**The Faculty of Arts and Education**

# MASTERS THESIS

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| Supervisor: Thomas Bjørnsen | |
| Title of thesis: Maximal Power, Sprinting and Jumping Adaptations in Ice Hockey Athletes In-Season: Comparing Different Strength Training Velocity Loss Thresholds | |
| Key words:<br>Velocity-based resistance training, semi-professional athletes, velocity loss, back squat | Pages: 97<br>Number of attachment/other: 5<br>Stavanger, 06.01.2023 |

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Lastly, I would like to thank the subjects who participated in this study. Their participation and effort during the training intervention are highly appreciated.

## Sammendrag

**Bakgrunn**: Teknologisk fremgang har popularisert bruken av objektive auto reguleringsteknikker som hastighetsstyrt styrketrening (HST) for å justere treningsintensitet og volum. Ingen har imidlertidig undersøkt HST i løpet av konkurranse sesongen for idrettsutøvere på høyt nivå. **Hensikt:** Denne studien hadde som mål å sammenligne effekten av HST med 20 % hastighetstap mot 40 % hastighetstap i hvert sett av knebøy, på maksimal power, sprint- og hoppevner på ishockeyutøvere i sesong. **Metode:** 15 semi-profesjonelle mannlige ishockeyspillere gjennomførte en 8-ukers styrketreningsintervensjon i sesong, og utførte 6 ukentlige knebøy sett, fordelt på 2 ukentlige treningsøkter. Deltakerne ble tilfeldig allokert til enten 20% (VL20) eller 40% (VL40) hastighetstapsgruppen, som kun var forskjellig i nådd hastighetstap under knebøy. Hopp med svikt, 30 meter sprint på og av is med 10 meter mellomtider og Keizer benpress maksimal power ble målt før og etter treningsintervensjonen. **Resultater:** VL40-gruppen hadde en signifikant større økning i Keizer benpress maksimal power, sammenlignet med VL20-gruppen (henholdsvis 4,4 ± 3,9 % vs 0,02 ± 3,7 %, $p = 0,045$). Ingen andre forskjeller ble observert i andre målinger fra før til etter test mellom de to gruppene. **Konklusjon:** Hovedfunnet i denne studien var at trening til 40% hastighetstap kan være fordelaktig for å forbedre maksimal power i underekstremitetene i løpet av en sesongperiode for veltrente idrettsutøvere. Fremtidige studier bør undersøke effekten av forskjellige hastighetstap hvor treningsvolum er likt mellom gruppene, med større utvalgsstørrelser på idrettsutøvere i sesong.



**Nøkkelord:** Hastighetsstyrt styrketrening, ishockey, maksimal power, eksplosiv styrke, knebøy

# Abstract

**Background:** Technological progress has popularized the use of objective autoregulation techniques such as velocity-based resistance training (VBT) for adjusting exercise intensity and volume. However, none have investigated VBT during the competitive season period for high-level athletes. **Purpose:** The present study aimed to compare the effects of VBT with 20% velocity loss vs. 40% velocity loss in each set of the back squat exercise, on maximal power, sprinting, and jumping abilities on in-season ice hockey athletes. **Method:** 15 semi-professional male ice hockey players completed an 8-week strength training intervention, performing 6 weekly back squat sets, distributed on 2 weekly workouts. The participants were randomly allocated to either the 20% (VL20) or 40% (VL40) velocity loss group, which differed only in degree of velocity loss during the back squat exercise. Countermovement jump (CMJ), 30 meter on/off ice sprint with 10-meter split times, and Keiser leg-press maximal power were measured before and after the training intervention. **Results:** The VL40 group had a significantly larger increase in Keiser leg press maximal power changes, compared to the VL20 group (4.4 ± 3.9% vs 0.02 ± 3.7%, respectively, $p = 0.045$). No differences were observed in other pre to post-test measurements between the two groups. **Conclusion:** The main finding of this study was that training to 40% velocity loss might be beneficial for improving maximal power in lower limbs during an in-season period for well-trained athletes. Future studies should investigate the effect of different velocity losses with training volume matched groups and larger sample sizes within athletes.



**Keywords:** Velocity-based resistance training, Ice hockey, maximal power, explosive strength, back squat

## Abbreviations

| | |
|---|---|
| **FV** | Force-Velocity |
| **VBT** | Velocity-Based resistance Training |
| **Pmax** | Maximal power output, extrapolated from a theoretical force-velocity curve |
| **RFD** | Rate of Force Development |
| **CSA** | Cross Sectional Area |
| **1RM** | One-Repetition Maximum |
| **RIR** | Reps In Reserve |
| **SD** | Standard Deviation |
| **RCT** | Randomized Controlled Trial |
| **CV** | Coefficient of Variation |
| **Kg** | Kilograms |
| **SSC** | Stretch-Shortening Cycle |
| **F0** | Theoretical Maximal Force extrapolated from a theoretical force-velocity curve |
| **Cm** | Centimeter |
| **RPE** | Rating of Perceived Exertion |
| **NHL** | National Hockey League |
| **V0** | Theoretical Maximal Velocity extrapolated from a theoretical force-velocity curve |

# Table of Content

**Part 1, scientific manuscript**: Presents a reaserch paper, written in accordance with the open access guidelines of the Scandinavian Journal of Medicine & Science in Sports. This part consists of an IMRAD style manuscript: Introduction, methods, results, discussion and conclusion.

**Part 2, thesis wrapper**: This part consists of a more in-depth description of the theoretical background and discussion of the methods used, which is supplementary information to the research paper.

**Part 3, attachments**: Consists of appendices such as approval, informed consents, and application of ethical approval.

# Part 1

# RESEARCH PAPER

**Maximal Power, Sprinting and Jumping Adaptations in Ice Hockey Athletes In-Season: Comparing Different Strength Training Velocity Loss Thresholds**

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

**Scandinavian Journal of Medicine & Science in Sports**

**Sander Remme**

**University in Stavanger**

**May 2023**

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**Background:** Technological progress has popularized the use of objective autoregulation techniques such as velocity-based resistance training (VBT) for adjusting exercise intensity and volume. However, none have investigated VBT during the competitive season period for high-level athletes. **Purpose:** The present study aimed to compare the effects of VBT with 20% velocity loss vs. 40% velocity loss in each set of the back squat exercise, on maximal power, sprinting, and jumping abilities on in-season ice hockey athletes. **Method:** 15 semi-professional male ice hockey players completed an 8-week strength training intervention, performing 6 weekly back squat sets, distributed on 2 weekly workouts. The participants were randomly allocated to either the 20% (VL20) or 40% (VL40) velocity loss group, which differed only in degree of velocity loss during the back squat exercise. Countermovement jump (CMJ), 30 meter on/off ice sprint with 10-meter split times, and Keiser leg-press maximal power were measured before and after the training intervention. **Results:** The VL40 group had a significantly larger increase in Keiser leg press maximal power changes, compared to the VL20 group ($4.4 \pm 3.9\%$ vs $0.02 \pm 3.7\%$, respectively, $p = 0.045$). No differences were observed in other pre to post-test measurements between the two groups. **Conclusion:** The main finding of this study was that training to 40% velocity loss might be beneficial for improving maximal power in lower limbs during an in-season period for well-trained athletes. Future studies should investigate the effect of different velocity losses with training volume matched groups and larger sample sizes within athletes.



**Keywords:** Velocity-based resistance training, Ice hockey, maximal power, explosive strength, back squat

# Introduction

Following the landmark Summit Series in 1972, ice hockey was globally recognized as a sport, leading to professional players being invited to compete in the Nagano Olympics in 1998. As of 2023, over 1.6 million players from more than 70 countries participate in the sport (Federation, 2023). Ice hockey is characterized by high-intensity, intermittent, full-contact bouts of anaerobic endurance (Spiering et al., 2003). Evidence suggests that successful play in ice hockey requires the key components of strength, speed, power, acceleration, aerobic endurance, balance, and agility (Behm et al., 2005; Bracko & George, 2001; Burr et al., 2008). For ice hockey outfield players, the typical game structure involves bouts of 45-60 seconds followed by rest intervals of 2-5 minutes, with NHL (National Hockey League) players typically not exceeding 15-20 minutes of active play time per 60-minute game (Cox et al., 1995). Despite the relatively short duration of each bout, these periods are characterized by repeated bursts of high-intensity skating, reaching speeds of up to 55 kph, rapid lateral changes, high-speed collisions, and frequent physical confrontations (Burr et al., 2008; Vigh-Larsen & Mohr, 2022).

Heavy resistance training is a commonly employed strategy to enhance physical attributes in athletes due to the strong association between muscle strength and general sports skills such as sprinting, jumping, and changing direction (Suchomel et al., 2016). The determination of set intensity often involves a direct 1-RM assessment, where a percent-based load is derived from a previous 1-RM lifted by the athlete (Jovanović & Flanagan, 2014). However, this method may not accurately reflect the current maximal strength level of the athlete, as strength can fluctuate due to factors such as strength improvements over time or training-induced fatigue, especially during the competitive season (Zourdos et al., 2016). Additionally, daily stressors such as sleep, nutrition, and illness can affect an athlete's readiness and, therefore, influence performance (Greig et al., 2020). To account for these fluctuations in performance at each workout, various training prescription methods, referred to as autoregulation has become popular to increase maximal strength (Helms et al., 2017). Autoregulation adjusts training variables, such as intensity, volume, and frequency, based on the daily fluctuations in an athlete's fitness, fatigue, and readiness.

Technological progress has enabled the use of objective autoregulation techniques for measuring exercise intensity, fatigue and volume. One of these techniques is velocity-based resistance training (VBT). VBT uses the principle that there exists a linear relationship between barbell velocity and %1RM, meaning that heavier loads cannot be lifted as fast as lighter loads (Weakley et al., 2021). Additionally, when an exercise is performed with maximal effort and fatigue sets in, the barbell velocity decreases (Sanchez-Medina & González-Badillo, 2011). Intra-set velocity loss has a strong correlation with mechanical, perceptual, and metabolic markers of fatigue (González-Badillo et al., 2017; Rodríguez-Rosell et al., 2018), as well as with the number of completed repetitions relative to the maximum number of repetitions possible in a set (Rissanen et al., 2022; Rodríguez-Rosell et al., 2020). Therefore, velocity loss can be used as an indicator of fatigue during resistance training and can be used to regulate proximity to failure with reasonable precision.

Several studies have investigated the impact of different velocity loss thresholds on athletic performance. A recent meta-analysis by Jukic et al. (2022) revealed an inverse relationship between velocity loss and subsequent improvements in countermovement jump (CMJ) and sprint performance. Specifically, training with a velocity loss of more than approximately 20% was found to have a negative effect on these performance measures, even though higher velocity losses were associated with greater hypertrophy. However, the level of velocity loss did not appear to affect the magnitude of strength gains, even though most studies reported substantial differences in training volume that increased linearly as the velocity loss increased. However, only a small number of these studies have been conducted on athletes, and none have been conducted during the in-season period when athletes have a high total volume of training and competitive games in addition to other physical training sessions. Ice hockey, along with several other sports, is characterized by a high frequency of competitive games during the in-season period. For example, ice hockey players often compete every two or three days, leaving little to no time for anything other than activities supporting on-ice performance and recovery. (Neeld, 2018; Nightingale, 2014)

The present study aimed to compare the effects of two resistance training programs on maximal power, sprinting, and jumping abilities on in-season athletes, where each program differed only in degree of velocity loss in each set of the back squat exercise (20% versus 40% velocity loss). Building on prior research, we hypothesized that improvements in jump, sprint and power performance would be greater with the resistance training program using only a 20% velocity loss, as opposed to the 40% velocity loss program.

