic et al. (2023b) also questions the prescription of velocity loss thresholds based on which phase of the season the athletes are present in (Jukic et al., 2023a; Włodarczyk et al., 2021). High (> 30%) velocity loss thresholds are usually prescribed during off-season since its commonly thought to induce hypertrophy adaptations (Jukic et al., 2023a; Pareja-Blanco et al., 2017a). Conversely, low (< 15%) and moderate (15-30%) velocity loss are usually prescribed during in-season, since its commonly thought to reduce fatigue, and provide benefit for power and strength respectively (Jukic et al., 2023a; Weakley et al., 2020b; Weakley et al., 2020c). Interestingly, this present study induced moderate-high velocity loss during in-seasons, which is the opposite procedure suggested in previous literature. However, since the velocity loss-repetition relationship seems to be individual, is difficult to speculate to which degree of exhaustion each subject experienced.

2.4 Measurements

Standardized procedures and precise equipment are crucial for valid and reliable performance assessments in sports (Haugen & Buchheit, 2016). The quality of the data in these assessments is affected by both reliability and validity (Golafshani, 2003). Reliability refers to the reproducibility or consistency of a test with the same individuals, while validity refers to the extent to which it measures what is intended to measure (Golafshani, 2003; Will G. Hopkins, 2000). Better reliability implies better precision of single measurements and better tracking of changes in measurements in research or practical settings (Will G. Hopkins, 2000). For high-performing athletes, the test-retest reliability and within-subject variation are essential to observe true changes in performance (Will G Hopkins, 2000). Test-retest reliability refers to the consistency in measurements when they are repeated (Will G. Hopkins, 2000; Hopkins et al., 2001). Especially when they are repeated over time, several factors (biological, equipment, procedures) can affect the consistency of measurements. Lack of consistency makes the test results potentially misleading and counterproductive (Will G. Hopkins, 2000). A simple, adaptable form of within-subject variation is the typical error of measurement, the standard deviation of an individual's repeated measurements. In sport medicine, the typical error is best expressed as coefficient of variation (CV) in percentage of mean (Will G. Hopkins, 2000).

2.4.1 Back squat 1RM

1RM testing of back squat was chosen due to its widespread preference among athletes, mainly due to it being essential for being well associated with performance in a plethora of sports (Braidot et al., 2007; Escamilla, 2001; Miletello et al., 2009; Myer et al., 2011; Myer et al., 2005). Back squat necessitates the coordinated interaction of primarily the hip, thighs, and back musculature, which are important muscle groups for explosive athletic movement such as sprinting, jumping and lifting (Braidot et al., 2007; Escamilla, 2001; Escamilla et al., 2001).

At both pre-test and post-test stages, the subjects underwent a series of assessments during the first test session. These assessments were carried out in a specific order, beginning with a 30m sprint off ice, followed by CMJ, and concluding with the back squat 1RM test. This procedural arrangement was designed to avoid subjecting the participants to any excessively demanding tests during the test session. The back squat 1RM test was conducted in a similar manner at both pre-test and post-test, beginning with 50% (self-estimated as pre-test) of 1RM and gradually increasing the weight increments of 10-15kg, and smaller increments (2.5-5.0kg) leading up to the 1RM. The initial increase of load differs from other VBT-interventions which increased the weight with increments of 10-15kg until a given mean propulsive velocity (MPV) was reached (i.e., 0.5 m/s or 0.6 m/s) (Pareja-Blanco et al., 2020a; Rissanen et al., 2022). However, the usage of smaller increments (2.5-5.0kg) leading up to the 1RM is consistent with (Pareja-Blanco et al., 2020a; Rissanen et al., 2022). Additionally, intra-set rest interval (< 3 minutes) for loads proximate to 1RM is sufficient compared other studies (Lindberg et al., 2022b; Pareja-Blanco et al., 2020a; Rissanen et al., 2022).

