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MASTERS THESIS

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Keywords: Ice hockey, Percent velocity loss feedback, Velocity feedback, Color feedback, maximal strength and power, Back squat	Pages: 91 Number of attachments/other: 8 Stavanger, 05.31.2024

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Sammendrag

Bakgrunn: Feedback under hastighetsbasert styrketrening gis vanligvis ved konsentrisk hastighetsfeedback for å maksimere hastighet, eller feedback på hastighetstap mellom repetisjoner som fokuserer på å motvirke fall i repetisjonshastighet. Ingen tidligere studie har sammenlignet effekten av de to vanligste feedbacktypene. **Hensikt:** Denne studien hadde som mål å sammenligne effekten av å trene knebøy med prosent hastighetstap med fargekodede varsler (TL: Trafikk lys gruppe) vs. konsentrisk hastighetsfeedback (HF gruppe) på treningsvolum, endringer i styrke, power, hopp og muskelstørrelse hos ishockeyspillere i deres konkurransesesong. **Metode:** En 10-ukers randomisert kontrollert studie inkluderte 35 semiprofesjonelle ishockeyspillere som ble tildelt TL eller HF. Pre- og post-intervensjonsmålinger inkluderte 1RM knebøy, isometrisk mid-thigh pull, Keiser benpress maksimal styrke og kraft, countermovement jump, og vastus lateralis muskeltykkelse. **Resultater:** TL-gruppen fullførte betydelig flere repetisjoner med et gjennomsnitt på 7±1, 6±1 og 6±1 reps i sett 1-3 per knebøy økt, sammenlignet med et gjennomsnitt på 5±1, 5±1 og 5±1 reps i HF-gruppen (alle sett p<0,001). TL viste betydelig større forbedringer enn HF-gruppen i 1RM knebøy (5,9 ± 3,3% vs. 3,1 ± 4,1%, p = 0,042, henholdsvis) og CMJ høyde (11,1 ± 7,2% vs. 5,2 ± 7,6%, p = 0,034, henholdsvis). Ingen gruppeforskjeller ble observert i mid-thigh pull, benpress styrke og kraft, eller endringer i muskeltykkelse. **Konklusjon:** Feedback som bruker prosent hastighetstap med fargekodede varsler kan forbedre prestasjon i styrketrening, samt styrke og kraftendringer i underekstremiteter hos godt trente idrettsutøvere i sesong. Videre forskning er nødvendig for å utforske effektene av denne type feedback under en styrketreningsperiode der treningsvolumet er likestilt for gruppene.

Nøkkelord: Ishockey, prosent hastighetstap feedback, hastighetsfeedback. Farge feedback, maksimal styrke og power, knebøy

Abstract

Background: Feedback during velocity-based strength training is traditionally given by concentric velocity feedback to maximize speed, or feedback on velocity loss between repetitions that focus on counteracting drops in repetition speed. However, no previous study has compared the effect of the two most common feedback types. **Purpose:** The present study aimed to compare the effect of training back squats with percent velocity loss and color-coded alerts feedback (TL: "Traffic light group") vs. concentric velocity feedback (VF) on training volume, changes in strength, power, jump performance, and muscle size in ice hockey players during their competitive season. **Method:** A 10-week randomized controlled trial included 35 semi-professional ice hockey players assigned to TL or VF. Pre- and post-intervention measures included 1RM back squat, isometric mid-thigh pull, Keiser leg press maximal force and power, countermovement jump, and vastus lateralis muscle thickness.
Results: The TL group completed significantly more repetitions with an average of 7±1, 6±1, and 6±1 reps in sets 1-3 per back squat session, compared to an average of 5±1, 5±1, and 5±1 reps in the VF group (all sets $p<0.001$). TL showed significantly greater improvements than the VL group in 1RM back squat (5.9 ± 3.3% vs. 3.1 ± 4.1%, $p = 0.042$, respectively) and CMJ height (11.1 ± 7.2% vs. 5.2 ± 7.6%, $p = 0.034$, respectively). No group differences were observed in mid-thigh pull, leg press strength and power, or muscle thickness changes.
Conclusion: Feedback using percent velocity loss with color-coded alerts can improve strength training performance, as well as strength and power changes of the lower limbs in well-trained athletes during the competitive season. Further research is needed to explore the feedback effects during a strength training period in training volume equated groups.

Keywords: Ice hockey, Percent velocity loss feedback, Velocity feedback, Color feedback, maximal strength and power, Back squat

Abbreviations:

NHL	National Hockey League
VBST	Velocity-based strength training
M/S	Meter per second
KG	Kilograms
CM	Centimeter
MM	Millimeter
W	Watt
N	Newton
RCT	Randomized controlled trial
TL	Traffic light and velocity loss feedback group
VF	Velocity feedback group
CMJ	Countermovement jump
MVIC	Maximum voluntary isometric contraction
1RM	One repetition maximum
Fmax	Maximal force in Keiser leg press, extrapolated from a theoretical force-velocity curve
Pmax	Maximal power output in Keiser leg press, extrapolated from a theoretical force-velocity curve
SD	Standard deviation
EMG	Electromyography
CV	Coefficient of variation

Table of content

Part 1, scientific manuscript: Outlines a research paper following the open access protocols established by the Scandinavian Journal of Medicine & Science in Sports. It is structured according to the IMRaD format, which includes sections for the Introduction, Methods, Results, Discussion, and conclusion.

Part 2, Thesis wrapper: Offers a more detailed explanation of the theoretical background and an in-depth discussion of the methods applied, which serves as additional information to the research paper.

Part 3, attachments: Includes appendices that feature necessary documents such as ethical board approval, consent forms, and application for ethical approval.

Part 1

RESEARCH PAPER

Feedback During Back Squats for Ice-Hockey Players In-Season: Comparing Color-Coded Velocity Loss Feedback with Concentric Velocity Feedback.

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

Scandinavian Journal of Medicine & Science in Sports

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Abstract

Background: Feedback during velocity-based strength training is traditionally given by concentric velocity feedback to maximize speed, or feedback on velocity loss between repetitions that focus on counteracting drops in repetition speed. However, no previous study has compared the effect of the two most common feedback types. **Purpose:** The present study aimed to compare the effect of training back squats based on percent velocity loss with color-coded alerts feedback (TL: “Traffic light group”) vs. concentric velocity feedback (VF) on training volume, changes in strength, power, jump performance, and muscle size in ice hockey players during their competitive season. **Method:** A 10-week randomized controlled trial included 35 semi-professional ice hockey players assigned to TL or VF. Pre- and post-intervention measures included 1RM back squat, isometric mid-thigh pull, Keiser leg press maximal force and power, countermovement jump, and vastus lateralis muscle thickness. **Results:** The TL group completed significantly more repetitions with an average of 7±1, 6±1, and 6±1 reps in sets 1-3 per back squat session, compared to an average of 5±1, 5±1, and 5±1 reps in the VF group (all sets $p<0.001$). TL showed significantly greater improvements than the VL group in 1RM back squat (5.9 ± 3.3% vs. 3.1 ± 4.1%, $p = 0.042$, respectively) and CMJ height (11.1 ± 7.2% vs. 5.2 ± 7.6%, $p = 0.034$, respectively). No group differences were observed in mid-thigh pull, leg press strength and power, or muscle thickness changes. **Conclusion:** Feedback using percent velocity loss with color-coded alerts can improve strength training performance, as well as strength and power changes of the lower limbs in well-trained athletes during the competitive season. Further research is needed to explore the feedback effects during a strength training period in training volume equated groups.

Keywords: Ice hockey, Percent velocity loss feedback, Velocity feedback, Color feedback, maximal strength and power, Back squat

Introduction

The origin of modern ice hockey can be traced back to Montreal, Canada, where the game was first played almost 150 years ago and ultimately earned its place in the Olympic Games in 1920 (Vigh-Larsen & Mohr, 2024). Today, the International Ice Hockey Federation includes 83 nations, showcasing its significant growth as an international sport (International Ice Hockey Federation, 2024). Ice hockey is characterized as a high-intensity team sport and is often described as the fastest sport on the planet played on two feet. (Cox et al., 1995; Vigh-Larsen & Mohr, 2024) A typical work interval, lasting from 45 to 60 seconds and comprising 5-7 high-energy actions, is followed by a recovery phase of 2 to 5 minutes before embarking on the subsequent interval. (Brockie et al., 2018; Wagner et al., 2021). Physical actions including enduring body checks, pressing opponents away from contested areas, and competing for the puck underscore the game's inherently physical character (Twist & Rhodes, 1993). This structure demands that top-level ice hockey players possess a wide range of physical capabilities, including significant muscle strength and power. (Cox et al., 1995; Johannesen et al., 1989). In addition, Burr et al. (2008) points out the critical role of strength and power in ice hockey, highlighting how these attributes significantly influence player selection within the National Hockey League (NHL).

Velocity-based strength training (VBST) has emerged as a popular training method with objective feedback measurements to assist in designing resistance training programs (Banyard et al., 2018). To improve athletic performance, VBST primarily employs two methods: prescribing loads through designated velocity zones and managing fatigue via velocity loss thresholds (Thompson et al., 2023). Velocity zones involve targeting specific velocities per lift or maintaining lifts within a present velocity zone (Wlodarczyk et al., 2021). Velocity loss, on the other hand, monitors the decline in the speed of the concentric phase of a lift across within-set repetitions, indicating fatigue from repetition to repetition and thereby the intensity of the workout by choosing a velocity loss threshold. Despite huge individual variations in the degree of fatigue at a given velocity loss threshold (Jukic et al., 2023), these methods have been shown to enhance athletic performance, as evidenced by recent research (Zhang et al., 2022; Weakley et al., 2023). VBST thus has the potential to influence training quality in form of repetition performance, not only by guiding exercises toward set velocity goals or managing fatigue but also through ongoing feedback during the session itself.