# Materials and Methods

## Subjects

Two semi-professional ice hockey teams, one consisting of 21 male and one consisting of 22 female players, were recruited to participate in the study. However, the female team withdrew from the intervention in the fifth week of training due to several reasons, including their lack of familiarity with heavy strength training during the in-season period, which resulted in increased levels of fatigue and soreness and reductions in perceived match freshness. Additionally, the team's in-season match performance was lower than expected prior to and during the first five training weeks, leading the head coach to decide that the team should reduce off-ice training during the remaining part of the season to ensure that the players were maximally prepared for matches. Consequently, the data collected from this team were deemed insufficient for inclusion in the data analysis of this master thesis. The female team were allowed to perform the post-tests after 5 weeks instead of the originally planned 8 weeks on request on the physical performance coach, but the data was not included in this study. Of the 21 males originally recruited, 5 withdrew due to injury or personal reasons, and one male participant was excluded due to inadequate training frequency (with a cut-off set at 75%). Hence, 15 players were included in the data analysis. All the included participants were semi-professional ice hockey players in the national "under 20s" league who had undergone at least two years of systematic resistance training that included regular back squats. All participants provided written and verbal informed consent, and the study was approved by 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) and was conducted in accordance with the Declaration of Helsinki.

## Experimental design

This study compared the effects of two velocity losses during an 8-week velocity-based resistance training (VBT) intervention in the back squat exercise. A randomized controlled experiment design was employed in which the subjects were allocated into one of two velocity loss groups stratified upon back squat 1RM at baseline using randomizer.org. One of the groups performed their sets until they reached 20% velocity loss from their fastest to their slowest repetition within each set (VL20), while the other group (VL40) ended their sets when they reached 40% velocity loss from fastest to slowest repetition. The total number of participants in each group was 8 in VL20 (17.6 years, 180.6 cm, 79.3 kg) and 7 in VL40 (17.4

years, 180.4 cm, 77.4 kg). The intervention period was set to last 8 weeks, with 2 weekly intervention workouts, separated by at least 48 hours. Notably, the study was conducted in-season for the athletes, who had an average of 2 matches per week during the study intervention, as well as 4-5 weekly on-ice hockey training sessions. The participants underwent pre- and post-training intervention testing on three different sessions. The first testing session included muscle size measurements, maximal power and force testing using the Keiser leg press machine. The following day, the participants completed tests of sprinting (off-ice), countermovement jump (CMJ), and strength (1RM back squat). On the third day, the participants performed a 30-meter sprint test on ice, with full hockey gear. The present master thesis aimed to investigate the effects of training to different velocity losses on maximal power, sprint and jump performance, hence muscle size, muscle strength and maximal force measurements from the overarching project will not be described or included in the analysis.

### Training intervention

All participants in both groups underwent the same training program during the 8-week intervention, with the only difference being the allocated velocity loss in the back squat exercise. The training program undertaken by the athletes was a continuation of their pre-existing routine developed in cooperation with their strength and conditioning coach. Participants were well familiarized with all included exercises but had not conducted VBT prior to the intervention. Back squat VBT was always performed as the first exercise, using an 80% 1RM load on the first session of the week and a 70% 1RM load on the second session of the week. The load was increased with 2.5kg in week 4 and week 7 to follow their expected progression in back squat strength. Participants performed 3 sets of back squats per session, except for week 5, where they performed 2 sets due to an important competition period. A complete overview of the back squat training program can be found in Table 1. Following the back squat exercise, participants completed 3-4 additional exercises, which varied from week to week and included a combination of different strength, plyometric, and core exercises (always similar between VL20 and VL40). A complete overview of all the training performed can be found in appendix 5, however the training was identical in the two groups, except the predetermined velocity loss in the back squat exercise.

**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 + 2.5kg | 3 sets at 70% 1RM + 2.5kg |
| **Session 9** | **Session 10** | **Session 11** | **Session 12** |
| 2 sets at 80% + 2.5kg | 2 sets at 70% + 2.5kg | 3 sets at 80% + 2.5kg | 3 sets at 80% + 2.5kg |
| **Session 13** | **Session 14** | **Session 15** | **Session 16** |
| 3 sets at 80% + 5kg | 3 sets at 70% + 5kg | 3 sets at 80% + 5kg | 3 sets at 70% + 5kg |

Abbreviations: Sets: The total number of sets performed in the back squat exercise per workout. %1RM: Percentage of baseline one repetition maximum in back squat. The weight was increased with 2.5kg from session 6 to 7. This new load was kept from session 7 to 12, and then it was again increased with 2.5kg again from session 12 to 13.

Prior to each training session, all participants underwent a standardized 20-minute warm-up routine consisting of cycling, dynamic mobility drills, and gradual increases in load for the back squat exercise. The back squat was performed with a controlled descent until the femurs were parallel to the floor, followed by an explosive concentric phase. The practitioners gave strong verbal encouragement during each training session to ensure maximal mobilization during the concentric phase. The back squat training was conducted on the Alphatek force platform (AlphatekPWR, Stavanger, Norway), which measures the MPV (mean propulsive velocity) in the concentric phase of each repetition and displays the concentric velocity as feedback in real-time on a screen in front of the participants. The participants were instructed to utilize the objective velocity feedback to try to lift faster than the previous repetition. The screen turned red when they reached their allocated velocity loss (20 or 40%), to signal the participants to terminate the set. The inter-set rest interval was standardized at 3 minutes for all sessions. The number of repetitions performed in each training session was personalized for each subject based on their assigned velocity-loss percentage and their capacity to endure fatigue.

## Measurements

To assess the athletic abilities of the participants, pre and post-tests on sprint (on/off ice), countermovement jump (CMJ) and leg press maximal power were performed.

### Off-ice 30m sprint test

The off-ice sprint test involved two maximal 30-meter sprints, which were conducted indoors on the same surface and location during both pre and post-tests. The two runs were separated by a 5-minute rest period, and participants were instructed to exert maximal effort in both sprints, with the best trial of the two kept for analysis. Prior to the sprint test, the participants underwent a warm-up of approximately 15 minutes that they were well familiarized with, consisting of jogging, dynamic stretching, and progressively faster runs. Photocell timing gates (Photocells, Brower Timing System, UT, USA) were placed at 0, 10, and 30 meters to measure the sprint times at 10 and 30 meters. All the sensors were placed 100 cm from the ground. A standing start with the lead-off foot placed 40 cm behind the first timing gate was employed.

### Vertical jump test

Following the sprint test, participants performed three maximal countermovement vertical jumps (CMJs) with a 30-second rest interval between each jump, and the highest jump was retained for analysis. During the CMJ test, participants rapidly lowered their body and then pushed explosively against the ground. Throughout the entire movement, hands were kept on the hips, and participants were encouraged to jump as high as possible with a self-chosen dept. The CMJ height were measured using a force platform (Alphatek).

### Keiser Leg press

The leg press exercise was carried out using the Keiser A300 horizontal leg-press dynamometer (Keiser Sport, Fresno, CA). The participants performed the 10-repetition force-velocity (FV) test with incremental loads. The maximal load on the baseline legpress test were determined individually by adding the athletes 1RM back squat together with their weight to estimate their leg press strength (for example, 140kg in 1RM back squat + body weight of 85kg = maximal load of 225). Prior to the test, the seating position was individually adjusted to achieve a vertical femur, corresponding to an 80-90° knee angle, and the participants were instructed to place their feet with heels at the bottom end of the foot pedal. During the test, the participants were instructed to extend both legs with maximal effort throughout the entire 10-repetition FV test. The test commenced with two practice attempts at the lightest load, equivalent to ∼15% of the maximal resistance chosen. Thereafter, the load was gradually increased with fixed steps (~20–30 kgf) for each subsequent attempt until reaching the predetermined maximal load, completing a total of 10 attempts across the FV curve (15%–100% of the predetermined maximal load). The rest period between attempts increased as the load increased, with ∼10–20 s rest periods for the initial five loads and 20–40 s rest periods for the last four loads. As a result of the pneumatic semi-isotonic resistance, maximal effort did not elicit ballistic action, and the entire push-off was performed with maximal intentional velocity. The leg press exercise was performed as a concentric-only action, without any countermovement, as the pedals were stationary in their predetermined position before each repetition. The eccentric phase was submaximal and not recorded. The theoretical maximal power from the FV-profile was then used to derive the power output from the leg press exercise.

**On-ice sprint test**

The on-ice sprint test was performed while wearing full match-kit, including a stick. Participants completed two maximal sprints with a 5-minute passive rest period between each attempt. To prepare for the test, players completed 10 minutes of individual warm-up drills on the ice. The on-ice sprint test used the same wireless timing gates and setup as the off-ice sprint test. Players started from a stationary sideways position, holding the stick in front of the photocells to ensure that the sensors were not obstructed by anything other than the body. Timing began when their body triggered the first sensor, which was placed 40 cm in front of the start line and 100 cm above the ground. To avoid prematurely breaking the photocells, players were instructed to keep the stick in contact with the ice. Post-test analysis included the trial with the best 30-m time.

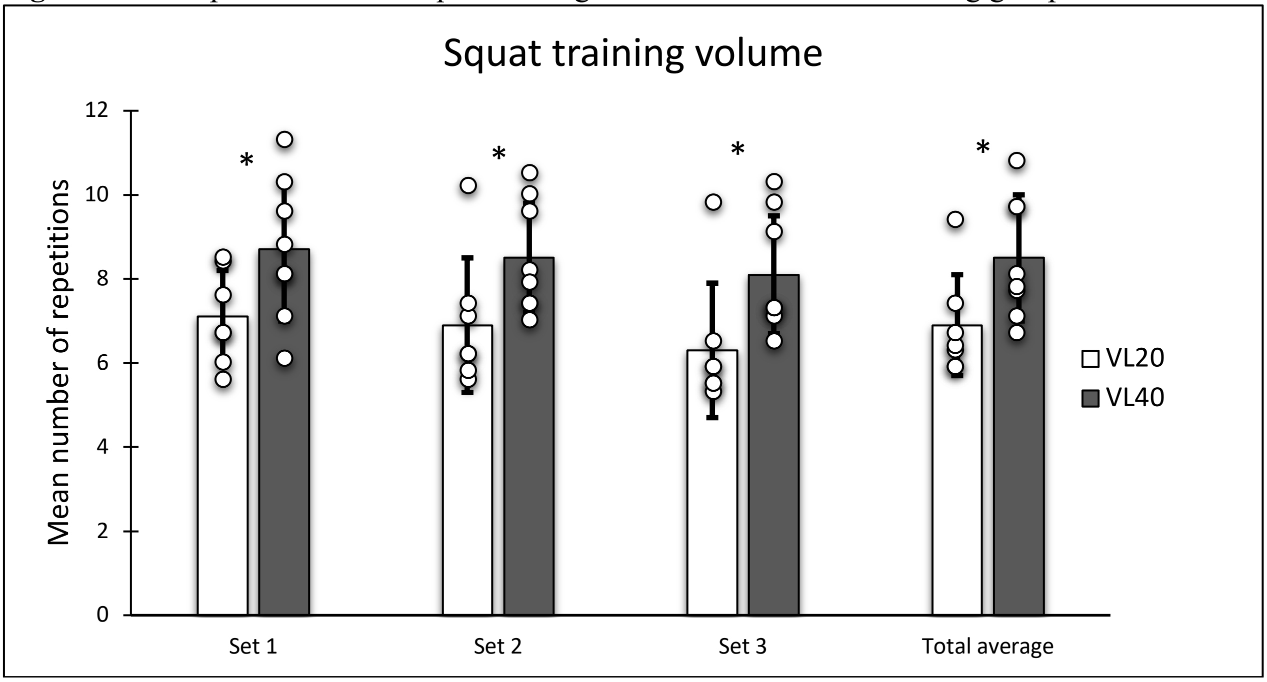
## Statistical analyses

The characteristics of the subjects at baseline were expressed using descriptive statistics, where mean and standard deviation were used. Examination of the distribution of the data involved analyzing the mean, median, skewness, and kurtosis, which led to the conclusion that the data was normally distributed. Between-group changes were then analyzed using an independent sample t-test, which yielded percentage mean difference and p-value, and percentage change statistics were performed. To investigate within-group pre to post changes, a paired sample t-test was used. Results were presented as percentage mean, standard deviation, in addition to the p-value. All analyses had confidence limits set at 95%, and the significance level at <0.05. The statistical analyses were conducted using Microsoft Excel.