Performing a repetition projected to be 1RM was conducted in a manner consistent with that reported in numerous studies (Braidot et al., 2007; Brocki & Bohlin, 2004; Escamilla, 2001; Schoenfeld, 2010; Swinton et al., 2012). The barbell was securely positioned on the back of the shoulders at the level of the acromion, with a shoulders-width grip. This positioning was implemented to exert greater pressure on the bar and maintain a straight back, reducing strain on the lumbar spine (Braidot et al., 2007; Escamilla, 2001). The subject was then instructed to perform a continuous descent by flexing the hips, knees, and ankles until reaching the desired squat depth, where the femur is parallel to the floor (Escamilla, 2001). This depth aligns with the standards mentioned in other relevant studies (Brocki & Bohlin, 2004; Schoenfeld, 2010). Prior to ascending, the practitioners provided verbal permission and encouragement to initiate triple extension of the hips, knees and ankles in continuous motion until the subject returned to the starting position (Brocki & Bohlin, 2004; Escamilla, 2001; Schoenfeld, 2010). If the repetition was completed successfully, the load was increased by 2.5kg for the next attempt. This progressive loading method is similar to that employed by Lindberg, Solberg, et al. (2022b), and was used until reaching a point where the subject was unable to perform the repetition. Conversely, if the subject failed to complete the repetition, a similar adjustment was made by reducing the weight by a minimum of 2.5kg until a successful repetition could be achieved.

The one repetition maximum (1RM) assessment is a well-established, valid, and reliable method of determining maximum strength in the lower body (Hopkins, 2010; Matuszak et al., 2003). It has been demonstrated by Grgic et al. (2020) to have good-to-excellent retest reliability, regardless of i.e., exercise, and the reliability seems to be even higher when conducted on athletes (Hopkins et al., 2001; Tagesson & Kvist, 2007). However, Lindberg, Solberg et al. (2022b) implies that when 1RM-tests are employed for back squats it should be used with caution, scoring the highest test-retest variation among common lower body strength tests. Others have reported a typical error ranging from 0.3-12.1% regardless of training status and familiarization process (Grgic et al., 2020). The range of typical error % is relatively wide compared to i.e., sprint test (1.1-3.3%) (Altmann et al., 2019; Haugen et al., 2012; López-Segovia et al., 2015). In contrast Seo et al. (2012) reported a CV of 3.5%, although highest of lower body tests. Nonetheless, back squat 1RM seems to be generally safe when applied with a standardized protocol and controlled by the same practitioner (Grgic et al., 2020; Lindberg et al., 2022b).

2.4.2 Leg press Fmax

The leg press machine by Keiser is a device commonly utilized by athletes to measure FV-variables of the lower limbs. Rather than weight-based exercises, the pneumatic leg press utilizes compressed air as resistance, making it minimally influenced by inertia and bodyweight (Frost et al., 2010; Lindberg et al., 2021a). It's convenient to use, requiring minimal technique as the individual is seated in a fixed seated position, making it suitable for standardized tests. Thus, increasing the reliability of the device compared to i.e., free weight tests like counter movement jump and squat jump (Janicijevic et al., 2020; Janicijevic et al., 2021; Williams et al., 2018a; Williams et al., 2018b). The subjects were seated in the same position (80-90 degrees angle) at both tests, performing the same 10 repetition protocol, of which a force-velocity profile was calculated in the Keiser Sport (A420) software.

Due to utilizing compressed air as resistance, it requires no need for decelerating a heavy external resistance when performing maximal assessments. As the resistance is not influenced by acceleration, the leg press can assess extremely low resistances. Therefore, the leg press device can obtain valid measurements over a wide range of forces and velocities, i.e., Fmax within a range of ± 5% . (Lindberg et al., 2021a). Fmax FV-variable is used to estimate theoretical maximum force and was therefore the FV-variable included for this study (Lindberg et al., 2021a; Lindberg et al., 2021b). Additionally, due to the lower extrapolation, it is possible that FV-variables can be obtained with higher reliability using a pneumatic leg press device compared with those of vertical jumping (Lindberg et al., 2021b; Redden et al., 2018). The test-retest reliability for the leg press device has shown reproducibility for the Fmax-variable with a CV of 3.7 ± 1.4% - 4.2 ± 1.3%, which is better than that of CMJ performed on a force platform (CV 5.1 ± 1.8% - 8.6 ± 2.6%) (Lindberg et al., 2021b).

2.4.3 Muscle size

Muscle size was measured with real time brightness mode (B-mode) ultrasound of the subject's vastus lateralis and rectus femoris, measuring muscle thickness. Ultrasound imaging was performed by using LogicScan 129 CEXT 1-Z REV;B, which is a portable equipment used in several field studies (Bakenecker et al., 2020; Bakenecker et al., 2022; Bjørnsen et al., 2016; Bjørnsen et al., 2021; Bourdier et al., 2021; Hahn et al., 2017; Lindberg et al., 2022a). Magnetic resonance imaging (MRI), computerized tomography (CT) and dual energy X-ray absorptiometry (DEXA) are the methods considered to have the highest level of validity and reliability for assessing skeletal muscle mass (Mitsiopoulos et al., 1998; Sanada et al., 2006). However, these methods are particularly expensive, time consuming, and not easily accessible (Miyatani et al., 2002). Therefore, B-mode ultrasound has several advantages compared to CT, MRI, and DEXA when conducting a field study. It is portable, cost-efficient, and serves as a safe (non-invasive) and convenient tool to use (English et al., 2012; Koppenhaver et al., 2009; Pillen & van Alfen, 2011).