Implementing these methods effectively relies on the critical role of feedback, with real-time feedback shown to significantly improve barbell velocity within a training set (Weakley et al., 2019). Moreover, providing high-frequency feedback, offering clear and immediate responses after each repetition, rather than waiting until after a set is completed, significantly enhances effort (Nagata et al., 2020). Such feedback is crucial in VBST, where the focus on maximal speed execution is beneficial for enhancing resistance training outcomes such as strength and power development (Dolezal et al., 2016). Indeed, a recent review from Weakley et al. (2023) concluded that providing feedback during resistance training can improve both immediate performance and long-term progress. Furthermore, Weakley et al. (2020) examined the effect of different types of feedback, specifically verbal kinematic feedback, visual kinematic feedback, and verbal encouragement on barbell velocity during a back squat exercise. They found that all three feedback methods led to enhancements in barbell velocity. However, Weakley et al. (2023) highlighted that although both verbal and visual feedback significantly outperformed the absence of feedback, visual feedback led to significantly better performance improvements compared to verbal feedback.

However, to the author's knowledge, no previous study has compared the effect of visual feedback on the velocity loss per se (% velocity loss in concentric velocities from repetition-to-repetition concomitant with increasing fatigue), vs. visual feedback on just the actual velocity during the concentric part of the lift (e.g. m/s in each rep of back squat). Historically, the most conventional approach has been to receive feedback on the velocity performed, with an aim to perform with the highest possible speed in each repetition. However, it could be speculated that feedback regarding velocity loss could potentially serve as a stronger motivator for individuals to maintain velocity in subsequent within-set repetitions. Improved overall repetition performance, especially in the later repetitions during each set, would also allow more repetitions performed before a given velocity-loss threshold, and possibly lead to better improvements in training outcomes such as strength and power development. Therefore, the present study aimed to compare the effect of a back squat program based on percent velocity loss feedback with color-coded alerts, vs. feedback by solely the concentric back squat velocity, on strength training volume performed before given velocity-loss thresholds, and changes in maximal strength, power, jumping performance and hypertrophy during 10 weeks of strength training.

Methods

Subjects

For this study, two semi-professional ice hockey teams with a total of 42 players were recruited. These teams included one consisting of 23 players under the age of 20 (U20) and 19 players under the age of 18 (U18). During the course of the study, four participants had to withdraw due to injuries. Furthermore, three additional participants were excluded from the data analysis due to limited participation below the determined cut-off set at 80% attendance.

A total of 35 male participants (age 17.2 ± 1.0 years; height 181.1 ± 6.2 cm; weight 77.4 ± 8.1 kg) completed the study and were included in the data analysis. Each of the participants had a minimum of one year experience with heavy resistance training. All participants provided their written consent prior to their involvement in the study. Ethical approval for the study was granted by the ethical board at the University of Adger`s Faculty of Health and Sport Science (Appendix 1) and by the Norwegian Centre for Research Data (Appendix 2). The research was carried out in accordance with the ethical standards established by the Declaration of Helsinki.

Design

The present study was conducted as a randomized controlled trial (RCT) and compared the effects of two visual feedback modalities during 10 weeks of back squat training (Appendix 6 & 7). Subjects were randomly allocated into one of two groups using an online service (randomizer.org). The "Velocity loss with traffic light feedback group" (TL) (n=17) received a digital display showing a percentage drop relative to the subject's fastest repetition accompanied by color-coded signals. The color-coded signals shifted from green to yellow as a preemptive alert. When the velocity decreased to the predetermined threshold from the fastest repetition (20% and 30%), the screen first switched to yellow (10 or 15% velocity loss), and then red (20 or 30% velocity loss), indicating the completion of the set. The second group, the "Velocity feedback group" (VF) (n=18), was provided with a display showing only the velocity in meters per second (m/s) for each lift, omitting the percentage drop and color indicators. Two weekly strength training workouts were spaced out by at least 48 hours during the 10-week intervention period. The study was carried out during the athletes' competitive season, and they participated in 4 to 5 weekly on-ice training sessions in addition to an average of two matches per week during the 10-week intervention. Two distinct sessions of pre-and post-tests were conducted before and after the intervention. Countermovement-jump

(CMJ) height, midthigh-pull maximum voluntary isometric contraction (MVIC), and one repetition maximum (1RM) back squats were all part of the first testing session. In the second session, subjects measured muscle thickness of vastus lateralis and maximal power and force with a Keiser pneumatic leg press machine.

Training intervention

All participants followed the same 10-week training program, the only difference between groups was the type of feedback provided during the back squat exercise. The back squat was the primary exercise in the subject's training routine during the intervention and was consistently performed first in every session. Subjects completed three sets of back squats twice weekly. The first session each week involved squats at 80% of their 1RM with a velocity loss threshold of 30%, and the second session involved 70% of 1RM to a 20% velocity loss. The TL group received automatic feedback from the screen in front of them to end their sets at the reached velocity threshold (at the velocity loss threshold), while the VF group was told to continue lifting until the researchers instructed them to end the set (at the same velocity loss thresholds, but the participants in the VF group were not aware of these VL thresholds). Importantly, all participants in both groups were instructed to lift with maximal mobilization and velocity during the concentric phase of all back squat repetitions. The second session each week involved a lower load and velocity threshold to ensure that the subjects would not be overly fatigued during their weekend matches. In week five, weights were increased by 2.5 kg, and then an additional 2.5 kg in week eight, aligning with the subject's expected progression in the back squat exercise.

Each session began with an approximately 15-minute warm-up routine, starting with cycling and moving on to dynamic flexibility exercises for the core and lower body. Then, all subjects performed two CMJ and squat jumps, followed by a reactive strength index (RSI) test consisting of ten consecutive jumps, which were part of another master thesis conducted simultaneously within the same overarching research project. Although these jumps were not the primary focus of the study, they were included in the warm-up and training routine prior to the back squat exercise. Thereafter, subjects gradually increased the weights on the barbell, reaching up to 80% and 70% of their 1RM. All subjects completed three to four warm-up sets prior to achieving the target weight. During the first three repetitions, verbal encouragement was provided to ensure maximal lifting velocity. Every set was performed on Alphatek's force platform (AlphatekPWR, Stavanger, Norway), (Appendix 8) which offered feedback on movement velocity, estimated from changes in the center of mass. Following the back squat, the subjects completed 3-4 additional exercises, part of their strength training program developed by their physical coach (Appendix 5).

Table 1 Back squat training program

Session 1, week 1	**Session 2, week 1**	**Session 3, week 2**	**Session 4, week 2**
3 sets at 80% 1RM, 30% velocity loss	3 sets at 70% 1RM, 20% velocity loss	3 sets at 80% 1RM, 30% velocity loss	3 sets at 70% 1RM, 20% velocity loss
Session 5 was not completed.	**Session 6, week 3**	**Session 7, week 4**	**Session 8, week 4**
3 sets at 80% 1RM, 30% velocity loss	3 sets at 70% 1 RM 20% velocity loss	3 sets at 80% 1RM, 30% velocity loss	3 sets at 70% 1RM, 20% velocity loss
Session 9, week 5	**Session 10, week 5**	**Session 11, week 6**	**Session 12, week 6**
3 sets at 80% 1RM, 30% velocity loss	3 sets at 70% 1 RM, 20% velocity loss	3 sets at 80% 1RM, 30% velocity loss + 2,5kg	3 sets at 70% 1RM, Velocity loss + 2,5kg
Session 13, week 7	**Session 14, week 7**	**Session 15, week 8**	**Session 16, week 8**
3 sets at 80% 1RM, 30% velocity loss + 2,5kg	3 sets at 70% 1 RM, 20% velocity loss + 2,5kg	3 sets at 80% 1RM, 30% velocity loss + 2,5kg	3 sets at 70% 1RM, 20% velocity loss + 2,5 kg
Session 17, week 9	**Session 18, week 9**	**Session 19, week 10**	**Session 20, week 10**
3 sets at 80% 1RM, 30% velocity loss + 5kg	3 sets at 70% 1 RM, 20% velocity loss + 5kg	3 sets at 80% 1RM, 30% velocity loss + 5kg	3 sets at 70% 1RM, 20% velocity loss + 5kg

Table 1 presents the 10-week back squat training program the subjects did. From week 6 - 8 subjects increased their back squat weights with 2.5 kg, and from week 9 – 10 subjects increased their weight with a further 2.5 kg. abbreviations: 1RM = 1 repetition maximum.

Measurements

Pre- and post-tests on CMJ height, Mid-thigh pull MVIC, 1RM back squat, leg press strength and power (Fmax and Pmax), and muscle thickness of vastus lateralis were performed to assess differences between the TL and VL group.

Countermovement jump height

The subjects performed the countermovement jump on a force plate provided by Alphatek. They were instructed to start from a stationary position and then quickly move downwards, followed by an immediate upward jump. Subjects kept their hands on their hips throughout the jump and could choose their own squat depth with the instruction to jump as high as possible. The correct technique was demonstrated to each participant before testing and all participants were familiarized with the technique before initiating the study. Each subject performed three maximal effort jumps with at least 30 seconds between each jump to ensure consistent trial performance. The mean score from the two best jumps was recorded for further analysis.

Mid-thigh pull

The mid-thigh pull test was performed using dual handles attached to a force plate (Alphatek) to measure peak isometric force during the measurement. Subjects began upright, placing their feet at shoulder width and securing the handles at mid-thigh level with an overhand grip. Subjects were given liquid chalk to enhance their grip to prevent the handles from slipping. They were then instructed to perform a maximal vertical pull with extended arms while maintaining a stationary semi-squat posture. All trials were conducted with verbal encouragement to provide elicit maximal effort. The peak force achieved for each subject was recorded for further analysis.

1 RM back squat

A 1RM back squat test was conducted following the CMJ and mid-thigh pull tests. Before the test, subjects engaged in a 10-minute dynamic warmup. Post-warm-up, the subjects initiated the 1RM testing protocol by starting with an unloaded barbell. The weight on the barbell was progressively increased with 10-20 kg per set. As the load increased, the number of repetitions was reduced, allowing the subjects to focus on single repetitions as they neared their potential 1RM. As the weight approached the subject's maximum lifting capacity, the increments were adjusted to smaller weights of 2.5-5 kg. When the subjects approached what they perceived to be their 1RM, they attempted the lift under observation. A practitioner was present to ensure that the 1RM test was performed correctly with the proper technique.

Subjects performed the 1RM test in an upright position, positioning the barbell on the upper back, like a high bar squat. They selected their own stance witch, typically around the shoulder-width. At the chosen squat depth (femur at a 90-degree angle parallel to the floor), a practitioner or the physical coach provided verbal feedback to initiate the concentric phase of the lift back to an upright position. If the 1RM repetition was completed, weights were increased by 2.5 kg until it became too challenging for the subject to complete a successful repetition. Conversely, if the 1RM test was unsuccessful, weights were reduced by 2.5 kg until a successful 1RM test could be performed.