## Results

The pre-tests did not reveal any significant differences between groups in any measurement. Adherence to training was 88 ± 11% in VL20 and 92 ± 9% in VL40, with no statistical differences between groups. The VL40 group completed 27% more repetitions than the VL20 group (6.9 ± 1.2 reps vs. 8.8 ± 1.3 reps, p = 0.012). The total number of repetitions performed in each set by both groups is shown in figure 1. The VL40 group performed significantly more repetitions than VL20 in the first- (9.1 ± 1.4 vs 7.0 ± 1.2, p = 0.012, respectively) second- (7.0 ± 1.5 vs 8.8 ± 1.3, p = 0.025, respectively) and third set (6.5 ± 1.5 vs 8.2 ± 1.5, p = 0.043, respectively). At the end of each set, the VL20 group had an average velocity loss of 25.3 ± 1.8% while the VL40 group had an average of 47.2 ± 4.8% (p = 0.001).

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




Data are expressed as mean ± SD. VL20 = The group training until 20% velocity loss, VL40 = the group training until 40% velocity loss. (*) indicates significant differences between groups from pre to post (p < 0.05).

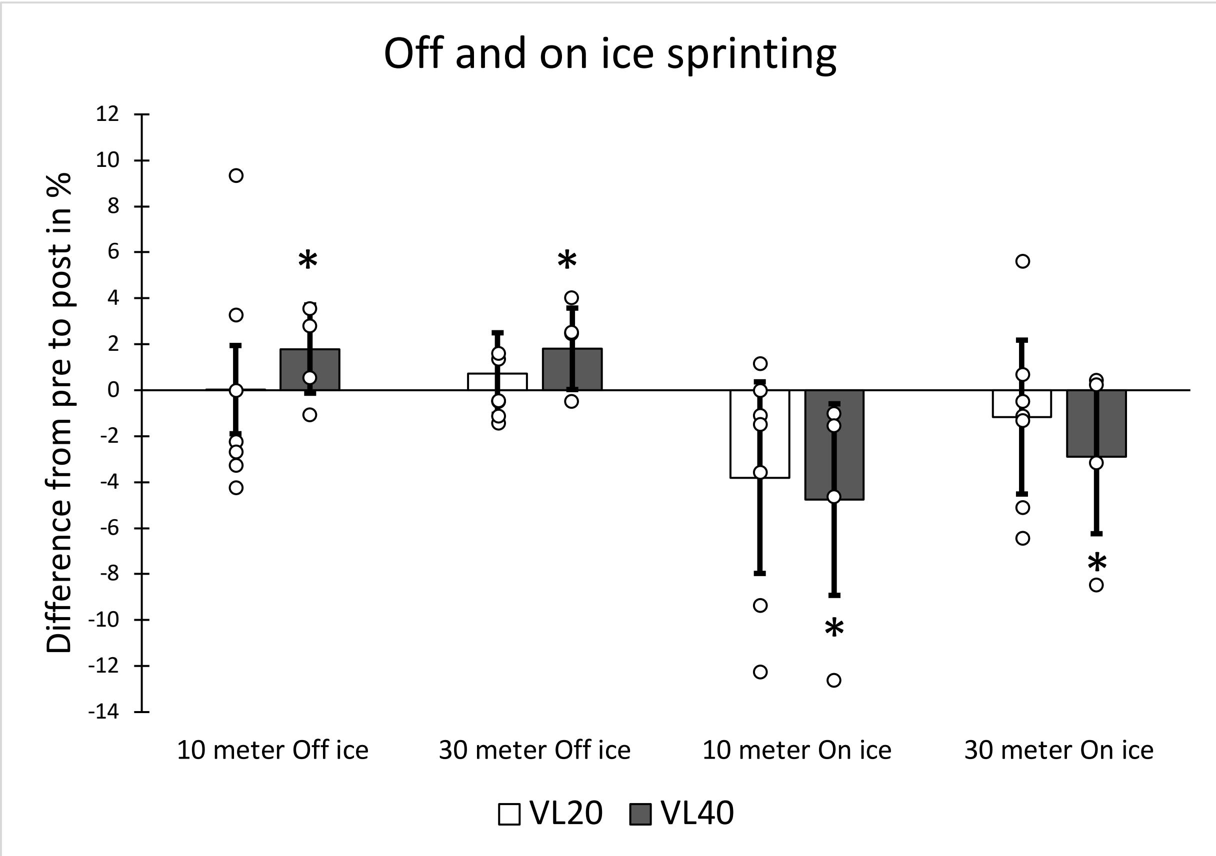
**Table 2** Results from both VL20 and VL40 training group from pre- to post test

| | **VL20** | | | | **VL40** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Pre** | **Post** | **Change** | **p-value, time** | **Pre** | **Post** | **Change** | **p-value, time** | **p- value group x time interaction** |
| 10m Off (s) | 1.85 ± 0.04 | 1.85 ± 0.08 | 0.00 ± 0.09 | 0.989 | 1.81 ± 0.07 | 1.84 ± 0.05 | 0.03 ± 0.03 | **0.014*** | 0.427 |
| 30m Off (s) | 4.30 ± 0.15 | 4.33 ± 0.18 | 0.03 ± 0.10 | 0.458 | 4.28 ± 0.12 | 4.35 ± 0.13 | 0.08 ± 0.08 | **0.008*** | 0.399 |
| 10m On (s) | 1.93 ± 0.12 | 1.85 ± 0.08 | -0.08 ± 0.10 | 0.095 | 1.92 ± 0.10 | 1.83 ± 0.12 | -0.09 ± 0.08 | **0.042*** | 0.787 |
| 30m On (s) | 4.38 ± 0.16 | 4.33 ± 0.10 | -0.06 ± 0.17 | 0.422 | 4.43 ± 0.17 | 4.30 ± 0.26 | -0.13 ± 0.15 | **0.02*** | 0.446 |
| CMJ (cm) | 39.0 ± 5.6 | 38.3 ± 4.6 | -0.8 ± 1.9 | 0.405 | 38.2 ± 5.0 | 39.4 ± 4.8 | 1.2 ± 2.7 | 0.140 | 0.185 |
| Leg press Pmax (w) | 2648 ± 415 | 2648 ± 428 | 0.4 ± 97.4 | 0.989 | 2342 ± 290 | 2449 ± 342 | 106.9 ± 93.8 | **0.004*** | **0.045**** |

Mean values are presented with standard deviations (SD). (*) indicates significant difference from pre to post within same group, while (**) indicates significant differences between groups from pre to post ($p < 0.05$). Abbreviations: VL20: The group training until 20% velocity loss, VL40: The group training until 40% velocity loss, 10/30m Off (s); 10- and 30-meter sprint time off ice, presented in seconds. 10/30m Off (s): 10- and 30-meter sprint time on ice, presented in seconds. CMJ (cm): Counter movement jump presented in centimeters, leg press Pmax (w): Keiser leg press machine to measure maximal power, presented in watts.

No significant differences were observed between the VL20 and VL40 groups in sprint measurement changes from pre to post intervention. Compared to baseline, off ice sprinting revealed no changes in 10- and 30-meter sprint time for the VL20 group (0.03 ± 4.8%, p = 0.989 and 0.7 ± 2.5%, p = 0.450), and a significant increase in sprinting time for the VL40 group (1.8 ± 1.9%, p = 0.014 and 1.8 ± 1.8%, p = 0.008, respectively). In contrast, on-ice sprinting time decreased in the VL40 group for both 10- and 30-meter sprints (-4.8 ± 4.2%, p = 0.004 and -2.9 ± 3.3%, p = 0.02, respectively), while the VL20 sprinting times did not change (-3.8 ± 5.1%, p = 0.071; -1.2 ± 3.9%, p = 0.448, respectively).

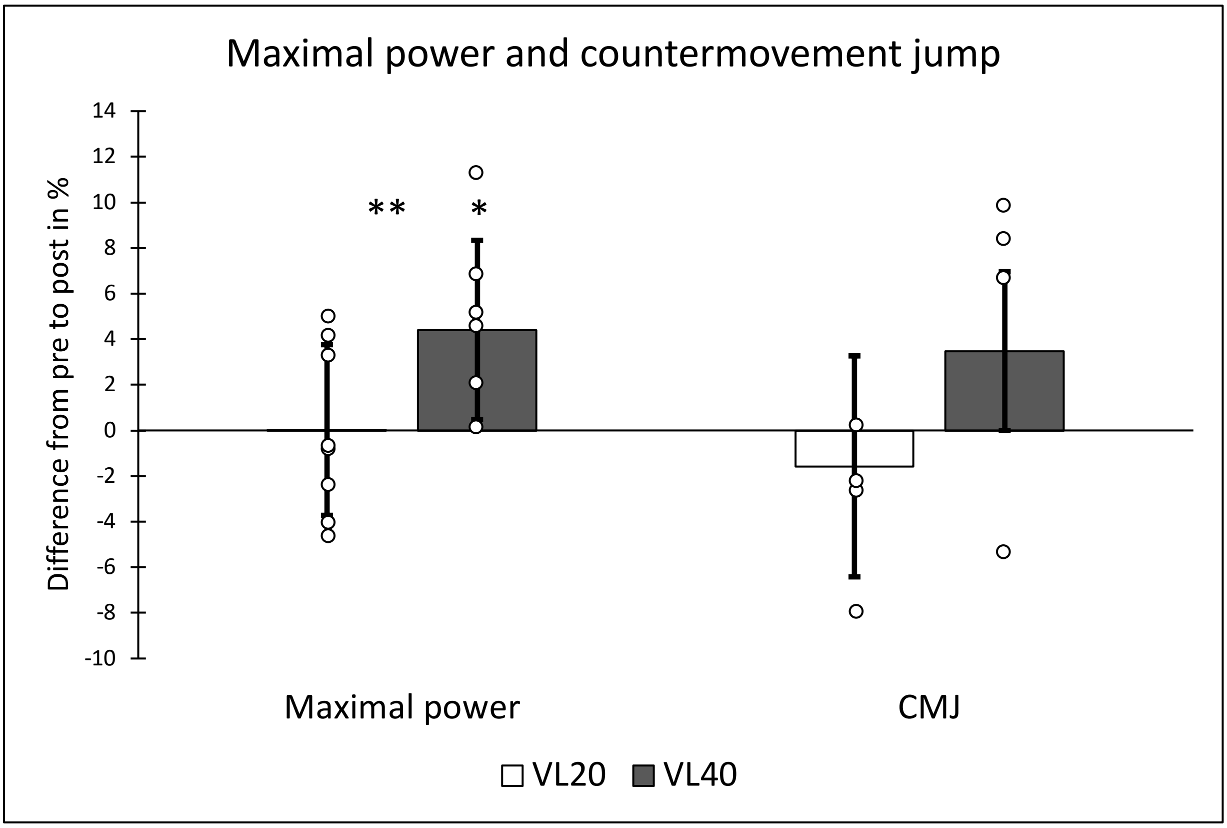
**Figure 2** An overview of difference in sprint time from Pre to Post test in %




Data are expressed as mean ± SD. VL20 = Training until 20% velocity loss, VL40 = training until 40% velocity loss. Within group significant change from pre to post: *p < 0,05

There were no significant differences between the two groups in pre to post test changes of CMJ. In addition, CMJ did not change from baseline in the VL20 (-1.6 ± 4.8%, p = 0.405) or VL40 group (3.5 ± 6.8%, p = 0.140).

**Figure 3** An overview of difference in CMJ and maximal power from Pre to Post in %.




Data are expressed as mean ± SD. VL20 = Training until 20% velocity loss, VL40 = training until 40% velocity loss. (*) indicates significant difference from pre to post within same group, while (**) indicates significant differences between groups from pre to post ($p < 0.05$).

The VL40 group increased Leg press maximal power significantly more than the VL20 group (4.4 ± 3.9% vs 0.02 ± 3.7%, respectively, p = 0.045). Compared to baseline, the VL40 group increased leg press power (p= 0.004) while it remained unchanged in the VL20 group (p= 0.989).

## Discussion

This study represents a novel investigation into the effects of VBT on ice hockey players during a competitive period of their season. The study examined the effects of training to velocity losses of 20% vs. 40% on maximal leg press power, countermovement jump (CMJ), and sprint performance. The only between group differences from pre to post-test were found in leg press maximal power, favoring the VL40 group. There were no differences between the two groups in on/off ice sprinting or jumping performance from pre to post-test. However, the VL40 group showed significant improvements in on-ice 10m sprint, on-ice 30m sprint and

Leg press maximal power from pre to post-test, perhaps indicating that training to a higher velocity loss was preferable for this specific group of participants.