The validity and reliability of B-mode ultrasound has been investigated in several studies (Betz et al., 2021; Cartwright et al., 2013; Eime et al., 2013; Hebert et al., 2009a; Hebert et al., 2009b; Miyatani et al., 2000; Miyatani et al., 2002). A systematic review by Pretorius & Keating (2008) concluded that ultrasound is a valid option for measuring muscle thickness compared to "gold standard" methods such as MRI and CT. Similarly, another systematic review by Perkin et al. (2003) found consistent results, with all 11 included articles identifying ultrasound as a valid and reliable tool for assessing muscle thickness under controlled conditions

However, Perkin et al. (2003) highlighted the importance of using strict protocols to ensure valid and reliable measurements. According to Herbert et al. (2009b) using mean measurements instead of single measures, has been shown to increase reliability and precision in muscle assessments. In this study, mean measurements were used by measuring three points on an ultrasound image. However Koppenhaver et al., (2009) recommended the use of two means for measurement, resulting in a substantial improvement in reliability and precision, even with a single examiner. Considering Koppenhaver et al. (2009) also reported higher level of measurement error when measurements were performed by a novice examiner, utilizing two means might have increased the precision of the ultrasound imaging.

More specifically, some studies have investigated validity and reliability of measuring muscle thickness of the vastus lateralis and rectus femoris, showcasing promising results (Betz et al., 2021; Ema et al., 2013). Due to its size and being the most meaningful proximal lower limb muscle, vastus lateralis should be considered an ideal index muscle to assess for changes in size after strength training in elite sports (Betz et al., 2021; Minetto et al., 2016). The test-retest reliability for muscle thickness in vastus lateralis has shown to be very good. Additionally, the validity showed good to very good in closeness of agreement with MRI (Betz et al., 2021). Rectus femoris has a possible greater training-induced hypertrophy than the three other muscle of the quadriceps (Housh et al., 1992; Narici et al., 2003). Therefore, rectus femoris might create unique variations of adaption experienced during a training intervention (Ema et al., 2013). B-mode ultrasound imaging of rectus femoris showed adequate reproducibility (CV 2.4 ± 1.4%). Therefore, it can be said by applying a standardized examination protocol, ultrasound imaging of vastus lateralis and rectus femoris is a valid and reliable method of detecting training-induced changes of muscle thickness (Betz et al., 2021; Ema et al., 2013).

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Part 3

Appendices

Appendix 1: Application for ethical approval of the research project

Per Thomas
Byrkjedal

Besøksadresse:
Universitetsveien 25
Kristiansand

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

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

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

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

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

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

FAKTURAADRESSE:
UNIVERSITETET I AGDER
FAKTURAMOTTAK
POSTBOKS 383 ALNABRU 0614 OSLO

Appendix 2: Approval from the Norwegian Centre for Research data

NSD NORSK SENTER FOR FORSKNINGSDATA

NSD sin vurdering

Prosjekttittel

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

Referansenummer

464080

Registrert

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

Behandlingsansvarlig institusjon

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

Prosjektansvarlig (vitenskapelig ansatt/veileder eller stipendiat)

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

Type prosjekt

Forskerprosjekt

Prosjektperiode

15.02.2020 – 31.12.2023

Status

31.05.2021 – Vurdert

Vurdering (2)

31.05.2021 – Vurdert

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

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

OPPFØLGING AV PROSJEKTET

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

Lykke til med prosjektet!

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

17.02.2020 – Vurdert

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Lykke til med prosjektet!

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

Appendix 3: Informed written consent signed by the subjects

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 to ulike protokoller av hastighetsstyrt styrketrening. I dette skrivet gir vi deg informasjon om hensikten med prosjektet og hva deltakelse som forsøksperson vil innebære for deg.