Keiser leg press Fmax and Pmax

The Keiser leg press (Keiser A300 model 2531, Keiser, Co. Inc., Fresno, California, USA) assessed the lower extremities' maximal force and power output. Subjects were instructed to position their feet firmly on both foot pedals, with seat adjustments made to ensure a 90-degree angle in the knee joint. The maximum load was determined by adding the subject's individual 1RM and an additional 100 kg, establishing the set weight. The leg press exercise required subjects to extend their knees fully with maximum effort. Force-velocity values were captured using the Keiser A420 software during the manufacturer's standard protocol of 10 repetitions with progressively increasing loads.

Prior to the 10-repetition test, subjects engaged in a brief familiarization exercise, performing no more than five reps, to acquaint themselves with the procedure. Thereafter, subjects completed a sequence of 10 repetitions, beginning at 15% of the predetermined maximal resistance and increasing to 100% by the final repetition. The load increments ranged from 20-30 kg for each repetition, with a rest period of 10-20 seconds following each of the initial five repetitions, which was increased to 20-40 seconds for the remaining five repetitions. After the 10^{th} repetition, the test was considered finished. Theoretical maximal force and power were extrapolated from the force-velocity profile.

Muscle size

Ultrasonography (LogicScan 128 CEXT-1Z REV; B, Telemed, Vilnius, LT, Lithuania) was used to measure the muscle thickness of the vastus lateralis in the axial plane. Ultrasound transmission gel (Aquasonic 100) was applied to a linear probe with a width of 40mm at a 9MHz excitation frequency. The probe was positioned halfway between the hip joint socket and the kneecap. All measurements were taken from the right leg, and all subjects maintained a partially supine position on the research table, with both knees fully extended during the procedure. Ultrasound settings, such as adjusting the focal depth (depth of ultrasound penetration) and image depth, were personalized for each subject to enhance the clarity of the final images. When a clear image of the vastus lateralis was displayed on the Echo Wave 4.1.0 program next to the practitioner, waterproof eyeliner (Isadora waterproof black eyeliner) was applied to mark both ends of the probe placement. To ensure precise probe placement from pre- to post-test, a transparent sheet was positioned on the subject's leg, aligning with the practitioner's probe markings and any notable skin features (birthmarks, moles, scars, etc.) Finally, the practitioner proceeded to mark these skin features on the sheet.

During the post-test procedure, the practitioner made small incisions in the transparent sheet where the probe was marked for each subject. The practitioner placed the transparent sheet over the subject's skin, aligning it with its pre-marked skin features. Following this, the practitioner used waterproof eyeliner to mark the precise points where the incisions were made. An iPhone was also positioned alongside the laptop, displaying the pre-test images to ensure a similar position between pre- and post-images for each subject. The practitioner marked three points on the final image on both pre and post-test of the vastus lateralis and drew a vertical line to measure muscle thickness. The average of these three points was used for further analysis.

Data analysis

Baseline characteristics were summarized using descriptive statistics, including the mean and standard deviation. Data distribution was assessed through mean, median, kurtosis, and skewness measures, indicating normality in the data. Within-group changes from pre- to post-tests were evaluated using a paired sample t-test. Between-group changes from pre- to post-tests were examined using an independent sample t-test. Results were displayed in terms of mean values, standard deviation, percentage mean change and p-values. Statistical analysis was carried out in Microsoft Excel version 2311, where the significance level was set at <0.05, with a confidence interval of 95.

Results

No significant group differences were observed at baseline in any measurement outcome. Adherence to training did not differ significantly between the "Traffic Light and Velocity loss feedback" (TL) group (88.2 ± 7.7%) vs. the Velocity Feedback (VF) group (86.8 ± 7.4%, *p* = 0,612). The TL group performed back squats with an average of 29% percent more repetitions per training session, compared to the VL group (19.4 reps vs. 15.0 reps, *p* = 0.001). The training volume also differed at all three sets per session, where the TL group performed significantly more repetitions than the VF group at the first (6.61 ± 0.77 vs. 5.12 ± 0.75, *p* = 0.001), second (6.49 ± 0.94 vs. 4.98 ± 0.67, *p* = 0.001) and third set (6.30 ± 0.77 vs. 5.06 ± 0.68, *p* = 0.001). The average back squat training volume per session is illustrated in Figure 1.

Figure 1 Back squat volumes between both groups.

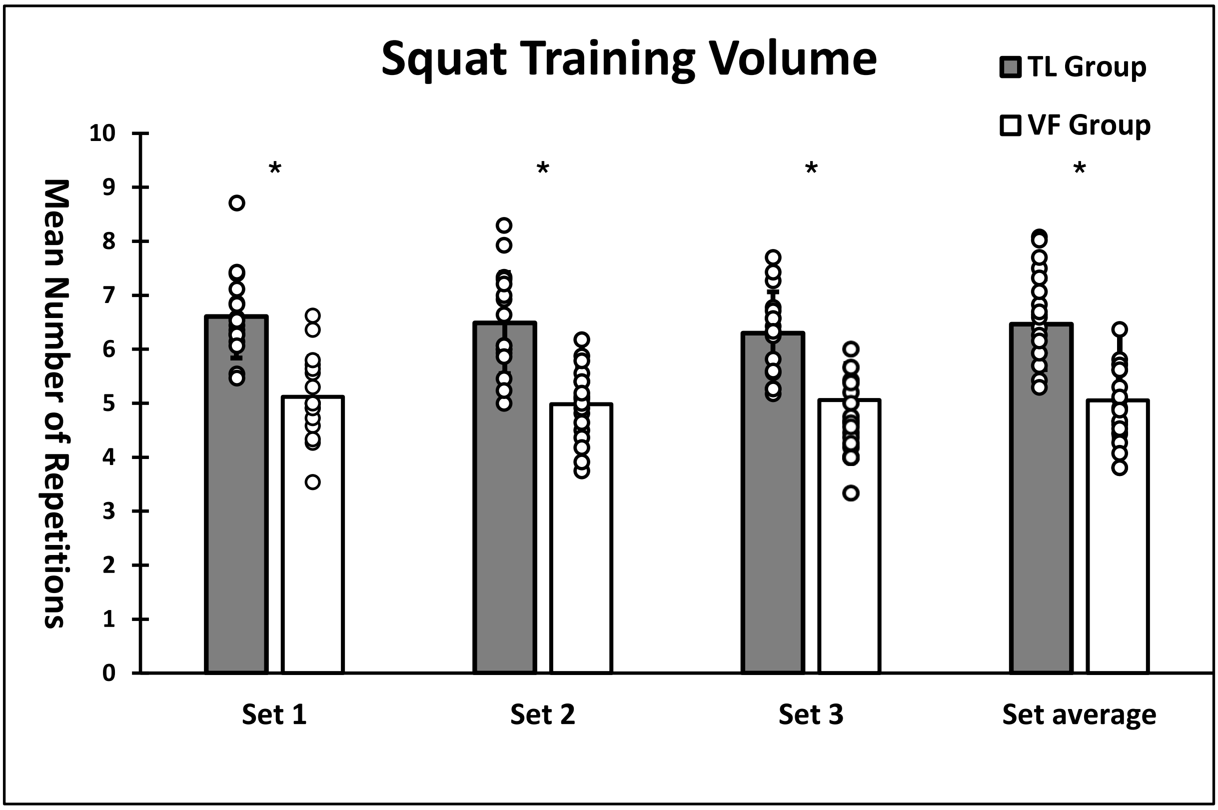

Fig. 1 presents the mean (± SD) of completed repetitions per set and the overall average for each set and both groups during the 10-week training period. A marked asterisk (*) highlights a significant difference between the groups (p < 0.05). Key abbreviations: TL = Traffic Light Feedback Group, VF = Velocity Feedback Group. SD = standard deviation.

Maximal strength and hypertrophy

Table 2 Pre and post-test measurements of back squat 1RM, mid-thigh pull MVIC, and Vastus lateral muscle thickness.

	TL group	VF group	p-value Group x time interactions
Back Squat 1RM			
Pre (kg)	130.3 ± 20.1	128.1 ± 20.5	
Post (kg)	137.6 ± 20.1	131.5 ± 23.5	**0.042***
Change (kg)	7.3 ± 3.7	3.4 ± 5.4	
Change (%)	5.9 ± 3.3	3.1 ± 4.1	
Baseline comparison p-value	**0.001#**	**0.006#**	
Mid-thigh pull MVIC			
Pre (kg)	261.5 ± 28.7	250.1 ± 37.9	
Post (kg)	289.9 ± 40.1	266 ± 43.3	
Change (kg)	28.4 ± 21.7	15.9 ± 21.0	0.197
Change (%)	10.7 ± 8.4	6.5 ± 9.1	
Baseline comparison p-value	**0.001#**	**0.008#**	
Vastus lateralis thickness			
Pre (mm)	29.9 ± 4.2	28.8 ± 3.6	
Post (mm)	30.7 ± 4.2	29.3 ± 3.5	0.078
Change (mm)	0.8 ± 0.6	0.5 ± 0.2	
Change (%)	2.7 ± 1.8	1.8 ± 0.5	
Baseline comparison p-value	**0.001#**	**0.001#**	

Table 2 presents pre and post-test measurements for the TL and VL Group, detailing changes in back squat 1RM, mid-thigh pull MVIC, and vastus lateralis muscle thickness. Results are presented as means with standard deviations (± SD). (#) indicate significant within-group changes from pre- to post-test, while (*) indicates significant between-group differences in changes from pre- to post-test ($p<0.05$). Abbreviations: TL = Traffic Light Group. VF = Velocity Feedback Group. 1RM = one repetition maximum. MVIC = maximal voluntary isometric contraction. Kg = kilograms. mm = millimeters.