The VL20 group completed 78% of the total repetitions that the VL40 group performed. In a similar study by Pareja-Blanco et al. (2017), there was a greater difference in completed repetitions between the VL20 and VL40 groups (VL20 completed 60% of the repetitions of VL40), despite similar squat execution and percentage resistance. One possible explanation for the discrepancies in repetitions numbers is that our study differs from Pareja-Blanco et al. (2017) and most other VBT studies in that we measured velocity from the center of mass (COM) on a force platform, rather than measuring barbell speed. Indeed, Lake et al. (2012) compared measures of power output from the velocity of COM versus the barbell in a squat exercise. They found that measuring barbell velocity significantly overestimated velocity and resulted in an overestimate of power output. The barbell undergoes significantly greater displacement at a significantly greater velocity compared to the COM during the back squat, possibly making barbell velocity a less accurate measure of power compared to measuring COM velocity on a force platform, as we did in our study.

Several authors have previously proposed that there is an inverted "U"-shaped relationship between training volume and neuromuscular improvements in muscle strength and physical performance (Busso, 2003; González-Badillo et al., 2005; Kuipers, 1996). According to this model, a minimum volume threshold is required for each load magnitude range to elicit neuromuscular enhancements. Beyond this minimum threshold, a progressive increase in training volume is typically accompanied by an increase in strength gains, up to a certain limit, beyond which an increase in training volume will not produce additional benefits in terms of muscle strength. Furthermore, exceeding a certain training volume value is likely to result in a decrease in gains in strength and physical performance. A similar theory is also suggested by recent research with VBT, as a review by Jukic et al. (2022) found that training to velocity losses greater than 20% can have adverse effects on strength, sprint, and jump performance. Similarly, a meta-analysis by Wlodarczyk et al. (2021) found that training to a velocity loss between 10-20% can induce robust neuromuscular adaptations with less neuromuscular fatigue compared to larger velocity losses in athletes. The reasoning behind this could be supported by the principle of training specificity (Behm & Sale, 1993), as several studies show that low to moderate velocity loss thresholds allow for higher average velocity and greater quality of repetitions throughout the exercise session compared to high velocity loss thresholds. When resistance training sets are performed to or near muscle failure, subsequent training repetition velocities end up being slower, concomitant with high levels of metabolic and mechanical fatigue (Gorostiaga et al., 2012; Sanchez-Medina & González-Badillo, 2011). Several studies have also shown a shift in muscle fiber type from IIx to IIa following a resistance training intervention performed to – or close to failure (Andersen & Aagaard, 2000; Andersen et al., 2010; Pareja-Blanco et al., 2017; Staron et al., 1991). If such a fiber type shift is more pronounced with higher velocity losses, the reduction in the percentage of IIx fibers might be detrimental in maximal power and velocity movements such as sprinting and jumping (Cormie et al., 2011a), which may partly explain how low to moderate velocity loss thresholds could be beneficial when the goal is to maximize neuromuscular adaptations while simultaneously maintain lower neuromuscular fatigue.

The VL40 group exhibited significant increases in leg press maximal power compared to the VL20 group. Although not significant between groups, these improvements were accompanied with increases in 10- and 30 meter on ice sprint performance from pre to post-test in the VL40 group. These findings may suggest that a higher velocity loss may have been more advantageous for this particular group, despite contradicting previous research. A possible explanation to why VL40 showed increases from pre to post-test could be because of the higher training volume. It is well established that there exist a dose-response relationship between training volume and muscle hypertrophy (Schoenfeld et al., 2017). Muscle cross-sectional area is an important factor for maximal muscle strength, and by adding more muscle mass, there is a high chance that this translates to increased strength (Cormie et al., 2011a). Grgic et.al (2018) also found a dose-response relationship between muscle strength and training volume, meaning that higher volume possibly leads to greater strength levels. As per the force-velocity relationship, maximal power is a product of force and velocity, and maximal strength has a strong correlation with force production (Cormie et al., 2011a). As a result, an increase in maximal strength may enhance force output, which can have a positive impact on maximal power, which again is an essential factor for athletic abilities such as jumping and sprinting. Consequently, one possible explanation for the observed results is that the VL40 group has benefitted from the higher training volume, leading to increased strength and hypertrophy, which in turn may have contributed to their improved power output and athletic abilities.

Another possible explanation as to why training to 40% velocity loss could be more beneficial for these exact participants, could be speculated to be that they were in-season during the training intervention. Their overall weekly training volume of higher velocity strength and power actions were high during the intervention with 2 games and 4-5 ice sessions per week. As mentioned before, ice hockey is a physical sport that exposes the players for a high frequency of explosive anaerobic actions during match play (Burr et al., 2008; Cox et al., 1995). Therefore, it could be speculated that the VL40 group may have had a better mix of complementary stimuli, such as all the explosive actions during hockey combined with slightly more heavy exhausting training stimuli from performing their back squat sets to 40% velocity loss. Previous research has demonstrated that training to a higher velocity loss can be more effective for muscle hypertrophy compared to lower velocity loss (Pareja Blanco et al., 2020; Pareja-Blanco et al., 2020; Pareja-Blanco et al., 2017; Rissanen et al., 2022), which could help maintain or increase muscle mass and ultimately contribute to improvements in strength and athletic abilities during the season. In addition, previous studies have shown that a combination of heavy strength training and plyometric exercises is preferable to training with only one of these modalities when the goal is increased strength, speed, and jumping ability (Fatouros et al., 2000; Hammami et al., 2019; Pareja-Blanco et al., 2017). However, as our study participants trained with the same percentage of 1RM in both groups, our findings cannot be fully compared with these studies, where the main difference were degree of fatigue. Nevertheless, the comparison to these studies may be the indication that a better mix of stimuli can be better, were we had a different mix of more or less exhaustion strength training, combined with explosive efforts during match play. This could be another potential explanation to the results, in addition to higher training volume in the VL40 group, which is a more likely candidate to explain possible beneficial effects of that training modalities.

No significant differences were observed between the groups in on- and off-ice sprinting and jumping performance from pre- to post-test. However, the VL40 group demonstrated a significant increase in on-ice 10m and 30m sprint performance. Conversely, the VL40 group also showed a significant decrease in off-ice 30m sprint performance from pre- to post-test. Off-ice sprint performance is considered to be the best predictor for on-ice skating speed, as it measures both leg power and speed as they relate to skating (Behm et al., 2005; Farlinger et al., 2007). The decrease in off-ice sprint performance in the VL40 group may be attributed to the absence of specific off-ice sprint training during the intervention period. However, both groups engaged in considerable on-ice sprinting during the intervention period, and the principle of specificity (Behm & Sale, 1993) could potentially explain the increase in on-ice sprint performance observed in the VL40 group. Additionally, the increases in maximal power observed in the VL40 group could also explain the improvement in skating sprint speed, as maximal power has previously been shown to be a good predictor of skate sprint speed (Behm et al., 2005; Burr et al., 2008).

The use of predetermined velocity loss as a mean to monitor and prescribe resistance training set-neuromuscular fatigue has been questioned. Previous studies have recommended that each training set should be terminated once a given velocity loss is reached rather than determining a fixed number of repetitions per set for each participant (González-Badillo et al., 2017; Sanchez-Medina & González-Badillo, 2011). The rationale behind this recommendation was the strong VL-%repetitions (percentage of performed repetitions out of the maximum possible in a set) relationship for back squat and bench press exercises performed in a Smith machine (Rodríguez-Rosell et al., 2020). Indeed, descriptive data reported by Gonzalez-Badillo et al. (2017) indicate low inter-individual variability for the %repetitions until reaching a given velocity loss. However, these findings are of limited ecological validity for free-weight exercises and provide insufficient empirical support for the use of velocity loss to monitor and prescribe RT set-volume. A study conducted by Jukic et al. (2023) raises doubts about the effectiveness of using VL-% repetitions relationships, both general and individual, for prescribing training volume with free-weight back squats. The study found that, firstly, there was poor agreement in the %repetitions completed until reaching a given velocity loss threshold in the free-weight back squat exercise, regardless of the load used, across two consecutive testing sessions. Secondly, the ability of general and individual VL-%repetitions relationships to predict %repetitions in a subsequent testing session was poor, with absolute errors exceeding 10%. Therefore, the study suggests that training to a predetermined velocity loss may not offer any additional advantages over traditional methods for managing strength training degree of fatigue (1RM, RPE, RIR) and should therefore not be used for monitoring and prescribing resistance training with a free-weight back squat exercise.

The positive performance effects observed in the study may not be solely attributed to variations in predetermined velocity loss between groups, but rather, to a greater extent, could be attributed to the use of objective velocity feedback. Several studies have established that receiving objective feedback on velocity after every repetition or set can be an effective tool to enhance training performance and quality through increased competitiveness and motivation (Argus et al., 2011; J. Weakley, K. Till, et al., 2019; J. Weakley, K. Wilson, et al., 2019; J. J. Weakley et al., 2019). Therefore, training with a goal of maintaining maximum concentric velocity in every repetition through objective feedback on velocity and velocity loss could be beneficial for athletes, even if the exact velocity loss threshold is not that accurate or important.

# Practical Implications

- Interestingly, training to a 40% velocity loss showed significant increases in leg press maximal power on in-season ice hockey players compared to training to 20% velocity loss, contradicting previous research. Furtherly, training to 40% velocity loss led to significant increases in on-ice 10- and 30m sprint performance, even though low to moderate velocity loss thresholds is recommended when training to improve neuromuscular adaptions such as sprinting and jumping within athletes.
- Questions have been raised about the reliability and validity of utilizing velocity loss thresholds as an effective method of prescribing training volume and intensity. There is a high variability in velocity loss before reaching volitionary fatigue in the free weight back squat exercise, both between training sessions and between individuals, hence raising questions if it provides any additional benefits compared to costless, traditional methods of resistance training.
- The small sample size of this study may have limited the ability to detect significant effects, highlighting the importance of conducting additional studies with similar designs to increase the power and generalizability of the findings.

# Conclusion

The only between group difference found from pre to post test in the current study, was the increase in leg press maximal power observed in the VL40 group. No between group differences were found in on/off ice sprint performance or CMJ height. The VL40 group might have benefitted from a higher volume and/or a better mix of stimuli, as the group showed significant increases in maximal power and on-ice sprint abilities from pre to-posttest. This study gives insight to how different velocity losses effects athletic abilities within semi-professional athletes in-season. The sample size in this study is very low however, making it hard to generalize the findings to others. Future reaserch should conduct similar study designs with athletes in season, to further analyze the effects of different velocity loss thresholds on athletic performance.

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# PART 2

# THEORETICAL BACKGROUND AND METHODS

# Table of content

# 1.0 Theoretical perspective

## 1.1 Physical characteristics for optimal performance in power demanding sports

Maximal power is a key measure of muscular performance, reflecting the highest level of power output achieved during a single movement (Gollnick & Bayly, 1986) with the aim of producing maximal velocity at take-off, release, or impact (Kraemer & Newton, 2000; Newton & Kraemer, 1994). It represents an important factor across a wide range of sports-related movements, including sprinting, jumping, changing direction, throwing, kicking, and striking. Previous research has shown that superior ability to generate maximal power is typically associated with enhanced athletic performance (Kraemer & Newton, 2000; Newton & Kraemer, 1994; Sleivert & Taingahue, 2004; Young et al., 2005). Therefore, maximizing maximal power output through appropriate training strategies represents an important goal for athletes seeking to optimize their athletic performance.