Formål

Formålet med denne studien er å undersøke effekten av to ulike hastighetsfall ved hastighetsstyrt styrketrening. Hastighetsstyrt styrketrening skiller seg fra tradisjonell styrketrening ved at det er hastigheten på løftene som er styrende for hvor mange repetisjoner som gjennomføres i hvert sett. Ved hastighetsstyrt styrketrening er det et prinsipp at vektene skal løftes så raskt som mulig i alle repetisjoner; det vil si maksimal mobilisering i løftefasen som er på vei opp i knebøy, men alltid rolig og kontrollert på vei ned i bremsefasen. Man gjennomfører knebøy på et måleinstrument som gir deg tilbakemelding på løftehastigheten i hver repetisjon («Alphatek» plattform tilknyttet skjerm). Etter hvert som du løfter flere repetisjoner vil hastigheten synke ettersom du gradvis blir mer sliten, du vil da få opp et rødt lys når hastigheten har sunket så mye at du ikke skal gjennomføre 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. Dere vil bli delt i to grupper, hvor den ene gruppen avslutter settet når hastigheten har sunket med 20%, og den andre stopper etter hastigheten er redusert med 40%. Vi ønsker med andre ord å undersøke om det er mest effektivt å gi seg før hastigheten faller betydelig (kun 20% hastighetstap), eller om det er best å løfte hver serie litt nærmere utmattelse (40% hastighetstap).

Hvem er ansvarlig for forskningsprosjektet?

Universitetet i Agder (UiA) er ansvarlig for prosjektet. Prosjektleder er Førsteamanuensis Thomas Bjørnsen (kontaktinformasjon nedenfor).

Hvorfor får du spørsmål om å delta?

Du blir spurt om å delta i prosjektet da du treffer målgruppen som er hockeyspillere hos Stavanger Oilers, med god helse, og du erfaring med styrketrening.

Hva innebærer det for deg å delta?

For å delta krever det at hver deltaker oppgir navn, fødselsår og kontaktinfo. Videre innebærer deltakelse at dere i første fase (uke 41 til 42) tester ulike fysiske parametere som måler fysisk kapasitet (hopphøyde, off- and on ice sprinttid, maksimal styrke og eksplosiv styrke). Vi skal også bruke ultralyd for å måle muskelstørrelse (tykkelse på muskel i fremside lår). Etter disse testene blir dere tilfeldig fordelt til en av to treningsgrupper, og vil trene hastighetsstyrt styrke to ganger i uken de neste åtte ukene under kampsesong (ca. 45-60min per økt). De to treningsøktene er allerede integrert i treningsprogrammet deres for konkurranseperioden dere befinner dere i, som betyr at dere ikke får noe ytterligere treningsbelastning. Treningsøktene i begge grupper har hovedfokus på å utvikle maksimal og eksplosiv styrke i underkroppen, hvor den dominerende øvelsen blir knebøy, gjennomført på Alphatek sin kraftplatform. Etter treningsperioden på 8 uker vil de samme testene som i fase 1 bli gjennomført på ny. Dette gjøres for å undersøke hvilke fremgang alle har hatt i fysisk kapasitet og muskelstørrelse.

Fordeler og ulemper med deltakelse som forsøksperson

I denne studien vil du få oppfølging og veiledning på alle treningsøktene, og treningsprogrammene er laget for at du skal oppnå best mulig økning i maksimal og eksplosiv styrke. Du vil også få innblikk en ny treningsmetode for å utvikle eksplosivitet, i idrettsforskning og få dine personlige 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 kan bli stiv og støl etter spesielt de første treningsøktene, og det er alltid en risiko for skader under testing og trening med tunge vekter. Dette vil imidlertid tilsvare ulemper med den styrketrening som dere allerede har drevet med fra før, og vår erfaring er at det sjelden oppstår skader i studier som dette. En annen mulig ulempe er at underveis i studien kan du ikke trene styrkeøkter på bein utenom det denne studien legger opp til.

Det er frivillig å delta

Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Alle dine personopplysninger vil da bli slettet. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger

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. Kun forskningsleder har tilgang til koblingen mellom måleresultatene og dine personopplysninger. Opplysningene vil anonymiseres når prosjektet avsluttes, noe som etter planen er 31.12.2022. Det vil ikke være mulig å identifisere deg ut fra måleresultatene etter opplysningene er blitt anonymisert.

Hva skjer med personopplysningene dine når forskningsprosjektet avsluttes?

Prosjektet vil etter planen avsluttes 31.12.22 og da vil kodelisten destrueres, noe som betyr at innsamlet informasjonen er anonymisert og ingen opplysninger kan spores tilbake til deg. Anonymisert innsamlede data vil bli slettet fem år etter prosjektslutt, eller når resultatene er publisert. Alle testresultater vil bli behandlet uten navn og fødselsnummer eller andre direkte persongjenkjennende opplysninger. En kode knytter deg til dine opplysninger og testresultater gjennom en navneliste. Det er kun prosjektleder som har adgang til navnelisten og som kan finne tilbake til deg. Det vil ikke være mulig å identifisere deg i resultatene av studien når disse publiseres. Deltakerne kan også bli kontaktet på et senere tidspunkt dersom det skulle bli aktuelt med oppfølgingsstudier. De kan velge å takke nei selv om de er med i treningsintervensjonen.