The TL group increased back squat 1RM (5.9 ± 3.3% mean ± SD) significantly more than the VF group (3.1 ± 4.1%, $p = 0.042$). Mid-thigh pull MVIC was improved by 10.7 ± 8.4% ($p = 0.001$) in the TL group and by 6.5 ± 9.1% ($p = 0.008$) in the VF group compared to baseline, but no significant between-group difference was detected ($p = 0.197$). Vastus lateralis muscle thickness increased from baseline by 2.7 ± 1.8% ($p = 0.001$) in the TL group and 1.8 ± 0.5% ($p = 0.001$) in the VF group, with no significant between-group difference in the training-induced changes ($p = 0.078$). Changes in maximal strength and muscle thickness are shown in Figure 2.

Figure 2 Pre to post changes in back squat 1RM, mid-thigh pull MVIC and muscle size.

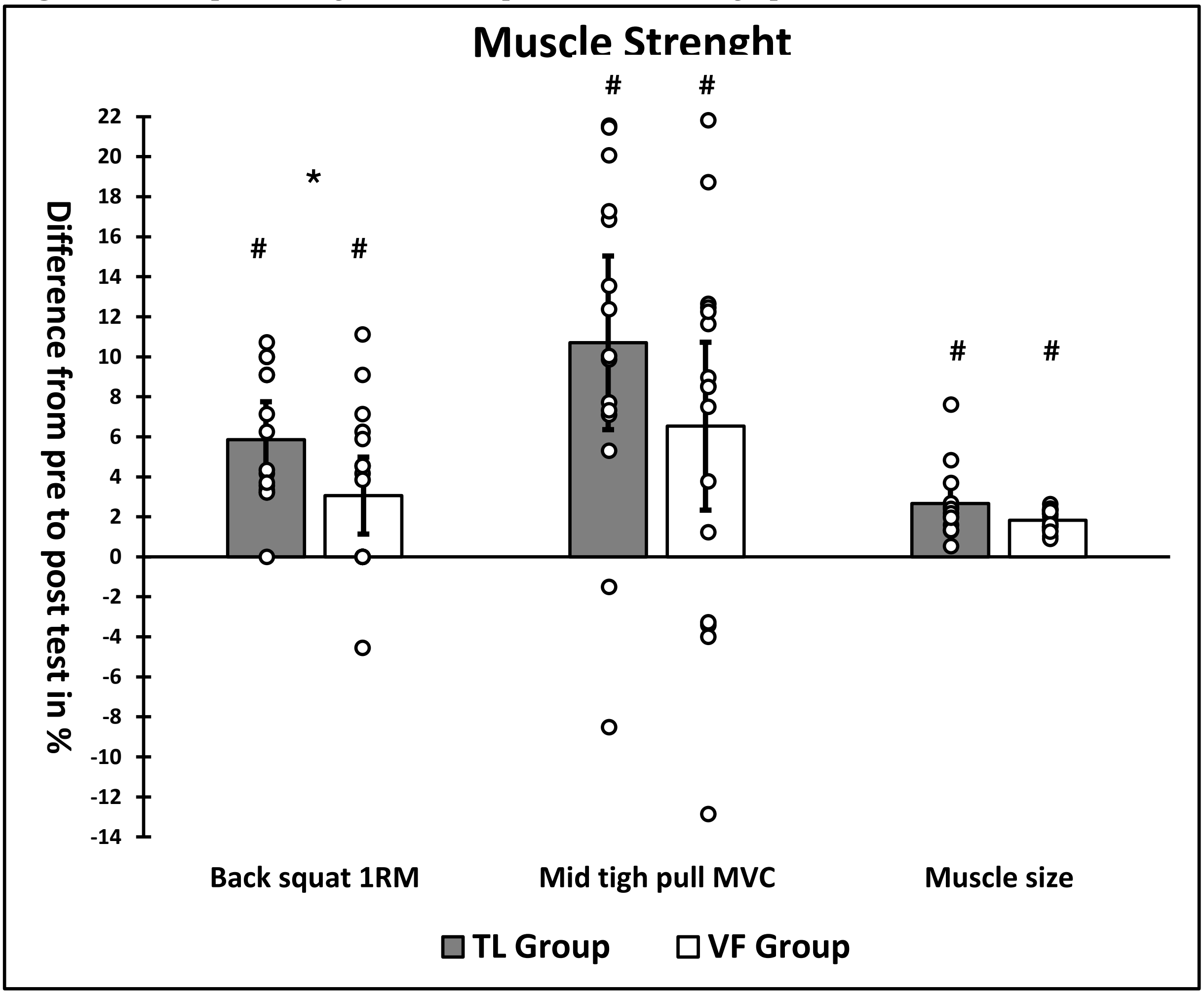

Fig. 2 Data are presented as mean ± Standard deviation. TL = Traffic Light Group, VF = Velocity Feedback group. 1RM = One repetition maximum. MVIC = maximal voluntary isometric contraction. Muscle size = muscle thickness of vastus lateralis. (#) indicate significant within-group changes from pre- to post-test, while (*) indicates significant between-group differences in changes from pre- to post-test ($p < 0.05$).

Leg press maximal force and power, and jump height

Table 2 Pre-posttest changes in leg press P-max, leg press F-max, and CMJ height.

	TL group	VF group	p-value Group x time interactions
Leg press P-max			
Pre (W)	2245 ± 521.	2259 ± 446.3	
Post (W)	2422 ± 426	2324 ± 516.2	0.221
Change (W)	176 ± 426	65 ± 173	
Change (%)	9.7 ± 12.4	4.4 ± 4.8	
Baseline comparison p-value	**0.046#**	0.167	
Leg press F-max			
Pre (N)	347 ± 42.5	352 ± 56.6	
Post (N)	354 ± 48.6	342 ± 59.2	0.339
Change (N)	7 ± 41	10 ± 38	
Change (%)	2.4 ± 8.6	-2.4 ± 10.8	
Baseline comparison p-value	0.595	0.300	
CMJ height			
Pre (cm)	41.2 ± 3.6	40.8 ± 5.44	
Post (cm)	45.7 ± 4.6	42.9 ± 6.3	**0.034***
Change (cm)	4.5 ± 2.9	2.1 ± 2.9	
Change (%)	11.1 ± 7.2	5.2 ± 7.6	
Baseline comparison p-value	**0.001#**	**0.010#**	

Table 2 presents pre and post-test measurements for the TL and VF groups, and detailing changes in leg press P-max, leg press F-max, and CMJ height. Results are presented as means with standard deviation (SD ±) (#) indicates significant changes within groups from pre- to post-test, while (*) indicates significant between-group differences in changes from pre- to post-test (p<0.05). Abbreviations: TL = Traffic light group. VF = Velocity Feedback Group. CMJ = countermovement jump. P-max = Peak power output, extrapolated across the force-velocity profile. F-max = Maximum force capability, extrapolated across the force-velocity profile. W = watt. N = newton.

Leg press F-max did not increase significantly in the TL group (2.4 ± 8.6%, p = 0.595) or VF group (-2.4% ± 10.8, p = 0.300) compared to baseline, and no significant differences between groups were detected. No significant group differences were detected in leg press P-max changes (p = 0.221), however, only the TL group improved leg press P-max compared to baseline (TL: 9.7 ± 12.4%, p = 0.046, and VF 4.4 ± 4.8%, p = 0.167). The TL group increased CMJ height (11.1 ± 7.2%) significantly more than the VF group (5.2 ± 7.6, p = 0.034). Changes in leg press strength and power and CMJ height are shown in Figure 3.

Figure 3 Pre to post changes in CMJ, F-max, and P-max on Keiser leg press.

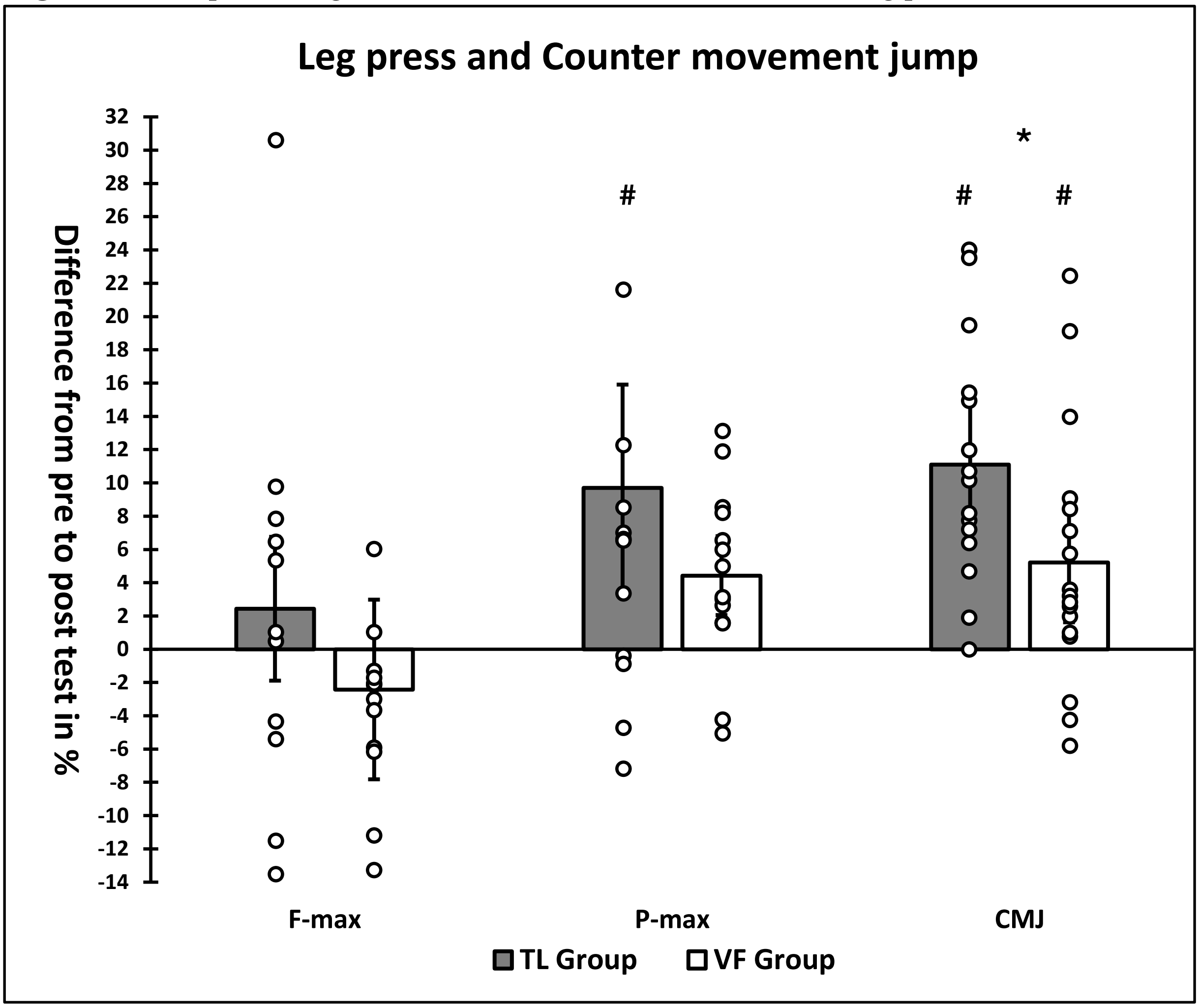

Fig. 3 Data are presented as mean ± Standard deviation. TL = Traffic Light Group. VF = velocity feedback Group. P-max = Peak power output, extrapolated across the force-velocity profile. F-max = Maximum force capability, extrapolated across the force-velocity profile. (#) indicates significant changes within groups from pre- to post-test, while (*) indicates significant between-group differences in changes from pre- to post-test ($p < 0.05$).