Ice hockey is a highly complex sport requiring multiple fitness components. It is a high-intensity, intermittent full-contact sport of anaerobic endurance (Spiering et al., 2003). In addition, strength, speed, power, acceleration, aerobic endurance, balance, and agility have all been shown to be key components for successful play (Burr et al., 2008; Cox et al., 1995)

## 1.2 The importance of strength, power, speed and jumping ability in ice hockey

Enhanced physical capabilities are crucial for maximizing game-related performance in ice hockey. Increased fitness levels are associated with improved explosive efforts such as during puck battles, body checks, and breaking free from opponents to score goals (Huard Pelletier et al., 2021). Moreover, superior fitness contributes to reduced physical and mental exhaustion, leading to improved decision-making, technical/tactical skills, and reduced injury risk (Haugen et al., 2021; Suchomel et al., 2016). Recent studies have demonstrated the importance of power, speed, and jumping abilities in elite hockey players. Cohen et al. (2022) found that peak leg power predicted league entry and early career success in the National Hockey League (NHL). Similarly, Peterson et al. (2015) showed that Division 1 players had significantly higher measures of anaerobic power, including vertical jump ($p = 0.001$), Wingate peak power ($p = 0.05$), grip strength ($p = 0.008$), top speed ($p = 0.001$), and fastest repeated shift test course time ($p = 0.001$), compared to Division 3 players. Another study by Vigh-Larsen et al. (2019) compared ten elite teams with ten sub-elite teams and found that the elite teams exhibited superior CMJ ($p = 0.05$), agility ($p = 0.05$), and sprint ($p = 0.05$)

performances. These findings emphasize the importance of power, speed, and jumping abilities in ice hockey and suggest that enhancing these physical capabilities can significantly improve players' performance.

## 1.3 Factors determining strength, power, sprint and jumping performance

**Strength**

Performances in sports, like all physical activity, are the result of coordinated activation of the appropriate skeletal muscles. Skeletal muscles act through the body's skeletal and tendinous systems and create the force that can be transferred to movement (Lieber & Fridén, 2000). It is common to distinguish between maximum strength (isometric and dynamic) and explosive strength. Several studies have shown that strength-enhancing adaptations are task-specific, which means that there is no direct transferability from dynamic to isometric exercises and vice versa (Baker et al., 1994; Mcguigan et al., 2010)

**Explosive strength/power**

Explosive strength training is defined as all training that is completed with maximal mobilization in every repetition (Cormie et al., 2010). Explosive strength is the ratio between force/time and is expressed, among other things, by power watts (W) or rate of force development (RFD) (Harris et al., 2000). Maximal power is achieved by optimal values of force and speed because power is the result of these two. Improvements after explosive strength training often include improvements in maximal power (Cormie et al., 2007; Harris et al., 2008), RFD (Winchester et al., 2008; Aagaard et al., 2002), CMJ (Cormie et al., 2007; McBride et al., 2002) as well as the maximum velocity (MV) and mean movement velocity (MMV) by absolute weight resistance (Cormie et al., 2007; González-Badillo & Sánchez-Medina, 2010).

**Sprinting**

Generating high levels of force quickly is essential for achieving faster top speeds, as demonstrated by research showing that faster sprinters produce significantly greater force, have shorter ground contact times, and cover more distance per stride compared to slower sprinters (Weyand et al., 2000). This ability to produce high amounts of horizontal force is closely linked to sprinting performance and the maximal power output (Pmax), which is influenced by lower limb strength and the ability to transfer that strength into forward sprinting motion (Lignell et al., 2018; Morin & Samozino, 2016). In sports like ice hockey, where short-distance acceleration and sprinting are crucial, there is a strong correlation between sprint performance and the ability to produce horizontal force. Activities like sprinting and jumping typically involve short ground contact times of 30-200 milliseconds, so producing force quickly is important for generating high impulse, momentum, and power output (Taber et al., 2016). The rate of force development (RFD) measures the speed at which force can be produced, making it a useful index of explosive strength (McLellan et al., 2011).

Normal sprinting and ice skate sprinting share many similarities, but they also have distinct characteristics. Hockey skating speed places a greater emphasis on impulse, which is the force exerted over a given period, rather than stretch-shortening cycle actions. Several studies have shown a strong correlation between vertical-jump performance and skating acceleration or speed (Bracko & Fellingham, 1997; Bracko & George, 2001; Diakoumis & Bracko, 1998). This indicates that maximum leg strength, rather than reactive leg strength, is a crucial determinant of skating speed. Research has supported this idea, showing that peak force and impulse during the push-off phase of the skating stride are positively associated with skating acceleration and top speed (Green, 2000).

**Jumping**

Jumping is a complex ability that involves accelerating the body mass as quickly as possible, and it depends on multiple factors such as maximal force production by the lower limbs, RFD, and neuromuscular coordination (McLellan et al., 2011; Samozino et al., 2012). The velocity at take-off is a crucial determinant of jumping performance and is influenced by the net mechanical impulse produced into the ground (Winter, 2005). The net mechanical impulse is calculated as the force produced multiplied by the time over which that force is exerted and has been linked to the ability to generate high levels of muscular mechanical power output (Newton & Kraemer, 1994; Winter, 2005).

Increasing squat depth has been found to improve jumping performance in both static jump and countermovement jump, according to research by Kirby et al. (2011). The study revealed that a greater range of motion during the squat results in increased relative net impulse, which is a key factor in vertical jumping performance. It is also known that plyometric training, either alone or combined with strength training, can increase jumping abilities (Haff & Nimphius, 2012).

**Relationship between strength and power**

Power and maximum strength are closely related. An individual's strength levels are a key factor dictating how powerful one can be (Stone et al., 2003). Several studies have showed that stronger athletes express higher power outputs compared with weaker athletes (Baker & Newton, 2008; Cormie et al., 2007; Kraska et al., 2009; McBride et al., 1999). Zamparo et al. (2002) suggests that working on your maximum strength should be the first athletes do when training for higher power outputs. Studies done by Cormie et al. (2010; 2010) support this theory by showing evidence of the importance of high strength levels before targeting specific power developing activities such as plyometrics and ballistic strength training. Cormie et al. (2010) demonstrates that in relatively week athletes (1RM back squat <1.5 x body mass), training that specifically target higher strength levels, is more effective than training that focuses on power generation when attempting to maximize an athletes power outputs. Also, Prue et al. (2010) found that stronger individuals (back squat = 1.97 x their body mass) had more effect and more performance gain after 10 weeks of ballistic training compared to weaker individuals (back squat = 1.32 x their body mass) who undertook the same training intervention. It seems to be highly favorable for all athletes to target maximal strength development first, to maximize their power outputs. Some evidence points towards that athletes should have a minimum back squat of 2 x their body mass before engaging in more specific training to maximize power development (Haff & Nimphius, 2012; Prue et al., 2010; Ruben et al., 2010; Seitz et al., 2014).

## 1.4 Neuromuscular factors determining maximal power, sprint and jump performance

### 1.4.1 Muscle mechanics

**Force-velocity relationship**

The force-velocity relationship is a crucial characteristic property of muscles that affects their power production capabilities. Researchers have used different levels of organization to study this relationship, from the molecular and single-cell levels to whole muscle and multi-muscle movements (Bottinelli et al., 1999; Caiozzo et al., 1981; Kaneko, 1983; Tihanyi et al., 1982; Widrick et al., 1996). Regardless of the approach, the inverse relationship between force and velocity during concentric muscle contraction is represented by the characteristic hyperbola (Hill, 1938). As the velocity of concentric muscle action increases, the amount of force capable of being generated decreases, which is due to actin-myosin cross-bridge cycling. Since the force generated by a muscle depends on the number of attached cross- bridges, force production decreases as the velocity of the contraction increases. Therefore, maximal power output is achieved at a combination of sub-maximal force and velocity values (Lieber, 2002)

Measurements of the force-velocity relationship during movements *in vivo* (more accurately termed load-velocity or torque-angular velocity relationship but referred to as force-velocity relationship throughout to prevent confusion) are challenging due to several factors, including mixed fiber composition (Edgerton, 1986; MacIntosh & Holash, 2000), architectural characteristics (Herbert & Gandevia, 1995; Wickiewicz et al., 1984), anatomical joint configuration (MacIntosh & Holash, 2000), and levels of neural activation (Caiozzo et al., 1981; Perrine, 1986; Wickiewicz et al., 1984). Although these limitations exist, examining the force-velocity relationship during such movements provides crucial insights into the capacity of the intact neuromuscular system to function under different loading conditions. This information is vital to understanding maximal power production during human movements.

**Force-velocity characteristics in sprinting and jumping**

Yamauchi and Ishii (2007) investigated the relationship between FV characteristics and vertical jump performance and found positive correlations between Pmax, Vmax, and maximum isometric force with vertical jump performance ($r = 0.76$, 0.48, and 0.68, respectively; $p < 0.001$). Pleša et al. (2021) explored the associations of mechanical variables derived from the FV relationship with approach jump, linear sprint, and change of direction in young male volleyball players. The study showed that maximal power output and force capacity ($r=0.51$ and 0.45, respectively) influenced jumping performance, while horizontal force production ($r = 0.45$) seemed to affect sprinting performance.

Weyand et al. (2010) found that high RFD during short ground contact times was more critical for sprint performance than the ability to apply force. For jumping performance, RFD showed a positive correlation ($r = 0.68$) with jumping performance, while peak force had mixed results as an indicator of vertical jump performance (Kirby et al., 2011). Newton et al. (1999) discovered that the jump squat group showed greater improvements in jumping performance than the back squat group, likely due to higher force production and RFD before take-off.

**Length-tension relationship**

The ability of skeletal muscle to generate force is highly dependent on sarcomere length, as evidenced by extensive research (Edman, 1966; Gordon et al., 1966; Lieber et al., 1994). Optimal overlap between the actin and myosin filaments, referred to as the "optimal length," results in the greatest potential for force production on activation of the cross-bridge cycle. This optimal length provides maximal cross-bridge interaction, allowing for the greatest levels of active tension development (Edman, 1966; Gordon et al., 1966; Lieber et al., 1994). On the other hand, when sarcomere lengths are shortened below the optimal length, force production is impaired due to the overlap of the actin filaments from opposite ends of the sarcomere and the compression of the myosin filament as it comes in contact with the Z-disk (Lieber, 2002). Additionally, stretching a sarcomere beyond the optimal length reduces force production capacity, as cross-bridge interaction is decreased due to less overlap between the actin and myosin filaments at longer lengths (Edman, 1966; Gordon et al., 1966; Lieber et al., 1994). Studies conducted in vivo have demonstrated that resting muscle lengths are typically slightly shorter than the optimal length (Close, 1972). Therefore, a slight stretch prior to activation may increase muscular force. While the force-velocity relationship defines muscular power, the length-tension relationship plays an important role in maximal muscular power production by influencing the ability of muscle fibers to develop force.

Active muscle-tendon units have the ability to store mechanical energy as elastic energy in series elastic components like fiber cross-bridges, aponeurosis, and tendon, upon being stretched (Cavagna et al., 1968; Kubo et al., 1999). The stored elastic energy acts as an energy supplier to enhance power output during muscle contractions (Cormie et al., 2011a). In jumping and sprinting, the leg spring compresses upon ground contact, stores energy, and then releases it at push-off, which minimizes displacement and enhances force production (Hobara et al., 2008). The fascicle length changes at a slower speed, allowing the muscle-tendon unit to work at high shortening velocities and achieve greater force production according to the force-velocity relationship (Fukashiro et al., 2006). Tendons with high stiffness release elastic energy faster and power athletes exhibit higher leg stiffness in the knee, ankle, and hip joints, compared to endurance athletes (Hobara et al., 2008; Turner & Jeffreys, 2010). Greater tendon stiffness in the preferred jumping leg leads to higher force production than the non-preferred leg (Bayliss et al., 2016). Additionally, Achilles tendon force production increases with sprint velocity, highlighting the role of tendon stiffness (Mero et al., 1992). Efficient stretch-shortening cycle (SSC) is vital for explosive activities such as sprinting and jumping, and drop jump with short ground contact time and CMJ have shown significant negative correlation with 30-m sprint performance, underlining the need for an efficient SSC ($r = -0.79$ and $-0.60$, respectively) (Hennessy & Kilty, 2001). Combination of heavy and explosive strength training has been found to increase knee tendon stiffness more significantly compared to heavy or plyometric training alone (Toumi et al., 2004).