Hva gir oss rett til å behandle personopplysninger om deg?

Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra Universitetet i Agder (UiA) har Personverntjenester (Norsk senter for forskningsdata) vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Dine rettigheter

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

- innsyn i hvilke opplysninger vi behandler om deg, og å få utlevert en kopi av opplysningene
- å få rettet opplysninger om deg som er feil eller misvisende
- å få slettet personopplysninger om deg
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger

Hvis du har spørsmål til studien, eller ønsker å vite mer om eller benytte deg av dine rettigheter, ta kontakt med:

- *Masterstudenter, Sander Remme (epost: sander.remme@hotmail.com, tlf: 954 29 085) og Nicholas Nyquist (epost: nicholasnyquist@hotmail.com tlf: 977 64 843).*
- *Fysisk trener Oilers, Eirik Haukali, epost: eirik@coretren.no, tlf: 934 44 203*
- *Prosjektleder og førsteamanuensis, Thomas Bjørnsen, epost: thomas.bjornsen@uia.no, tlf: 986 19 299*

- Kontakt vårt personvernombud ved Universitetet i Agder:
  - Rådgiver Ina Danielsen (ina.danielsen@uia.no, +47 452 54 401)

Spørsmål knyttet til Personverntjenester sin vurdering av prosjektet, kan du ta kontakt med:

- Personverntjenester på epost (personverntjenester@sikt.no) eller på telefon: 53 21 15 00.

Med vennlig hilsen

Thomas Bjørnsen	*Sander Remme og Nicholas Nyquist*	*Eirik Haukali*
(Prosjektleder/veileder)	(Masterstudenter)	(Fysisk trener Oilers)

Samtykkeerklæring

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

- ☐ å gjennomføre alle fysiske prestasjonstester (maksimal og eksplosiv styrke, sprint, hopp)
- ☐ å gjennomføre målinger av muskelstørrelse og kroppssammensetning (ultralyd og Inbody)
- ☐ Å gjennomføre styrketreningen tilhørende den gruppe man blir fordelt til

Jeg samtykker til at mine opplysninger behandles frem til prosjektet er avsluttet

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(Signert av prosjektdeltaker, dato)

Appendix 4: Author guidelines Scandinavian Journal of Medicine & Science In Sports

Author Guidelines

Sections

1. SUBMISSION

Thank you for considering *Scandinavian Journal of Medicine & Science in Sports* for the publication of your research.

Due to the large number of inquires we are currently receiving, we will no longer offer comments on the suitability of a paper prior to submission. If you believe your paper to be within scope of the journal, we encourage you to submit so our editors can easily review your submission and follow up with you directly if needed.

Please read carefully the following Guidelines for Authors. As a reminder, the journal aims to publish high quality and impactful articles in the fields of orthopaedics, rehabilitation and sports medicine, exercise physiology and biochemistry, biomechanics and motor control, health and disease relating to sport, exercise and physical activity, as well as on the social and behavioural aspects of sport and exercise.

Following our initial check, all manuscripts are screened by the Editorial Board for suitability for publication; to ensure that they meet essential criteria for sending out to peer review and, subsequently, to be read and cited and, thereby, make a contribution.

Authors should kindly note that submission implies that the content has not been published or submitted for publication elsewhere except as a brief abstract in the proceedings of a scientific meeting or symposium.

New submissions should be made via the Research Exchange submission portal **https://wiley.atyponrex.com/journal/SMS**. For all new submissions, it is required that you indicate which Section Specialty your manuscript falls under. The Section Specialties Areas are used to assign manuscripts to the appropriate editor. Please choose the appropriate Section Specialty from the list provided **in this document**. Should your manuscript proceed to the revision stage, you will be directed to make your revisions via the same submission portal. You may check the status of your submission at any time by logging on to submission.wiley.com and clicking the “My Submissions” button. For technical help with the submission system, please review our **FAQs** or contact **submissionhelp@wiley.com**.

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Click here for more details on how to use Research Exchange.

For help with submissions, please contact: **TBEDeditorial@wiley.com**

We look forward to your submission.

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Scandinavian Journal of Medicine & Science in Sports now offers Free Format submission for a simplified and streamlined submission process.