Discussion

The current study compared the effects of a back squat training approach utilizing feedback on in-set percent velocity loss with color-coded alerts, and the other focusing solely on feedback based on the velocity of the concentric movement in each repetition. The study compared the effects acutely on back squat training volume per session performed within the given velocity loss thresholds, and on training-induced changes of 1RM back squat, isometric mid-thigh pull, leg press maximal power and force, jumping performance, and muscle hypertrophy between the training groups.

The velocity loss with color-coded alerts feedback group (TL) performed significantly more repetitions before hitting the velocity loss cut-off within each set and increased back squat 1RM and CMJ more during the training period than the velocity feedback group. No significant between-group differences were observed in changes of leg press maximal power and force, isometric mid-thigh pull or vastus lateralis muscle thickness from pre to post-test. Overall, however, the TL group seemed to induce higher relative changes in most tests, indicating that incorporating feedback based on velocity loss and color-coded alerts may enhance power training performance within training sessions, and training-induced changes in performance outcomes.

Effect of Feedback on velocity-based strength training

Both groups followed the same training program with identical velocity loss thresholds (30% or 20%), with the only difference being the types of feedback provided. However, the TL group performed back squat with an average of 29% more repetitions per session than the VF group (19.4 reps vs. 15.0 reps), which highlights the impact of feedback mechanisms in enhancing training volume within a velocity loss threshold and, subsequently, training outcomes. Notably, both feedback groups demonstrated significant within-group improvements from pre to post-test in 1RM back squat, IMPT, CMJ and muscle thickness in the vastus lateralis during the competitive season where strength and power performance often just is maintained or even decreases (Astorino et al., 2004). Although we did not compare the responses to a group not receiving feedback, these observations align with the systematic review by Weakley et al. (2023), highlighting beneficial improvements of real-time feedback on both short-term performance and greater chronic adaptions. Notably, recent studies observed that the greatest benefits are when feedback is provided with high frequency, specifically after every repetition, and potentially when kinematic feedback is provided visually (Nagata et al., 2020; Perez-Castilla et al., 2020; Weakley et al., 2023). Both groups in the present study received real-time frequent feedback with each repetition performed. However, it seems like the TL group feedback motivated the participants better at subsequent repetitions, as they kept their repetition performance higher for longer, and thereby achieved more repetitions before they reached the velocity loss threshold.

Effect of training volume

The observed group differences in training-induced changes between the TL and VF group are likely explained by the differences in training volume prompted by their respective feedback methods, but also the higher repetition performance during each repetition within the TL group. As highlighted by Schoenfeld et al. (2017), training volume plays a key role in muscle adaption and muscle hypertrophy, suggesting that training volume is one of the important causes of the observed differences in training outcomes between the groups. Moreover, Grgic et al. (2018) observed a strong relationship between training volume and muscle strength, implying that higher training volumes may lead to increased strength levels. In line with this, the TL group demonstrated a significant increased back squat 1RM significantly more than the VL group (6% vs. 3%, respectively), and although not significantly different, the relative increases in isometric mid-thigh pull were slightly higher in the TF group (11% vs. 7% in VL). The TL group´s notably larger improvement in back squat 1RM, compared to the VF group, suggests that increased training volume may be a significant factor in the maximal strength enhancements. This hypothesis aligns with the findings by Shoenfeld (2010), that higher training volume can amplify mechanical tension and neuromuscular stimulus – both critical stimuli for muscle adaptions and strength progression.

The TL group demonstrated significantly better improvements in CMJ performance than the VL group (11% vs. 5%, respectively), and although not significantly different, the relative increases in leg press maximal power also favored the TF group (10% vs. 4% in VL). These improvements in maximal power and jumping performance are in line with the TL group's superior progress in maximal strength measurements. There exists a strong relationship between strength and power capabilities, given that power (work/time) is derived from force development per unit of time at a given load (Cormie et al., 2011). In addition, improving maximal strength will often also improve maximal force development at higher velocities/lower loads as they are dependent on many of the same physiological mechanisms, and therefore contribute to the progressive enhancement of power development at a variety of loads (Cormie et al., 2011). The significant improvements in leg press maximal power and

CMJ performance observed in the TL group can therefore be connected to the relationship between power and maximal strength, and the neuromuscular adaptations obtained during high-load maximal effort strength training.

Effect of Lifting Velocity

Although the training volume differed significantly between the groups, it is likely that the group differences in training-induced outcomes was not solely explained by the differences in training volume. Additionally, it is worth considering that the enhanced efforts and lifting velocity during the repetitions may have played a role in influencing the results. Gonzalez-Badillo et al. (2014) suggested that training with higher concentric velocities may contribute to greater strength gains by enhancing efferent neural drive, leading to changes in motor unit recruitment and firing frequencies. Although speculative, the TL group likely trained some repetitions with higher motor unit recruitment and/or firing rates (rate coding) compared to the VL group when they performed repetitions with faster velocities derived from that they performed more repetitions before hitting the velocity thresholds and thereby terminating the sets. Moreover, intramuscular EMG studies have shown training-induced increases in motor unit firing frequencies during maximal contractions compared to submaximal efforts (Patten et al., 2001; Kamen & Knight, 2004). Taken together these observations can support the hypothesis that the larger training-induced changes in strength and power of the TL group, can partly be explained by performing their back squats with higher efforts and repetition velocities, and possibly enhanced improvements in motor unit recruitment and/or firing rates.

In further support of this speculation, studies conducted by Gonzalez-Badillo et al. (2014) and Pareja-Blanco et al. (2014) suggest that the velocity at which loads are lifted significantly impacts the resulting training effect. Pareja-Blanco et al. (2014) compared the effect of two resistance training programs differing only in repetition velocity: maximal intended velocity (MaxV) and half-maximal velocity (HalfV) at loads of 60 – 80 % of 1RM. Over six weeks, MaxV training was more beneficial than HalfV for improving squat performance, showing greater increases in maximal strength (ES: 0.94 vs. 0.54) and countermovement jump (CMJ) height (ES: 0.63 vs. 0.15). Similarly, Gonzalez-Badillo et al. (2014) compared a MaxV and HalfV group during a six-week bench press training program at loads of 60 – 80 % of 1RM. The study found that the MaxV group achieved significantly larger gains in 1RM strength, showing an 18.2% improvement compared to 9.7% in the HalfV group. These findings imply that strength and power gains can be maximized when repetitions are performed with maximal intended velocity, which supports the hypothesis that the better improvements in the

TL group were induced by a combination of higher training volumes and performing back squat repetitions with higher efforts.

Color feedback

Another potential important and influential factor for the TL group achieving a significantly higher training volume induced by faster lifting velocities during the sets, could be related to the provision of novel color based visual feedback throughout their working sets. This approach, featuring alerts in green at the initiation of the set within 0 to 1/2 of their velocity loss threshold (e.g up to 15% loss in velocity with a 30% velocity loss threshold), and then subsequently shifting to yellow and alerting the participants to re-focus and keep the velocity as high as possible so that the sets would not be ended. This kind of feedback could potentially have played a pivotal role in maintaining or enhancing the subject's motivation and focus, thereby contributing to improved performance during the back squat repetitions. Therefore, the color-coded feedback likely served to re-engage the subject's interest and focus, contributing to a sustained or even elevated effort throughout the training session. According to Wulf and Lewthwaite (2016), feedback mechanisms that encourage an external focus of attention, by steering the subject's concentration toward achieving clear and defined goals are advantageous for better performance. The color-coded feedback used in the TL group can be an example of a clearly defined external focus mechanism. This feedback method did not just provide numbers and data of the lifting velocity in front of the participants as in the VF group in the present study. Instead, it visually directed the subject's attention toward re-engaging and achieving specific performance goals as they hit 1/2 of their velocity loss thresholds, represented through different colors.

Furthermore, visual feedback with colors has been demonstrated to have a distinct psychological impact that can influence both behavior and motivation (Elliot & Maier, 2012; Weib et al., 2022). Early research by Pellegrini et al. (1980) and O'Connell et al. (1985) also highlights how color can impact physical performance. Pellegrini et al. (1980) found that quadriceps extension strength in 60 male participants was significantly higher after viewing blue stimuli compared to pink. Similarly, O'Connell (1985) showed that 40 male students exhibited greater grip strength when exposed to red compared to green, indicating that the stimulating effects of red increased grip strength. The present study also used color stimuli in a squat program to provide real-time feedback. Although different colors were used compared to Pellegrini et al. (1980) and O'Connell et al. (1985), both prior studies investigated the impact of specific colors on muscle strength. This study supports their findings by further demonstrating that visual stimuli can improve performance in training programs through the use of color cues. The interplay between color associations, as well as the introduction to "new" motivational cues within a set, likely played an important role in the TL group achieving higher training volumes, contributing to their notable performance improvements. However, as discussed in Weib et al. (2022) empirical research on color and human behavior in sports remains limited.