### 1.4.2 Morphological factors

**Muscle fiber type**

Muscle force-velocity properties depend on the fiber type composition of the muscle, with type II fibers generating greater power per unit cross-sectional area (CSA) than type I fibers due to differences in specific force, Vmax, and the curvature of the force-velocity curve (Bottinelli et al., 1999; Faulkner, 1986; Thorstensson et al., 1976; Tihanyi et al., 1982; Widrick et al., 2002). At sub-physiological temperatures, peak power per unit CSA is 5- and 10-fold greater in type IIa and IIx fibers, respectively, compared with type I fibers, although differences at closer to in vivo muscle temperatures are smaller (Faulkner, 1986; Lionikas et al., 2006; Widrick et al., 2002). Type II fibers are characterized by high sarcoplasmic reticulum and myofibrillar adenosine triphosphatase (ATPase) activities, high Vmax, short contraction time/twitch duration, and the ability to develop force rapidly, whereas type I fibers display comparatively low ATPase activity and Vmax with long contraction times/twitch durations (Barany, 1967; Bottinelli et al., 1994). Muscle fiber type composition is influenced by both genetic and environmental factors, with elite strength-power athletes having predominantly type II fibers, and elite endurance athletes displaying a predominance of type I fibers (Costill et al., 1976; Gollnick et al., 1972; Simoneau & Bouchard, 1995). Resistance training can elicit transformations in myosin heavy chain gene expression within type I and II fibers, with type IIx isoforms being reduced at the expense of an increase in the expression of type IIa isoforms following strength training (Staron et al., 1994; Widrick et al., 2002).

Methenitis et al. (2016) reported positive correlations between squat jump (SJ) height and lean body mass of the lower extremities as well as cross-sectional area (CSA) of type IIX fibers ($r = 0.32$ and $0.32$, $p \leq 0.05$, respectively). In addition, they found that countermovement jump (CMJ) performance was associated with longer fascicle length of the vastus lateralis ($r = 0.32$, $p \leq 0.05$). Trappe et al. (2015) observed that a champion sprint runner had a relatively high proportion of type IIA fibers and an extraordinary amount of type

IIX fibers. These findings suggest that jumping and sprinting performance requires not only lower or moderate extremities lean body mass but also a high percentage of fast-twitch fibers, particularly type IIX, and longer fascicle lengths.

**Cross-sectional area**

The cross-sectional area (CSA) of a single muscle fiber is directly proportional to its maximal force generation regardless of fiber type (Bodine et al., 1982; Edgerton, 1986). Therefore, a muscle fiber with a greater CSA can generate higher Pmax, which heavily influences power (Malisoux et al., 2006; Shoepe et al., 2003; Widrick et al., 2002). Research comparing single muscle fibers of sedentary and resistance-trained men showed significantly greater CSA, Fmax, and Pmax in resistance-trained men for both type I and II fibers (Shoepe et al., 2003). However, the differences disappeared when Fmax was normalized to CSA and Pmax was normalized to fiber volume (Shoepe et al., 2003). Studies on whole-muscle CSA using CT scans also demonstrated significantly higher Fmax in muscles with greater CSA (Maughan et al., 1984). Additionally, there are strong relationships between knee extension Fmax and quadriceps CSA in both men and women (Jones et al., 1989; Rutherford & Jones, 1986). Although not all of the variation in whole-muscle Fmax is solely due to variation in muscle CSA, evidence shows that hypertrophy induced by heavy strength training is effective in increasing CSA and Fmax, leading to improvements in maximal muscular power (Kaneko, 1983; Malisoux et al., 2006; Widrick et al., 2002; Wilson et al., 1993; Aagaard et al., 2001). The hypertrophic response occurs in both type I and II muscle fibers but is more significant in type II fibers. However, as the training age of the athlete increases, the influence of increased CSA on muscular power is theorized to diminish (Sale, 1988). Moreover, the degree of muscle hypertrophy depends on the type of training and the specific program variables such as intensity, volume, and frequency (Wernbom et al., 2007). In a recent study by Tottori et al. (2021), it was found that larger CSA of the gluteus maximus ($r = -0.366$, $p < 0.05$) and psoas major ($r = -0.388$, $p < 0.05$) were significantly associated with better 100-m sprint performance. Sprinters exhibited 18.4% and 21.7% larger CSA of the gluteus maximus and psoas major, respectively, compared to non-sprinters. Heavy strength training primarily increases maximal muscular power mediated by improved CSA, whereas specific power training may not elicit significant hypertrophic responses (Häkkinen et al., 1987; Kyröläinen et al., 2005; Potteiger et al., 1999; Wernbom et al., 2007).

### 1.4.3 Neural factors

**Motor unit recruitment**

Muscle force is influenced by the number and type of motor units recruited. Motor units are recruited according to the size principle, whereby the smaller motor units are activated initially, followed by progressively larger ones, during graded, voluntary contractions of increasing force (Henneman et al., 1974; Henneman et al., 1965). Although the size principle applies to isometric and ballistic contractions, the threshold of motor unit recruitment is lower during ballistic movements due to the rapid force escalation (Van Cutsem et al., 1998). Recruitment of high-threshold motor units is beneficial for maximal power production (Enoka & Fuglevand, 2001). Motor unit recruitment during training may adapt in several ways, including increased recruitment, preferential recruitment of high-threshold units, and lowered recruitment thresholds (Sale, 1988, 2003). Each of these possible adaptations would increase agonist activation, leading to increased tension development by the muscle and consequently improved power output.

According to Saplinskas et al. (1980), sprinters may possess a superior ability to selectively activate fast-twitch motor units compared to untrained and endurance athletes. It is proposed that the selective activation allows motor units to generate tension without having to overcome elastic damping from the tendon, thereby increasing force production (Lind & Petrofsky, 1978). This synchronization of motor units appears to be a strategy of inter-muscular coordination, affecting both force and RFD during complex multi-joint movements such as jumping and sprinting (Mellor & Hodges, 2005).

**Firing frequency**

The firing frequency of a motor unit, which represents the rate of neural impulses transmitted from the α-motoneuron to the muscle fibers, can impact the ability of a muscle fiber to generate force in two ways. Increasing the firing frequency enhances the magnitude of force generated during a contraction, with force of contraction estimated to increase by 300–1500% when the firing frequency of a motor unit is increased from its minimum to maximum rate (Enoka, 1995). Moreover, motor unit firing frequency influences the RFD of muscle contraction, with high initial firing frequency resulting in increased RFD (Zehr & Sale, 1994). Training-induced enhancement of maximum motor unit firing frequency has been proposed as a possible mechanism driving improvements in neuromuscular performance (Cracraft & Petajan, 1977). Although most resistance training studies involving healthy adults indicate that voluntary activation does not increase following training (Harridge et al., 1999; Herbert et al., 1998; Sale et al., 1992), research involving intramuscular EMG has reported training-induced increases in motor unit firing frequency during maximal contractions (Kamen & Knight, 2004; Patten et al., 2001; Van Cutsem et al., 1998). Improved activation of fast-twitch fibers and increased force production at both fast and slow velocities lead to enhanced maximal voluntary contraction speed and power output, thereby contributing to improved sprinting and jumping performance (Kamen & Knight, 2004; Patten et al., 2001; Van Cutsem et al., 1998).

**Inter-muscular coordination**

Inter-muscular coordination is a crucial factor for skill transfer in sports, as it refers to the synchronized interaction of muscles involved in a particular movement (Young, 2006). Thus, emphasizing movement-specific training programs that facilitate high activation of agonist muscles, increased synergist activity, and decreased antagonist co-contraction is essential for efficient movement patterns (Cormie et al., 2011a). Coactivation of the antagonist muscles can hinder the activation of the agonist and produce force in the opposite direction of the desired movement, leading to negative transfer in athletic movements (Young, 2006). However, a certain degree of coactivation is necessary for joint stabilization and movement coordination (Cormie et al., 2011a). Therefore, decreasing the coactivation of antagonistic muscles to some extent can be advantageous (Young, 2006).

In both sprinting and jumping, the coordinated triple extension of ankles, knees, and hips is crucial for successful performance and requires suitable interaction between musculotendinous units (Cormie et al., 2011a). Elite athletes possess highly developed motor programs and exhibit superior responses to high-intensity sprint training compared to less-trained athletes, as observed in their increased stride rate and length (Mero & Komi, 1985). Studies have shown that intensive drop jump training can optimize coordination and activation patterns, leading to improvements in jumping performance (Alkjaer et al., 2013) (Alkjaer et al., 2013), as ballistic, plyometric, and weightlifting exercises can potentially enhance both the rate of neural activation and inter-muscular coordination (Prue et al., 2011b) (Cormie et al., 2011b).

## 1.5 Resistance training to enhance athletic abilities

Successful athletic performance in many sports is highly dependent on the ability to generate maximal power during complex motor skills. Developing effective and efficient training programs that improve maximal power production in dynamic, multi-joint movements is a crucial challenge faced by scientists and coaches. In this regard, two critical factors should be considered. First, maximal strength is a fundamental prerequisite for high levels of power, and thus, enhancing and maintaining maximal strength is essential for the long-term development of power (Haff & Nimphius, 2012; Prue et al., 2011b). Second, power training programs should be designed considering movement pattern, load, and velocity specificity (Prue et al., 2011b). Ballistic, plyometric, and weightlifting exercises can be used effectively as primary exercises within a power training program that enhances maximal power. The loads applied to these exercises should vary depending on the specific requirements of each sport and the type of movement being trained. In most sports, ice hockey included, athletes encounter a wide spectrum of loads during play, making it beneficial to increase maximal power outputs across a variety of loads (Prue et al., 2011b). The use of ballistic exercises with loads ranging from 0% to 50% of 1RM and/or weightlifting exercises performed with loads ranging from 50% to 90% of 1RM appears to be the most potent loading stimulus for improving maximal power in complex movements (Prue et al., 2011b). Additionally, plyometric exercises should involve stretch rates as well as stretch loads that are similar to those encountered in each specific sport and involve little to no external resistance. These loading conditions allow for superior transfer to performance because they require similar movement velocities to those typically encountered in sport (Saez de Villarreal et al., 2012).

## 1.6 Autoregulation in resistance training

Individualization is a widely accepted concept in sport and exercise science (Wing, 2018), which suggests that adjusting training to align with an individual's response to training and non-training stressors can maximize performance and prevent injury and overtraining (Borresen & Lambert, 2009; Thorpe et al., 2017). This individual response is typically estimated by measuring performance in tests that assess the physical quality being trained. Autoregulation, which involves adjusting training based on an individual's performance measurements, is believed to be superior to traditional fixed training regimes (Colquhoun et al., 2017; Mann et al., 2010). Autoregulation provides a closer match between intended and delivered training stimulus on a session-by-session basis and at the program level, avoiding periods of sub-optimal loading that may occur due to day-to-day performance fluctuations or short-term adaptations (Wallace et al., 2014).

It is normal to separate between subjective and objective markers of autoregulation in resistance training. Subjective markers of autoregulation such as rating of perceived exertion (RPE) and reps in reserve (RIR), have gained popularity among coaches and athletes as practical tools for monitoring and adjusting training loads. RPE is a subjective measure of the perceived effort or intensity of a given set or exercise and has been shown to correlate with measures of physiological stress and fatigue in resistance training (Helms et al., 2018). RIR is a measure of how many repetitions an individual can perform before reaching failure and has been shown to be an accurate predictor of the load and volume required for strength and hypertrophy adaptations (Zourdos et al., 2016). Helms et al. (2017) found that RPE had strong relationships with percentage 1-RM for squat, bench press, and deadlift for powerlifters ($r = 0.88–0.92$), indicating it as a reliable tool for prescribing intensity. However, RIR may be less accurate for untrained individuals (Steele et al., 2017) and in sets with high repetitions (Hackett et al., 2017; Zourdos et al., 2021). It is suggested that RIR based RPE may be more effective for prescribing training intensity among experienced resistance-trained participants during sets with a relatively low number of repetitions.