Before you submit, you will need:

- Your manuscript: this should be an editable file including text, figures, and tables, or separate files – whichever you prefer. All required sections should be contained in your manuscript, including abstract (which does need to be correctly styled), introduction, methods, results, and conclusions. Figures and tables should have legends. Figures should be uploaded in the highest resolution possible. If the figures are not of sufficiently high quality your manuscript may be delayed.References may be submitted in any style or format, as long as it is consistent throughout the manuscript. Supporting information should be submitted in separate files. If the manuscript, figures or tables are difficult for you to read, they will also be difficult for the editors and reviewers, and the editorial office will send it back to you for revision. Your manuscript may also be sent back to you for revision if the quality of English language is poor.
- An ORCID ID, freely available at https://orcid.org. (*Why is this important? Your article, if accepted and published, will be attached to your ORCID profile. Institutions and funders are increasingly requiring authors to have ORCID IDs.*)
- The title page of the manuscript, including:
  - Your co-author details, including affiliation and email address. (*Why is this important? We need to keep all co-authors informed of the outcome of the peer review process.*)
  - Statements relating to our ethics and integrity policies, which may include any of the following (*Why are these important? We need to uphold rigorous ethical standards for the research we consider for publication*):
    - data availability statement
    - funding statement
    - conflict of interest disclosure
    - ethics approval statement
    - patient consent statement
    - permission to reproduce material from other sources
    - clinical trial registration

To submit, login at **https://wiley.atyponrex.com/dashboard?siteName=SMS** and create a new submission. Follow the submission steps as required and submit the manuscript.

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Scandinavian Journal of Medicine & Science in Sports aims to foster inclusive research that reflects the disciplinary, human, and geographic diversity of scientists, clinicians and other health professionals working in this area. Submissions are welcomed from authors of all ethnicities, races, colours, religions, sexes, sexual orientations, gender identities, national origins, disabilities, ages, or other individual status.

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For help with submissions, please contact: **SJMSSedoffice@wiley.com**

2. AIMS AND SCOPE

The *Scandinavian Journal of Medicine & Science in Sports* is a multidisciplinary journal published 12 times per year under the auspices of the Scandinavian Foundation of Medicine and Science in Sports.

It aims to publish high quality and impactful articles in the fields of orthopaedics, rehabilitation and sports medicine, exercise physiology and biochemistry, biomechanics and motor control, health and disease relating to sport, exercise and physical activity, as well as on the social and behavioural aspects of sport and exercise.

3. MANUSCRIPT CATEGORIES AND REQUIREMENTS

i. Original Article

Word limit: **Page charges will apply to articles exceeding 6 pages**. Please see the **Publication Process after Acceptance** section.

Abstract: 250 words maximum.

Keywords: Please provide 3-8 keywords.

References: Maximum of 40 references.

Figures/Tables: A total of 8 figures and/or tables is allowed.

Main text structure: Introduction; Materials and Methods (including statement that informed consent and local ethics committee approval has been provided for human studies); Results; Discussion; Perspective.

Perspective: It is mandatory that all manuscripts include a brief perspective paragraph at the end of the discussion in which the findings are put into perspective in the relevant area of sports medicine. This includes reference to possible previous articles in this and other journals and the potential impact of the present findings. This paragraph should not exceed 200 words.

ii. Review

Word limit: **Page charges will apply to articles exceeding 6 pages**. Please see the **Publication Process after Acceptance** section.

Abstract: 250 words maximum.

Keywords: Please provide 3-8 keywords.

References: Maximum of 120 references.

Figures/Tables: Authors are encouraged to keep the number of figures and tables to a minimum.

Perspective: It is mandatory that all manuscripts include a brief perspective paragraph at the end of the discussion in which the findings are put into perspective in the relevant area of sports medicine. This includes reference to possible previous articles in this and other journals and the potential impact of the present findings. This paragraph should not exceed 200 words.

iii. Brief Report

High quality short papers presenting early or a case report of particular interest. Where possible, this article type will have expedited peer review.

Word limit: Up to 1,500 words.

Abstract: 100 words maximum.

Keywords: Please provide 3-8 keywords.

References: Maximum of 20 references.

Figures/Tables: May include two figures or tables or one of each.

iv. Letter to the Editor

Are welcomed.

Word limit: 700 words maximum. Please see the **Publication Process after Acceptance** section.

v. Notice

Notices and other topics of interest can be submitted.

vi. Abstracts

Abstracts of sports medicine interest and other topics of interest can be submitted.

vii. Book Review

Book reviews and other topics of interest can be submitted.

viii. Consensus Statement

Announcement of consensus statements or meeting reviews and other topics of interest can be submitted.