Percentage velocity loss vs. velocity feedback

Percent velocity loss-based feedback can be argued to provide a clearer indication of performance loss relative to the subject's fastest repetition, compared to velocity feedback only (e.g. average meters per second (ms) of the concentric phase in each lift). The percentage-based form of relative measurement may be easier to interpret for the athletes than absolute velocity feedback where they have to interpret when the m/s. data is starting to decline. For instance, understanding a 15% reduction in velocity directly conveys the extent of performance decline, which is more straightforward than interpreting specific velocity numbers that may require greater cognitive effort to analyze. As highlighted by Sweller's (1998) in the cognitive load theory, the effect can be augmented by minimizing the cognitive load associated with processing the feedback, and percent-based feedback may therefore enable athletes to adjust their performance during the set more efficiently, which can potentially lead to better training outcomes during the training period as observed in the TL group.

Muscle hypertrophy

Both groups experienced significant within-group change from baseline, and the TL group had a slightly higher but not significant ($p = 0.078$) relative increase in VL thickness with 2.7 ± 1.8%, compared to the VF group's increase of 1.8 ± 0.5. However, it's important to acknowledge the wider range of individual variations, as reflected by the larger standard deviation. The only difference in the intervention treatment between the TL and VF group was the feedback types, resulting in the TL group achieving a 29% higher training volume per session. If the training volume had been equal between the groups, it can be speculated that there would likely not be any group differences in muscle hypertrophy measurements. However, since we did equate for training volumes as that was one of the aims of the study to compare (i.e. how many reps the participants achieved before hitting the velocity loss thresholds), it is conceivable that group differences in training volume led to the differences in muscle hypertrophy. Consistent with the findings of this study, training protocols with higher training volumes have been shown to be more beneficial for muscle hypertrophy (Schoenfeld, 2010). In addition, Grgic et al. (2022) discuss that as individuals near their genetic limit for muscular adaptions (i.e. higher strength training status), a greater intensity of effort (i.e. training closer to failure) seems to be beneficial to stimulate further gains. The participants in the present study were well strength-trained individuals, and it is plausible that since the TL group performed each of the back squat sets with more repetitions and therefore fatiguing the muscle to a larger degree, that factor ultimately induced more muscle growth.

Strengths and limitations

The strengths of the study include the participation of highly strength-trained and high-level ice-hockey athletes, suggesting that the findings may be relevant for advanced training regimens in strength-trained populations. All sessions in the present study were supervised, which guaranteed adherence to the two feedback training protocols and accurate data collection. Additionally, the study benefited from high attendance rates and numerous training sessions (2 times per week for 10 weeks) conducted during the competitive season, allowing for a comprehensive evaluation of the training intervention groups.

One of the main limitations of this study was the inability to clearly differentiate between the effects of training volume vs. the increase in repetition velocity per se. A fixed number of repetitions across all sets in each of the two groups would have facilitated a more precise assessment of the impact of maintaining higher repetition velocity performance induced by a more effective feedback strategy. However, velocity loss thresholds as applied in the present study are frequently used in research and by athletes in practice (Hernández-Belmonte & Pallarés, 2022). Thus, one of the main aims of the present study was to assess the effect of the two feedback strategies on strength training volume obtained before hitting the given velocity thresholds, by maintaining higher velocities in subsequent within-set repetitions. Another limitation may have been having all participants in the same training room, which in theory could have induced a placebo or nocebo effect, where individuals perceive better or less benefit from their specific feedback type compared to others (Hurst et al., 2019). Nonetheless, the highly strength-trained athletes were used to training with differing strength training regimes between the individuals and frequently reported during the present study that they were satisfied with each of their respective feedback type, and were quite engaged in a competitive atmosphere, with most participants in both groups stating that they believed their feedback method would be the most effective. Finally, the present study could not assess whether the performance improvements from the feedback in the TL group were due to color-coded alert feedback on velocity drops (the screen turned yellow mid-set as the velocity drop increased) vs. the feedback in percent velocity drop (numbers of %-velocity loss on the screen). The combination of these two types of visual feedback (color-coded and numbers) in the present study makes it impossible to distinguish their individual impacts, highlighting a need for future research to isolate and specifically examine each feedback type's influence on training outcomes.

Conclusion

The TL group showed greater improvements in 1RM back squat and CMJ performance compared to the VF group. Therefore, the present study suggests that implementing feedback on percent velocity loss with color-coded alerts during back squat training regimes can enhance the performance outcomes of maximal strength and power among semi-professional ice hockey players during the competitive season. These results indicate that immediate and dynamic feedback mechanisms, such as velocity loss with color-coded alerts between repetitions within a set, are more effective in motivating athletes to increase their efforts during training sessions. Given these findings, future research should investigate the effectiveness of percent velocity loss feedback vs. color-coded alerts for velocity loss feedback separately, and across different sports and training contexts. In addition, future research should investigate the effectiveness of a training period with the different feedback types in training volume-equated groups.

Practical implications

This study introduces novel feedback comparisons, with velocity loss feedback and color-coded alerts, which to the author's knowledge have not been previously explored in resistance training context. The use of visual color-coded velocity loss feedback provides athletes and coaches with real-time data about changes in execution speeds, enabling dynamic adjustments in effort to attempt to refrain from further decrease in performance within a working set. This immediate, visually engaging feedback could help athletes re-engage mid-set, thereby potentially increasing effort and enhancing overall training effectiveness. Taken together, these feedback types can probably significantly improve strength and power training protocols by providing precise real-time insight into performance. They offer practical ways to enhance athletes' engagement and ensure consistent training intensity during a workout.

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Part 2

Theoretical background and methods

Table of content

1.0 Theory **36**

1.1Physical demands in ice hockey 36

1.2 Muscle strength 36

1.3 Power 37

1.4 Relationship between muscle strength and power 37

1.5 The critical role of strength and power in ice hockey 38

1.6 Autoregulation in Strength Training 39

1.6.1 Subjective autoregulation 40

1.6.2 Objective autoregulation 40

1.7 Feedback 41

1.7.1 Effect of Different Feedback Types 41

1.7.2 Effect of feedback frequencies 42

1.7.3 Optimized Feedback Strategies for Training Performance 43

1.7.4 Understanding why feedback improves performance. 43

1.8 Summary 44

2.0 Methodological discussion **44**

2.1 Subjects 44

2.2 Design 45

2.3 Training intervention 46

2.4 Measurements 47

2.4.1 Back squat 1RM 47

2.4.2 isometric Mid-thigh pull 48

2.4.3 Countermovement jump 49

2.4.4 Keiser leg press 49

3.4.5 Muscle size 50

3.0 References: **51**

1.0 Theory

1.1Physical demands in ice hockey

Ice hockey consists of intense skating sessions requiring quick changes in speed and direction, along with significant physical contact and the need to execute complex maneuvers (Cox et al., 1995; Flik et al., 2005; Green. 1979; Molsa et al: 2003). Players typically engage in shifts lasting from 45 to 60 seconds, during which they perform five to seven intense activities. After each shift, they have a rest period of 2 to 5 minutes before starting their next shift (Brocherie et al., 2018; Vigh-Larsen et al., 2020; Wagner et al., 2021).

Due to the intense physical nature of ice hockey, players must possess several crucial physiological attributes (Cox et al., 1995; Twist & Rhodes, 1993). Success at the highest levels requires significant strength and power (Cox et al., 1995; Twist & Rhodes, 1993). Such key attributes significantly contribute to the success in the NHL, widely regarded as the top hockey league worldwide (Burr et al., 2008). Notably, in the last decades, the size, speed, and strength of the players have increased, emphasizing the growing importance of physical attributes in enhancing performance on ice (Quinney et al., 2008).

1.2 Muscle strength

Strength can be defined as the ability to produce force (Stone, 1993). Moreover, muscle strength can be defined as the greatest amount of force that an athlete's neuromuscular system can generate in a single voluntary contraction, carried out in a particular movement at a specified rate (Knuttgen & Kraemer, 1987; Kumar, 2004). According to Warneke et al. (2023) achieving high maximal strength is vital for attaining top-level performance across numerous sports. Because of its importance, maximum strength is often included in performance monitoring programs to assess training progression (Lum et al., 2020). Multiple approaches have been employed to assess maximal strength including maximal voluntary isometric contraction (MVIC) and dynamic testing methods using the one repetition maximum (1RM) (Beckham et al., 2013; Buckner et al., 2016). MVIC is considered a simple and time-saving test (Mcguigan et al., 2010), which can maintain consistent test conditions with high test-retest reliability (Lynch et al., 2021; Drake et al., 2017). However, dynamic strength assessments using the 1RM test are still favored, as they don’t require expensive equipment like force plates or strain gauges (McMaster et al., 2014). The 1RM represents the maximum weight an individual can lift a single repetition with the correct form, representing their peak strength for a given exercise (Seo et al., 2012).

1.3 Power

Mechanical power is commonly defined as the rate at which work is performed (Knudson, 2009) and can be calculated by multiplying force by velocity (Newton & Kraemer, 1994). Based on the equation for calculating mechanical power, it becomes clear that two key factors significantly influence an athlete's ability to produce high power outputs. First, athletes need the capability to rapidly apply high levels of force, and second, they must be able to achieve high speeds during muscle contractions, meaning they need to maintain force even as the speed of their movement increases (Kawamori & Haff, 2004). Therefore, it can be said that maximal power is achieved when optimal levels of force and velocity are applied to a movement. According to Haff and Nimphius (2012), producing high power outputs is essential for excelling in various activities, such as jumping, throwing and changing direction. Additionally, Stone et al. (2002) indicated that the capacity to rapidly develop force and generate high power outputs is crucial for achieving success in a wide range of sports.

1.4 Relationship between muscle strength and power

Strength is recognized as an essential foundation for power development (Baker, 2001; Minetti, 2002; Zamparo et al., 2002). Research shows that athletes who possess higher strength levels tend to achieve greater power outputs (Baker, 2001; Stone et al., 2002). Typically, younger and less trained athletes lack the strength necessary to generate high power outputs (Haff & Nimphius, 2012). Thus, for these groups, merely enhancing strength levels can lead to significant increases in power output and overall athletic performance (Cormie et al., 2010a; Hakkinen & Komi, 1985; Stone et al., 2002).