The advancement of contemporary technology has facilitated the use of objective autoregulation techniques for measuring exercise intensity, which can adjust both intensity and volume. One such training method is velocity-based resistance training (VBT), which employs reliable measuring tools like accelerometers, high-speed/velocity cameras, linear position transducers, or velocity transducers to monitor the movement velocity of an exercise (Jovanović & Flanagan, 2014)

## 1.7 Velocity based strength training

### What is VBT?

VBT encompasses a wide range of training topics and approaches that can be integrated to varying degrees. At its simplest level, velocity can be used as an adjunct to traditional percentage-based training. For instance, athletes can receive visual or verbal velocity feedback to boost performance and increase motivation and competitiveness. Receiving objective feedback on velocity after every repetition or set has proven to be a very effective tool to enhance performance through increased competitiveness and motivation (Argus et al., 2011; J. Weakley, K. Till, et al., 2019; J. Weakley, K. Wilson, et al., 2019; J. J. Weakley et al., 2019). On the other hand, VBT can be incorporated into all aspects of a resistance training program, including load prescription, set and rep numbers, and programming methodology (Banyard et al., 2018; Jovanović & Flanagan, 2014). Hence, VBST is best described as a technique that "uses velocity to inform or enhance training practice."

**Why VBT?**

Velocity is often preferred over other kinetic or kinematic outputs, such as power, when performing resistance training for three reasons. Firstly, it is a well-established fact that as the external mass increases, lifting velocity decreases (Izquierdo et al., 2006; Weakley et al., 2020). This decrease in velocity continues until the minimum/terminal velocity threshold (V1RM) is reached, which corresponds to the 1RM load (Izquierdo et al., 2006). Secondly, there is a near-perfect linear relationship between velocity and intensity as a percentage of maximum capacity (% of 1RM). This has been consistently demonstrated across a range of exercises and submaximal loads (Conceição et al., 2016; García-Ramos et al., 2018). Thirdly, exercise-induced fatigue often leads to a transient decline in muscle fiber shortening speeds, relaxation times, and force-generating capacity, resulting in subsequent reductions in voluntary exercise velocity (González-Badillo et al., 2017; Sanchez-Medina & González-Badillo, 2011). In other words, exercise velocity decreases as fatigue accumulates. By acknowledging these fundamental concepts, practitioners can use velocity outputs to prescribe external loads and training volumes accurately and objectively for each session, regardless of fluctuations in fatigue and athlete readiness.

### 1.7.1 Velocity loss thresholds

A common method to integrate VBST, is by using velocity loss thresholds. Load and volume prescriptions in VBST are based on the assumption of an inverse linear relationship between %1RM and barbell velocity (Weakley et al., 2021). When an exercise is performed with maximal concentric intent and fatigue ensues, velocity of the barbell inevitably will decrease (Sanchez-Medina & González-Badillo, 2011). A strong correlation seems to exist between intra-set velocity loss and mechanical, metabolic and perceptual markers of fatigue, as well as between velocity loss and the total number of repetitions completed relative to the maximal number of repetitions possible to perform in a set (González-Badillo et al., 2017; Rodríguez-Rosell et al., 2018; Sanchez-Medina & González-Badillo, 2011). In a back squat exercise for example, stopping a set after reaching 20% VL would approximately result in 50% of the possible repetitions being completed (Sanchez-Medina & González-Badillo, 2011), while a VL of 40 or 50% would lead to repetitions being performed to, or very close to muscle failure (Pareja-Blanco et al., 2017). VL thresholds can therefore be used to regulate volume and how close one is to failure with reasonable precision (González-Badillo et al., 2017; Sanchez-Medina & González-Badillo, 2011).

**Effects of different velocity loss thresholds**

In recent years, numerous studies have investigated the impact of training to a specific velocity loss threshold on various performance outcomes, including strength, hypertrophy, athletic abilities, and fatigue. A recent meta-analysis by Jukic et al. (2022) revealed an inverse relationship between velocity loss and subsequent improvements in CMJ and sprint performance. Specifically, training to more than approximately 20% velocity loss was found to have a detrimental effect on these performance measures, likely due to the principle of training specificity (Behm & Sale, 1993). Average velocity during training was higher for low to moderate velocity loss thresholds compared to high thresholds, and significant correlations have been reported between repetition velocity and improvements in jumping and sprinting performance (Rodríguez-Rosell et al., 2020; Rodríguez-Rosell et al., 2021).

Interestingly, achieving a certain VL during resistance training does not appear to impact the magnitude of strength gains when controlling for other factors such as exercise choice, strength levels, and training duration (Jukic et al., 2022). This suggests that training to a lower VL threshold may be just as effective for strength gains as training to a higher threshold, even if the latter results in greater training volume and proximity to task exhaustion. Several studies have suggested that an inverted U-shaped relationship may exist between velocity loss and maximal strength gains (Alcazar et al., 2021) (Pareja-Blanco et al., 2020) (Rodiles-Guerrero et al., 2020), with further increases in strength gains not observed once a moderate velocity loss threshold is exceeded (e.g., 20 or 25% velocity loss).

In contrast to maximal strength gains, increasing velocity loss has been shown to lead to a linear increase in muscle hypertrophy (Jukic et al., 2022), likely due to the concomitant increase in training volume. A meta-analysis by Schoenfeld et al. (2017) similarly found a dose-response relationship between training volume and muscle hypertrophy. However, a higher VL threshold may also lead to a decrease in early rate of force development and a reduction in the expression of fast-twitch muscle fibers, potentially compromising muscle strength (Grgic et al., 2021). Thus, low to moderate VL thresholds may be more beneficial for optimizing maximal power adaptations to resistance training.

These findings support both the notion of not needing to perform high volume protocols and also not training to failure when optimizing strength gains and athletic abilities (Grgic et al., 2021; Jukic et al., 2022). Taking all this into consideration, low to moderate rather than high VL thresholds could be more beneficial to optimize maximal power adaptations to RT.

## 1.8 Strength training in season

In-season strength training is essential for maintaining and improving physical performance in athletes during the season. The demands of competition and practice can lead to a decline in strength and power, which can negatively impact performance and increase the risk of injury (Rønnestad et al., 2011). During a competition period, physical training often gets overlooked and given a lower priority compared to tactical and technical training, and fatigue management.

Rønnestad et al. (2011) found that professional football players who performed resistance training once per week for 12 weeks maintained their strength and speed, while those who trained once every two weeks experienced an average strength loss of 10% in a 1RM half squat. This aligns with previous studies in recreationally strength-trained subjects, collegiate soccer players, and cyclists (Graves et al., 1988; Rønnestad et al., 2010; Silvestre et al., 2006).. However, performing in-season strength training twice per week during an 11-week soccer season resulted in a reduction in strength, jump height, and sprint performance, possibly due to catabolic processes leading to acute overtraining (Kraemer et al., 2004). Proving what a thin line there is between optimal training for enhancing performance and overtraining due to the increased physical demands during the in-season. In-season strength training is typically aimed at maintaining the fitness level achieved during the preparatory period, as it competes with the increased demands of competition, technical and tactical training.

### 1.8.1 High or low velocity loss for athletes in-season

Effective management of fatigue and optimization of training is essential for athletes during their in-season period. VBST can be used as a valuable tool for regulating load, volume, and individual readiness among athletes to ensure training efficiency (Weakley et al., 2021). Research suggests that training at low to moderate velocity loss thresholds may maximize neuromuscular adaptations while reducing fatigue (Jukic et al., 2022). This approach appears to be effective for professional athletes as well, with the review conducted by Wlodarczyk et al. (2021) indicating that applying velocity losses of 10-20% can help induce neuromuscular adaptations while reducing neuromuscular fatigue, leading to better quality work in professional athletes.

# 2.0 Methodological discussion

## 2.1 Subjects

The data analysis included 15 semi-professional ice hockey players. Initially, 43 participants from two separate teams, a men's team (n=21) and a women's team (n=22), were recruited for the intervention. However, 6 male subjects dropped out, and the female group discontinued the intervention in week 5, resulting in a reduced sample size compared to the original design. The smaller sample size and dropout of subjects present challenges for the study, such as insufficient statistical power to address the research question and an increased risk of type 2 error (Andrade, 2020).

The number of subjects in the velocity loss groups (VL20 n = 8 and VL40 n = 7) is also smaller compared to other studies utilizing velocity-based resistance training (VBST), which typically include ≥10 participants in each group (Pareja-Blanco et al., 2017; Pareja-Blanco et al., 2017; Rissanen et al., 2022; Rodríguez-Rosell et al., 2021). According to Pareja-Blanco et al. (2020), a sample size of 12 subjects per group would satisfy assumptions for alpha (0.05) and power (0.95). Therefore, our study had a relatively small number of participants per group, making it more challenging to detect significant differences and increasing the risk of type 2 error.

The biggest reason as to why the sample size was so small, was because the women’s team only completed 5 weeks of training instead of the intended 8. Initially, we thought that the two teams were equally used to heavy strength training. After talking to some of the players, we quickly found out that the women’s team were not accustomed to heavy resistance training during the competitive part of the season. This meant that they felt a high degree of fatigue in connection with the intervention training, which meant that they were not as fresh leading into competitive games. This ultimately made their head coach decide that the team should reduce off-ice training during the remaining part of the season to ensure that the players were maximally prepared for matches. Consequently, the data collected from this team were deemed insufficient for inclusion in the data analysis of this master thesis. The female team were allowed to perform the post-tests after 5 weeks instead of the originally planned 8 weeks on request on the physical performance coach, but the data was not included in this study.

## 2.2 Experimental design

This study was carried out as a randomized controlled trial (RCT), which involves randomly assigning participants to comparison groups under strictly controlled circumstances (Bhide et al., 2018). RCTs are considered the most reliable and systematic method for establishing a cause-and-effect relationship between an intervention and an outcome (Bhide et al., 2018). Observational data is more susceptible to bias, defined as a systematic tendency of any factors associated with the design, conduct, analysis, evaluation, and interpretation of results to deviate from the true value of the effect (Bhide et al., 2018). Randomization reduces bias by ensuring that participant characteristics are balanced across groups, allowing any outcome differences to be attributed to the intervention (Hariton & Locascio, 2018). However, one limitation of RCTs is the potential difficulty in generalizing the results to populations outside of the study group (Hariton & Locascio, 2018). Therefore, it is crucial to consider this criterion while designing RCTs, and the results may only apply to patients similar to those enrolled in the trial, while the extrapolation of the findings to other populations may not be entirely valid (Bhide et al., 2018). Additionally, it is important to recognize the Hawthorne effect, where subjects' behavior may change because of their awareness of being studied, potentially obscuring the impact of the training intervention (McCambridge et al., 2014).

The study's design did not incorporate a non-training control group, which may have facilitated the distinction between changes brought about by the intervention and changes that occurred spontaneously (Polit & Beck, 2010). In-season athletes must maintain their physical capabilities, making it difficult to include a non-training group, however the absence of a non-training group limits the study's ability to compare and evaluate the impact of the training intervention (Polit & Beck, 2010). Thus, the absence of a non-training control group can be considered a limitation of the study.

Blinding is a technique to help eliminate unconscious information bias between the subjects (Bhide et al., 2018). This was however not possible considering the subjects all came from the same team and trained together at the same time. Although blinding is a desirable approach to minimize bias, the nature of the study made it impractical to implement, and it can be seen as a weakness.

## 2.3 Training intervention

The intervention in this study consisted of an 8-week VBT program, which aligns with the typical duration observed in a systematic review of 19 longitudinal VBT interventions (Jukic et al., 2022). The selection of an 8-week duration is consistent with several studies covered in Jukic et al. (2022) that employed the same velocity loss thresholds, indicating that an 8-week intervention is adequate for observing training effects and facilitates meaningful comparisons (Alcazar et al., 2021; Pareja-Blanco et al., 2017; Pareja-Blanco et al., 2020; Rissanen et al., 2022). Furthermore, Jukic et al. (2022) also revealed that a common approach in studies employing squats with similar duration and velocity loss thresholds is to distribute 16 training sessions over two sessions per week.