4. PREPARING THE SUBMISSION

Cover Letters

Cover letters are not mandatory; however, they may be supplied at the author's discretion.

Parts of the Manuscript

The manuscript should be submitted in separate files: main text file; figures.

Main Text File

Manuscripts can be uploaded either as a single document (containing the main text, tables and figures), or with figures and tables provided as separate files. Should your manuscript reach revision stage, figures and tables must be provided as separate files. The main manuscript file can be submitted in Microsoft Word (.doc or .docx) or LaTex (.tex) format.

If submitting your manuscript file in LaTex format via Research Exchange, select the file designation “Main Document – LaTeX .tex File” on upload. When submitting a Latex Main Document, you must also provide a PDF version of the manuscript for Peer Review. Please upload this file as “Main Document - LaTeX PDF.” All supporting files that are referred to in the Latex Main Document should be uploaded as a “LaTeX Supplementary File.”

Your main document file should include:

- The appropriate Section Specialty Area for your paper should be indicated at the top of your main manuscript file or in your title page. Please select the appropriate Section Specialty Area from this list
- A short informative title containing the major key words. The title should not contain abbreviations
- The full names of the authors with institutional affiliations where the work was conducted, with a footnote for the author’s present address if different from where the work was conducted;
- Acknowledgments;
- Up to eight keywords;
- Main body: formatted as introduction, materials and methods, results, discussion, acknowledgements, conflict of interest statement;
- References;
- Tables (each table complete with title and footnotes);
- Figures: Figure legends must be added beneath each individual image during upload AND as a complete list in the text.

Best Practices for Manuscript Transformation

- The main manuscript file must be submitted in Microsoft Word (.doc or .docx) or LaTex (.tex) formats.
- Figures should be numbered in the order that they are cited in the text, and presented in that order after the text of the paper
- Full names (First, Middle, and Last) should be provided for all authors
- Authors should include the complete affiliation addresses in the manuscript. At minimum, authors should include the institution name and country, but a complete affiliation also includes department name and institution city. The institution postal code is optional.

Authorship

Please refer to the journal’s authorship policy the **Editorial Policies and Ethical Considerations section** for details on eligibility for author listing.

Acknowledgments

Contributions from anyone who does not meet the criteria for authorship should be listed, with permission from the contributor, in an Acknowledgments section. Financial and material support should also be mentioned. Thanks to anonymous reviewers are not appropriate.

Conflict of Interest Statement

Authors will be asked to provide a conflict of interest statement during the submission process. For details on what to include in this section, see the section 'Conflict of Interest' in the **Editorial Policies and Ethical Considerations section** below. Submitting authors should ensure they liaise with all co-authors to confirm agreement with the final statement.

Keywords

Please provide a maximum of 8 keywords.

References

All references should be numbered consecutively in order of appearance and should be as complete as possible. In text citations should cite references in consecutive order using Arabic superscript numerals. For more information about AMA reference style please consult the **AMA Manual of Style**

Sample references follow:

Journal article

1. King VM, Armstrong DM, Apps R, Trott JR. Numerical aspects of pontine, lateral reticular, and inferior olivary projections to two paravermal cortical zones of the cat cerebellum. J Comp Neurol 1998;390:537-551.

Book

2. Voet D, Voet JG. Biochemistry. New York: John Wiley & Sons; 1990. 1223 p.

Internet document

3. American Cancer Society. Cancer Facts & Figures 2003. http://www.cancer.org/downloads/STT/CAFF2003PWSecured.pdf Accessed March 3, 2003

Tables

Tables should be self-contained and complement, not duplicate, information contained in the text. They should be supplied as editable files, not pasted as images. Legends should be concise but comprehensive – the table, legend, and footnotes must be understandable without reference to the text. All abbreviations must be defined in footnotes. Footnote symbols: †, ‡, §, ¶, should be used (in that order) and *, **, *** should be reserved for P-values. Statistical measures such as SD or SEM should be identified in the headings.

Figure Legends

Legends should be concise but comprehensive – the figure and its legend must be understandable without reference to the text. Include definitions of any symbols used and define/explain all abbreviations and units of measurement.

Figures

Although authors are encouraged to send the highest-quality figures possible, for peer-review purposes, a wide variety of formats, sizes, and resolutions are accepted.

Click here for the basic figure requirements for figures submitted with manuscripts for initial peer review, as well as the more detailed post-acceptance figure requirements.