Once an athlete achieves a sufficient level of strength, they can fully exploit the benefits of incorporating specialized training designed to enhance power development. Stronger athletes typically show higher responsiveness to specialized training focused on increasing power, such as explosive or plyometric training exercises (Cormie et al., 2010b). However, determining when an athlete has reached sufficient strength levels to transition to power-focused training can be challenging. Research indicates that athletes who can squat at least 2x their body weight tend to produce higher power outputs, especially in vertical and horizontal jumps, compared to those squatting 1.7 or 1.4 times their body mass (Barker et al., 1993; Ruben et al., 2010; Stone et al., 2002) Wisløff et al. (2004) indicate that athletes who squat

>2.0x body mass perform significantly better in terms of speed and jumping abilities compared to those who squat <2.0x body mass. Additionally, Keiner et al. (2012) suggest that with proper training programs, youth athletes aged 16 to 19 can typically reach and exceed a back squat of twice their body mass.

It's important to understand that the benchmark of reaching >2.0x body mass in the squat exercise is only a recommended strength level aimed at maximizing power performance for both male and female athletes (Haff & Nimphius, 2012). Continuing to build strength is not only beneficial but often essential. Notably, if stronger athletes cease to focus on developing strength, they tend to rapidly decrease in strength, which can ultimately lead to diminished performance that demands high power outputs (Cormie et al., 2010b).

1.5 The critical role of strength and power in ice hockey

In ice hockey, physical demands are evident as players absorb hits, displace rivals from strategic zones, and compete fiercely for the puck. These interactions underscore the crucial roles of strength and power, in mastering the challenges of the game (Huard Pelletier et al., 2021; Twist & Rhodes 1993). Electromyographic (EMG) studies have revealed that during simulated game sprints, ice hockey players exhibit high levels of maximal-intensity muscle contractions in the quadriceps and hamstrings (Behm et al., 2005). Additionally, research has shown a significant relationship between maximal isokinetic force production and speed over short distances on ice among both male and female players (Gilenstam & Thorsen, 2011; Potteiger et al., 2010). This indicates the critical need for substantial force generation during the acceleration stages of skating.

In a study by Preyer et al. (2011), the relationship between players' strength and their performance was further explored. One coach subjectively categorized the players into two groups: the top six and the bottom six, which facilitated further analysis of their preseason performance. The study found that the top players, categorized by their coach, exhibited stronger performance in strength tests like bench press, chin-ups, and leg press compared to the players ranked in the bottom group. This suggests that strength can be an indicator of better competitive abilities in ice hockey. Additionally, Hoff et al. (2005) observed that indicators of strength can be crucial in distinguishing elite from junior ice hockey players. The study noted that first-team players showed superior muscle mass and stronger performances in one repetition maximum (1RM) in the bench press and squat exercise, as well as higher jump force production, compared to the junior players. This suggests that junior athletes with higher strength levels and more muscle mass have a better chance of advancing to the elite first-team level (Hoff et al., 2005).

Burr et al. (2008) analyzed physical performance data from 853 participants over eight years of the national hockey league entry draft (NHLED). Their findings highlighted that peak anaerobic power, measured by a 30-second Wingate test, significantly predicted draft positions. Additionally, Burr et al. (2007) suggested utilizing leg power rankings to anticipate the draft order of elite junior players in the NHLED. The study found significant correlations between draft positions and performance in countermovement jumps (CMJ) ($r = 0.42$) and squat jumps ($r = 0.47$), highlighting leg power as a critical measure for assessing the potential of elite ice hockey players. Supporting these observations, Peterson et al. (2015) found that division I ice hockey players exhibited significantly better performances in CMJ ($p = 0.001$) and peak power in the Wingate test ($p = 0.05$) compared to division III players. These findings highlight the crucial roles of strength and power and suggest that developing these physical attributes can lead to improvements in player performance on the ice.

1.6 Autoregulation in Strength Training

Percentage-based training (PBT) is commonly used to calculate training loads, determining relative sub-maximal weights based on an established one-repetition maximum (1RM) in a given exercise (Fleck & Kraemer, 2014). This method has proven dependable and effective among various populations (Dorrell et al., 2019; Rhea & Alderman, 2004). Despite this, experience indicates that the actual 1RM can shift significantly after just a few training sessions, and often, the measured value does not accurately represent the subject's actual maximal strength (Gonzalez-Badillo et al., 2011). If there are issues during the initial 1RM test due to performance inconsistencies or testing errors, using a percentage of 1RM for training loads can result in inappropriate training stimuli (Zourdos et al., 2016). Moreover, the number of repetitions an athlete can perform at a given percentage of their 1RM varies significantly due to individual differences in genetics and training experience (Richens & Cleather, 2014). Due to potential variations in performance, autoregulation has emerged as a favored method for enhancing maximal strength (Helms et al., 2017). This method aims to adjust key elements of resistance training, such as intensity, volume, and frequency to align with the athlete's daily changes in fitness, fatigue levels, and readiness (Larsen et al., 2021). According to Larsen et al. (2021), autoregulation can be divided into two types: subjective and objective autoregulation.

1.6.1 Subjective autoregulation

Subjective autoregulation approaches in resistance training include Borg's (1982) rating of perceived exertion (RPE), where the athlete subjectively rates intra-set effort on a scale from 1-10. If an athlete aims to set exercise intensity using RPE on a set-to-set basis, it is important to acknowledge its limitations. Multiple studies indicate that RPE scores are often reported below the maximum even when they perform as many repetitions as possible with a given weight (Hackett et al., 2012; Pritchett et al., 2009; Shimano et al., 2006). Given these findings, Zourdos et al. (2016) explored the implementation of a 1-10 scale, where the RPE value directly relates to the number of repetitions in reserve (RIR). On this Scale, an RPE of 10 equates to 1RIR, an RPE of 9 to 2 RIR, and so on. They concluded that an RIR-based RPE scale was a practical method for regulating daily training load. In addition, Gramham and Cleather (2021) compared the effects of RIR in contrast to fixed loading. They found that the RIR group demonstrated greater improvements in both front and back squat performance compared to the fixed loading group. However, RIR has been reported to be less reliable for untrained individuals (Steele et al., 2017) and during sets that involve a high number of repetitions (Hackett et al., 2017; Zourdos et al., 2021).

1.6.2 Objective autoregulation

Several authors suggest that monitoring movement velocity could provide a more precise and objective method to measure resistance training intensity (Gonzalez-Badillo & Sanchez-Medina, 2010; Jovanovic & Flanagan, 2014; Mann et al., 2015; Sanchez-Medina & Gonzalez-Badillo, 2011). Research has suggested that monitoring the movement velocity could provide a more accurate and sensitive measure of relative intensity compared to the traditional percentage-based 1RM approach (Gonzalez-Badillo & Sanchez-Medina, 2010; Gonzalez-Badillo et al., 2017). This is supported by the clear linear relationship between movement velocity and %1RM across various exercises, including the back squat and leg press (Conceicao et al., 2015; Sanchez-Medina et al., 2017). Weakley et al. (2021) describe two primary methods for setting training intensity in velocity-based training (VBT). The first method, velocity targets + velocity loss, involves starting the exercise with a specific velocity target or range. The set is terminated once the velocity decreases by a predefined percentage (Galiano et al., 2020; Pareja-Blanco et al., 2020a; Rodriguez-Rossel et al.,2020; Sanchez-Moreno et al., 2020). The second method, set average + velocity loss thresholds, focuses on adjusting the load to maintain a predetermined average velocity within the set. (Dorell et al., 2019; Orange et al., 2019; Shattock & Tee, 2020). Both methods have proven effective, and using VBT to monitor intensity is recommended as it may be more effective than methods like RPE and RIR-based training for increasing maximum strength (Larsen et al., 2021). Furthermore, Larsen et al. (2021) suggest that the potential advantage of VBT could be attributed to its ability to provide objective, augmented feedback to athletes throughout the exercise.

1.7 Feedback

To encourage positive adaptions such as power and high-velocity strength, resistance training must be conducted with great effort, pushing athletes to achieve high kinematic outputs (Pareja-Blanco et al., 2017). Yet, athletes often fail to reach these maximal outputs, possibly due to physiological factors like neuromuscular fatigue (Roe et al., 2016; Weakley et al., 2017) or psychological issues such as low motivation (Weakley et al., 2019; Wilson et al., 2017). Thus, identifying methods that boost these aspects could greatly benefit both coaches and athletes. One possible way to achieve this is by providing augmented feedback, which refers to feedback from an external source that provides information about the outcome of a performed task (Wälchli et al., 2016). According to Weakley et al. (2023) can this type of feedback greatly enhance kinematic and kinetic outputs, as well as the adaptations that follow, during resistance training.

1.7.1 Effect of Different Feedback Types

The effects of different forms of feedback have been researched in the context of resistance training, including verbal kinematic feedback, verbal encouragement, and visual kinematic feedback (Weakley et al., 2020a). Argus et al. (2011) investigated the effect of verbal kinematic feedback in elite rugby players during a resistance training session. Nine athletes performed 3 sets of bench throws with 4 repetitions over four sessions, with verbal kinematic feedback provided in two sessions and none in the other two. Results showed that receiving verbal kinematic feedback led to an increase in peak power (1.8%) and velocity (1.3%). These improvements were most noticeable in the second and third sets, suggesting that verbal kinematic feedback can enhance upper body power output. Alternatively, offering verbal encouragement is a cost-efficient way to improve performance during resistance training (McNair et al., 1996). Previous research has demonstrated that physical adaptions and adherence to training programs improve when a strength and conditioning coach is present (Smart & Gill, 2013). McNair et al. (1996) investigated how verbal encouragement affected peak force in elbow flexors during isometric contractions. Using a crossover design, 20 subjects performed trials with and without verbal encouragement. The results indicated that verbal encouragement led to a significant increase in mean peak force (from 296 newton to 311 newton, a 5% increase).

Recently, collecting performance data has become increasingly popular among recreational exercises. Advancements in technology and human expertise, now allow for real-time tracking and display of exercise data in ways previously not achievable (Wilson et al., 2018). Weakley et al. (2019) investigated the effect of visual feedback on barbell velocity and motivation in younger male athletes. In a randomized crossover design, feedback on mean visual barbell velocity was either given or withheld during 10 repetitions of the back squats. The results showed that providing feedback led to a higher mean concentric barbell velocity (0.70 ± 0.04 m/s vs. 0.65 ± 0.05 m/s) and enhanced motivation. The authors suggested that offering visual kinematic feedback can help maintain barbell velocity throughout a set, potentially improving training outcomes.