What sets this study apart from those included in Jukic's systematic review is that the participants were semi-professional athletes in-season. It is well known that an athlete's training load and volume can vary significantly depending on the time of the year. During the competitive season, many sports involve a high frequency of games, leaving limited time for activities other than those directly supporting on-ice performance and recovery. Consequently, it has been recommended that off-ice efforts during the in-season period in ice hockey should primarily focus on maintaining the power and strength gains achieved during the off-season (Neeld, 2018; Nightingale, 2014). In this study, the participants had an average of two games per week throughout the intervention period, in addition to 4-5 weekly on-ice hockey sessions. The high volume of training and games raised concerns about the potential for achieving enhanced physical capabilities in the intervention period. While several studies have demonstrated improvements in physical attributes with in-season heavy strength training performed twice a week (Hermassi et al., 2017; Rønnestad et al., 2010; Silvestre et al., 2006), it is worth noting a study by Kraemer et al. (2004) which reported a decline in strength, vertical jump, and sprint performance in professional football players after an 11-week in-season heavy strength training intervention. This decline was hypothesized to be a result of an excessive stress stimulus leading to acute overtraining. Such a scenario could also occur in this study, particularly in the VL40 group, as training to or near failure can increase mechanical, perceptual, and metabolic markers of fatigue (González-Badillo et al., 2017; Rodríguez-Rosell et al., 2018).

The practioners were present at all the strength training sessions, to ensure that the participants performed the back squat in a satisfactory way, and to encourage them and provide verbal feedback. This ensures that the back squat repetitions are performed with the right technique, as well as the participants are being verbally pushed and encouraged to perform the repetitions with maximal intent.

## 2.4 Measurements

Standardized procedures and precise equipment are crucial for valid and reliable performance assessments in sports (Haugen & Buchheit, 2016). The data quality of these assessments is affected by both reliability and validity (Golafshani, 2003). Reliability refers to the degree of consistency and repeatability of a test, while validity refers to the extent to which it measures what it is intended to measure (Golafshani, 2003). For high-performing athletes, test-retest reliability and within-subject variation are essential to observe true changes in performance (Hopkins, 2000). The coefficient of variation (CV%) is often used to assess reliability across testing sessions, with acceptable reliability considered as CV ≤ 10% and good as CV ≤ 5% (Lindberg, Solberg, et al., 2021). To increase reliability, it is important to control the working conditions and perform similar pre-and post-test procedures (Thomas et al., 2022). Therefore, testing protocols were standardized through similar procedures for both pre-and post-test to boost reliability. Familiarization sessions and an information meeting were conducted before the intervention to minimize learning effects, and standardized testing protocols were used for both pre-and post-tests. The test personnel provided verbal motivation to encourage maximal performance output, although the degree of motivation provided may have varied between subjects and could have affected the results.

**On and off-ice sprint tests**

The sprint performance of the subject was evaluated using the 30-meter sprint test, which employed dual-beamed photocells that triggered time only when both beams were broken, ensuring accurate results (Haugen & Buchheit, 2016). This test has demonstrated high reliability with a coefficient of variation of 1.4% for 20-m sprint times (Haugen et al., 2014). Conducting the test indoors eliminated the influence of uncontrollable factors such as wind, altitude, temperature, barometric pressure, and humidity (Haugen & Buchheit, 2016). The subjects initiated the test, thereby eliminating the impact of their reaction time on the results. Generating a high impulse during sprinting requires applying a large force to the ground, which promotes high momentum and power output (Taber et al., 2016). The friction between the subject's footwear and the ground plays a critical role in efficiently producing force. Additionally, an optimal shoe bending stiffness has been shown to improve performance to some extent, and the weight of the subject's clothing could have affected the results (Haugen & Buchheit, 2016). The lack of uniformity in clothing between pre-and post-tests could have influenced the results, which is a limitation of this study.

Naturally, ice hockey players never sprint off-ice in a competition, and very little during their training. This raises questions about the validity with a sprint test off-ice for hockey players. However, off-ice sprinting have shown to be the best predictor for on-ice sprinting abilities in hockey players (Behm et al., 2005; Farlinger et al., 2007), which is why it was included as part of the test-battery. The same dual-beamed photocells were used on both off-ice and on-ice sprinting. The subjects performed the on-ice sprint test in full hockey gear, including stick and protective equipment to make it as match like as possible. This ensured that the test was highly relevant with a high level of validity. The on-ice sprint test was part of the team's usual test-battery, making it more reliable since it was a familiar test.

**Vertical jump test**

Potential jumping performance progress of the subjects was measured using the results from the CMJ, a reliable test with a CV of approximately 5-6% for jump height (Souza et al., 2020). Compared to the squat jump (SJ), the CMJ has shown better test-retest reliability, possibly due to its more natural and familiarized jumping technique including countermovement (Bobbert et al., 1996). The participants were allowed to choose squat depth, and this could affect their jumping performance as the vertical impulse produced into the ground is a critical determinant of jumping ability (Kirby et al., 2011). Greater squat depth allows the muscles to generate force for a longer duration, increasing relative vertical impulse and enhancing jumping performance (Kirby et al., 2011). Despite the absence of jumping movements in hockey match play, vertical jump testing remains a popular and widely utilized assessment among hockey players due to its strong correlation with on-ice sprint performance (Bracko & Fellingham, 1997; Haukali & Tjelta, 2015; Runner et al., 2016).

**Keiser Leg press**

Measurements of lower limb strength and power in the Keiser Leg Press have shown to be a reliable and valid method (Redden et al., 2018). It can be assumed that the reliability of the test is high when measuring extrapolated variables such as the F0, V0, and the Pmax (Lindberg, Solberg, et al., 2021). We used the leg press Keiser machine to measure the theoretical maximal power extrapolated from the force-velocity curve obtained from the 10-repetition protocol. The subjects performed the test with the same seat position on both tests. When looking at between-session reliability, the Keiser Leg Press has shown good reliability for the Pmax value, with a CV value of 4.2% (Lindberg, Solberg, et al., 2021). In addition, an investigation of the validity of the Keiser Leg Press found that valid measurements could be obtained over a wide range of forces and velocities (Lindberg, Eythorsdottir, et al., 2021). Therefore, the obtained results from the Keiser Leg Press can be seen as valid and reliable. Ice hockey is a sport characterized by a high number of sprints and anaerobic actions during games (Burr et al., 2008; Spiering et al., 2003). Maximal power levels have shown to be a good indicator of playing level and early career success (Cohen et al., 2022; Peterson et al., 2015; Vigh-Larsen et al., 2019), while also showing high correlation with on-ice sprint performance (Burr et al., 2008; Runner et al., 2016). Further proving why a maximal power test is an important measurement for ice hockey players.

## 3.0 References


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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)**

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**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) |

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## 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**.

The submission system will prompt you to use an ORCiD (a unique author identifier) to help distinguish your work from that of other researchers. Click **here** to find out more.

**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.

**Free Format Submission**

*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.

### Equity, Diversity and Inclusion

*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.

### Data Sharing and Data Availability

This journal expects data sharing. Review **Wiley's Data Sharing policy** where you will be able to see and select the data availability statement that is right for your submission.

### Data protection

By submitting a manuscript to or reviewing for this publication, your name, email address, and affiliation, and other contact details the publication might require, will be used for the regular operations of the publication, including, when necessary, sharing with the publisher (Wiley) and partners for production and publication. The publication and the publisher recognize the importance of protecting the personal information collected from users in the operation of these services, and have practices in place to ensure that steps are taken to maintain the security, integrity, and privacy of the personal data collected and processed. You can learn more at **https://authorservices.wiley.com/statements/data-protection-policy.html**.

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.

### Data Citation

**Please review Wiley's data citation policy here**.

### Additional Files

### Appendices

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

**Supporting Information / Supplementary Material**

Supporting information is information that is not essential to the article, but provides greater depth and background. It is hosted online and appears without editing or typesetting. It may include tables, figures, videos, datasets, etc.

**Click here** for Wiley's FAQs on supporting information.

Note: if data, scripts, or other artefacts used to generate the analyses presented in the paper are available via a publicly available data repository, authors should include a reference to the location of the material within their paper.

**General Style Points**

The following points provide general advice on formatting and style.

- **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).
- **Trade Names:** Chemical substances should be referred to by the generic name only. Trade names should not be used. Drugs should be referred to by their generic names. If proprietary drugs have been used in the study, refer to these by their generic name, mentioning the proprietary name and the name and location of the manufacturer in parentheses.
- **Use mass not weight**

**Wiley Author Resources**

***Manuscript Preparation Tips:*** Wiley has a range of resources for authors preparing manuscripts for submission available **here**. In particular, authors may benefit from referring to Wiley's best practice tips on **Writing for Search Engine Optimization.**

***Article Preparation Support:*** **Wiley Editing Services** offers expert help with English Language Editing, as well as translation, manuscript formatting, figure illustration, figure formatting, and graphical abstract design – so you can submit your manuscript with confidence.
Also, check out our resources for **Preparing Your Article** for general guidance about writing and preparing your manuscript.

***Guidelines for Cover Submissions:*** If you would like to send suggestions for artwork related to your manuscript to be considered to appear on the cover of the journal, please follow these **general guidelines**.

## 5. EDITORIAL POLICIES AND ETHICAL CONSIDERATIONS

### Peer Review and Acceptance

The acceptance criteria for all papers are the quality and originality of the research and its significance to journal readership. Manuscripts are single-blind peer reviewed. Papers will only be sent to review if the Editor-in-Chief determines that the paper meets the appropriate quality and relevance requirements.

Wiley's policy on the confidentiality of the review process is **available here.**

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**Please review Wiley's policies surrounding human studies, animal studies, clinical trial registration, biosecurity, and research reporting guidelines here.**

### Conflict of Interest

The journal requires that all authors disclose any potential sources of conflict of interest. Any interest or relationship, financial or otherwise that might be perceived as influencing an author's objectivity is considered a potential source of conflict of interest. These must be disclosed when directly relevant or directly related to the work that the authors describe in their manuscript. Potential sources of conflict of interest include, but are not limited to: patent or stock ownership, membership of a company board of directors, membership of an advisory board or committee for a company, and consultancy for or receipt of speaker's fees from a company. The existence of a conflict of interest does not preclude publication. If the authors have no conflict of interest to declare, they must also state this at submission. It is the responsibility of the corresponding author to review this policy with all authors and collectively to disclose with the submission ALL pertinent commercial and other relationships.

### Funding

Authors should list all funding sources in the Acknowledgments section. Authors are responsible for the accuracy of their funder designation. If in doubt, please check the Open Funder Registry for the correct nomenclature: **https://www.crossref.org/services/funder-registry/**

## Authorship

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:

1. Have made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data; and
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.

## Author Name Changes

In cases where authors wish to change their name following publication, Wiley will update and republish the paper and redeliver the updated metadata to indexing services. Our editorial and production teams will use discretion in recognizing that name changes may be of a sensitive and private nature for various reasons including (but not limited to) alignment with gender identity, or as a result of marriage, divorce, or religious conversion. Accordingly, to protect the author's privacy, we will not publish a correction notice to the paper, and we will not notify co-authors of the change. Authors should contact the journal's Editorial Office with their name change request.

## Correction to Authorship

In accordance with **Wiley's Best Practice Guidelines on Research Integrity and Publishing Ethics** and the **Committee on Publication Ethics' guidance**, the *Scandinavian Journal of Medicine & Science in Sports* will allow authors to correct authorship on a submitted, accepted, or published article if a valid reason exists to do so. All authors – including those to be added or removed – must agree to any proposed change. To request a change to the author list, please complete the **Request for Changes to a Journal Article Author List Form** and contact either the journal's editorial or production office, depending on the status of the article. Authorship changes will not be considered without a fully completed Author Change form. [Correcting the authorship is different from changing an author's name; the relevant policy for that can be found in **Wiley's Best Practice Guidelines** under "Author name changes after publication."]

### Additional Authorship Options

Joint first or senior authorship: In the case of joint first authorship, a footnote should be added to the author listing, e.g. 'X and Y should be considered joint first author' or 'X and Y should be considered joint senior author.'

### Data Sharing and Data Accessibility

*Scandinavian Journal of Medicine & Science in Sports* recognises the many benefits of archiving research data. The journal encourages you to archive all the data from which your published results are derived in a public repository. The repository that you choose should offer you guaranteed preservation (see the registry of research data repositories at **https://www.re3data.org/**) and should help you make it findable, accessible, interoperable, and re-useable, according to FAIR Data Principles (**https://www.force11.org/group/fairgroup/fairprinciples**).

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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