Colour Figures. Figures submitted in colour may be reproduced in colour online free of charge. Please note, however, that it is preferable that line figures (e.g. graphs and charts) are supplied in black and white so that they are legible if printed by a reader in black and white.

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Appendices will be published after the references. For submission they should be supplied as separate files but referred to in the text.

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- **Abbreviations:** In general, terms should not be abbreviated unless they are used repeatedly and the abbreviation is helpful to the reader. Initially, use the word in full, followed by the abbreviation in parentheses. Thereafter use the abbreviation only.
- **Units of measurement:** Measurements should be given in SI or SI-derived units. Visit the Bureau International des Poids et Mesures (BIPM) website for more information about SI units.
- **Numbers:** numbers under 10 are spelt out, except for: measurements with a unit (8mmol/l); age (6 weeks old), or lists with other numbers (11 dogs, 9 cats, 4 gerbils).
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- **Use mass not weight**

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The list of authors should accurately illustrate who contributed to the work and how. All those listed as authors should qualify for authorship according to the following criteria:

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2. Been involved in drafting the manuscript or revising it critically for important intellectual content; and
3. Given final approval of the version to be published. Each author should have participated sufficiently in the work to take public responsibility for appropriate portions of the content; and
4. Agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Contributions from anyone who does not meet the criteria for authorship should be listed, with permission from the contributor, in an Acknowledgments section (for example, to recognize contributions from people who provided technical help, collation of data, writing assistance, acquisition of funding, or a department chairperson who provided general support). Prior to submitting the article all authors should agree on the order in which their names will be listed in the manuscript.

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8. POST PUBLICATION

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Appendix 5: Complete overview of the strength training program performed during the intervention

	Session 1			Session 2		
	Exercise	**Sets**	**Reps**	**Exercise**	**Sets**	**Reps**
Week 1	Back squat 80% 1RM	3	VL%	Back squat 70% 1RM	3	VL%
	Weighted pullups	3	6	Hurdle jumps	4	4
	Narrow grip bench press	3	6	Bench press	3	5
	Romanian deadlift	3	10	Weighted pull ups	3	5
	Pallof press	3	10			
Week 2	Back squat 80% 1RM	3	VL%	Back squat 70% 1RM	3	VL%
	Trap bar jumps	3	4	Hurdle jumps	4	4
	Barbell romanian dead lift	3	10	Single leg hamstring curl	3	8
	Pallof press	3	10	GHD hip extensions	3	12
Week 3	Back squat 80% 1RM	3	VL%	Back squat 70% 1RM	3	VL%
	Weighted pull ups	3	6	Hurdle jumps	4	4

	Narrow grip bench press	3	6	Single leg hamstring curl	3	8
	Romanian dead lift	3	6	GHD hip extensions	3	12
	Pallof press	3	10			
Week 4	Back squat 80% 1RM	3	VL%	Back squat 70% 1RM	3	VL%
	Weighted pull ups	3	8	Hurdle jumps	4	4
	Narrow grip bench press	3	6	Single leg hamstring curl	3	8
	Barbell romanian dead lift	3	8	GHD hip extensions	3	12
	Pallof press	3	10			
Week 5	Back squat 80% 1RM	2	VL%	Back squat 70% 1RM	2	VL%
	Trap bar jumps	2	4	Hurdle jumps	4	4
	Pull ups (weighted)	3	10	Single leg hamstring curl	3	10
	Barbell Romanian dead lift	4	4	GHD hip extensions	3	12
	Dumbbell bench press	2	10			
Week 6	Back squat 80% 1RM	3	VL%	Back squat 70% 1RM	3	VL%
	Seated box jumps	4	4	Hurdle jumps	4	4
	Weighted pull ups	3	3	Single leg hamstring curl	3	10
	Romanian dead lift	3	10	GHD hip extensions	3	12
	Dumbbell bench press	3	8			
Week 7	Back squat 80% 1RM	3	VL%	Back squat 70% 1RM	3	VL%
	Trap bar jumps	4	4	Hurdle jumps	4	4
	Seated box jumps	3	3	Single leg hamstring curl	3	10
	Romanian dead lift	3	8	GHD hip extensions	3	12

	Pallof press	3	10			
Week 8	Back squat	3	VL%	Back squat	3	VL%
	Trap bar jumps	4	4	Hurdle jumps	4	4
	Seated box jumps	3	3	Dumbbell bench press	3	10
	Barbell romanian dead lift	3	8	Horizontal sling row	3	10
	Pallof press	3	10			

Abbreviations: 1RM, one-repetition maximum; Rep, repetitions; Set, training sets: GHD hip extensions, Glute Hamstring Developer hip extensions