1.7.2 Effect of feedback frequencies

Since feedback has proven to be significantly more effective compared to when no feedback is given, questions have emerged regarding the optimal amount and frequency to maximize its effectiveness throughout resistance training. Nagata et al. (2020) compared the effects of various augmented feedback types and frequencies during a 4-week velocity-based training program. 37 collegiate rugby players were divided into four groups: immediate feedback, visual feedback, average feedback, and no feedback. Each group followed 3 sets of 5 repetitions of loaded jump squats per session. During each session, the immediate feedback group received feedback on their lifting velocity after every repetition, while the average feedback group received average loaded squat jump data following each set. The visual feedback group received visual feedback via video after each set. The results indicated that the Immediate feedback group outperformed all other groups in the loaded jump squat exercise, with effect sizes ranging from 1.02-1.25 when compared to the no feedback group, 0.78-0.82 relative to the average feedback group, and 0.74-1.60 compared to the visual feedback group. This study demonstrated that immediate feedback following each repetition optimizes performance and should be considered an effective tool in velocity-based training.

Additionally, Perez-Castilla et al. (2020) investigated the effects of varying frequencies of feedback on velocity performance in ballistic training. Fifteen men participated in four identical training sessions (three sets of six repetitions at 30 % of their one-rep max during countermovement jump and bench press throw). The only difference between sessions was the type of feedback provided; no feedback, velocity feedback after the first half of repetitions per set, immediate feedback velocity feedback after each repetition, and feedback on the average velocity of each set. Results showed that the immediate feedback group had the greatest improvement in velocity performance (1.9-5.3%) compared to no feedback. This further demonstrates that immediate velocity feedback after each repetition can significantly increase velocity performance in resistance training.

1.7.3 Optimized Feedback Strategies for Training Performance

Even though feedback is known to be an effective tool in resistance training, the literature still contains inconsistencies regarding the best methods of delivery. Thus, Weakley et al. (2023) conducted a meta-analysis to determine the most effective strategies for providing feedback in resistance training. Their analysis included 13 studies on the acute effects of providing feedback. The results showed that providing feedback led to an 8.4% immediate increase in concentric velocity during resistance training compared to when no feedback was given. This occurred even though participants in all studies were instructed to exert maximal effort under both feedback and non-feedback conditions. Moreover, adding verbal encouragement to verbal or visual kinematic feedback does not seem to offer any extra advantage (Campenella et al., 2000; Kimura et al., 1999). According to Weakley et al. (2023), there are no significant differences in the effectiveness of feedback based on load intensity (above or below 50% 1RM), upper or lower body exercises, mean or peak velocity, or the number of sets used. However, visual kinematic feedback had a statistically better effect on velocity outcomes than verbal feedback. These findings, along with those of Nagata et al. (2020) and Perez-Castilla et al. (2020), provides clear insight into the potentially most effective way to implement feedback during resistance training. Taken together, it is recommended that individuals receive consistent, high-frequency visual feedback during their resistance training sessions (Weakley et al., 2023)

1.7.4 Understanding why feedback improves performance.

Various mechanisms have been suggested to clarify why resistance training performance improves when feedback is provided. For instance, heightened motivation and competitiveness associated with visual feedback have been linked to improved velocity and power output during resistance training (Weakley et al., 2019; Wilson et al., 2017). Furthermore, it has been shown that providing feedback during resistance training reduces the perceived physical demands (Weakley et al., 2019). In particular, improvements in motivation and competitiveness have been shown to lessen the acute effects of fatigue during each set, which allows athlete's to perform a higher number of repetitions and achieve greater training volume before reaching concentric failure set (Ok & Bae, 2019).

1.8 Summary

Feedback in resistance training is important and seems to enhance performance by up to 10% during a training session. Training with such an elevated performance level is likely to result in better training responses over time, which is consistent with existing studies (Weakley et al., 2023). However, within the field of visual feedback during resistance training, there is still much to learn about the most effective methods. Some methods focus on maintaining specific speed targets, while others focus on velocity loss. Additionally, most feedback during resistance training uses numerical data, offering precise measurements that athletes can respond to. However, the potential to use colors as an additional form of feedback can influence both behavior and motivation (Weib et al., 2022). Color-coded alerts might simplify complex data, making it easier to understand and act on. Despite this potential, research on the impact of color feedback on human behavior in sports remains limited (Weib et al., 2022). To the author's knowledge, no previous studies have explored the effect of color-coded alerts and percent velocity loss feedback, making it an interesting topic for future research.

2.0 Methodological discussion

2.1 Subjects

The initial sample size of the present study consisted of 42 semi-professional ice hockey players aged 17 to 19 years. During the study, seven participants withdrew, due to injuries not related to the present study (n=4) or not attending at least 80% of the training sessions (n=3). According to Nagpal et al. (2021), high attendance in exercise trials is typically described as exceeding 70% attendance. However, it's important to note that adherence is not a clear-cut concept, but it varies widely based on individual and intervention-specific factors (Alberga et al., 2019; Picorelli et al., 2019).

After accounting for the dropouts, the velocity loss with traffic light feedback group (TL) was left with 17 participants, and the velocity feedback group (VF) had 18. Based on an expected SD of 6%, we had 80% power to detect a true mean group difference of 5% in muscle strength (1RM) with a minimum of 17 participants in each group (alpha: 0.05; two-tailed).

Our study met these criteria, suggesting sufficient statistical power to detect a true meaningful difference in training performance between the feedback groups. A greater difference between groups, combined with smaller variability in each group, would require fewer participants to identify a genuine difference in performance from pre- to post-test (Bhide et al., 2018). Given that both the TL and VF groups were quite homogenous groups of well strength trained ice-hockey players, this likely provides stronger evidence that the intervention was the most likely reason for the observed differences in training outcomes.

2.2 Design

The present study was designed as a randomized controlled trial (RCT), meaning we randomly assigned participants into two different groups. This type of study is often seen as the gold standard in research because helps us understand if the intervention directly causes the outcomes we observe (Bhide et al., 2018). We specifically used an active treatment-controlled trial, a type of RCT where we compared our new intervention against an already existing, well-established treatment (Evans & Ilstad, 2001). In particular, the VF group received visual feedback on the concentric velocity during the lift, which is already known to be effective (Weakley et al., 2023). On the other hand, the TL group was given a new type of feedback that to the authors' knowledge hasn't been tested yet. This setup allowed us to compare the new feedback method against the existing one to see if it provided any additional benefits. The inclusion of an additional training group without feedback would allow us to assess the effect of feedback per se. However, that was not the aim of the present study.

In the study design, we did not facilitate an equal training volume for the groups. The groups differed not only in the type of feedback they received and the velocities of the repetitions but also in training volume. This can be seen as a limitation because having different training volumes can lead to a somewhat unfair comparison of training outcomes between the feedback types, as we know that training volume is crucial for results (Shoenfelt et al., 2017). However, we chose not to ensure equal training volumes between groups because one of our main aims was to see how many repetitions they could complete before reaching the velocity thresholds. Another potential limitation is that we could not determine whether the percentage velocity loss in numbers or the color-coded alerts were central, or if both worked in synergy. This can be seen as a limitation as we were unable to distinguish between these factors. Therefore, future research should examine the effects of these feedback methods separately to better understand their individual contributions more clearly.

One drawback of the RCT is that the findings might not be easy to generalize to people outside the study group (Hariton & Locascio, 2018). It is important to keep in mind that an RCT study might only be relevant for populations like those who participated in the trial. Given that the participants in the present study were well-trained and highly motivated it is plausible that the results may be most relevant for individuals with similar characteristics and training backgrounds as the participants in the study. Another potential limitation of the study design is the introduction of the placebo and nocebo effect. A placebo effect occurs when there is a favorable outcome due to the belief or expectation that one has received a positive intervention (Beedie & Foad, 2009), while a nocebo effect occurs when negative expectations, beliefs, or experiences about the treatment lead to harmful outcomes (Wartolowska, 2019). Since it was not possible to separate the feedback groups during their training sessions, both groups were aware of each other's feedback types. This might have led to a placebo and nocebo effect, with some participants possibly thinking the other group's feedback was better or worse than their own. According to Wartolowska (2019), the nocebo effect is often overlooked in clinical research, which is concerning as it can negatively impact the results of treatments and trials. However, we made it clear to everyone that we had no preference or knowledge regarding which type of feedback was superior. Additionally, we observed that there was a competitive atmosphere, with each group reporting that their feedback was the best.

2.3 Training intervention

The present study consisted of a 10-week velocity-based training (VBT) program where each group received different types of feedback. Jukic et al. (2023) reviewed 19 longitudinal VBT studies and found that the studies lasted around eight weeks on average. Since the athletes in our study were well-trained, a 10-week program was chosen. This longer duration could potentially help accumulate the participant's strength gains further, as it becomes harder to see improvements when athletes are better strength trained and get closer to their genetic potential (Grgic et al., 2022). Additionally, a systematic review by Weakley et al. (2023) found that seven studies had investigated the effects of feedback on long-term training outcomes, with all interventions lasting between 4-6 weeks. On average, the participant groups in these studies consisted of 23±8 participants. Given that our study lasted over 10 weeks and included in total 35 participants, it can be considered a strength of the study, especially when compared to the previous studies within the subject that have fewer participants and shorter duration. Nevertheless, according to Beato (2022), there is a need for more solid RCTs in strength and conditioning research, which should involve more participants, have a longer duration, and include the right type of control group.

The aim of the present study was to compare these specific feedback training regimes during the athletes' competitive season. With a packed schedule that includes games, on-ice training, and strength sessions, both players and coaches need to carefully manage fatigue, injuries, and performance issues (Donaldson et al., 2014). Their training schedule included four to five on-ice sessions, and two strength training sessions, in addition to an average of two games per weekend. According to Neeld et al. (2018), with the heavy demands of on-ice training and overall stress during the hockey season, off-ice training should aim to maintain strength and power while also aiding in recovery. Given the high volume of games and training, we hypothesized that it might be difficult to observe large pre-post improvements in training outcomes during the intervention period. Therefore, it was crucial to design a training program that aimed to balance both fatigue management and enhancing strength and power. In the present study, the participants used a 30% velocity loss on Tuesdays and a 20% velocity loss on Fridays, right before their weekend matches. Weakley et al. (2020b) recommend using lower velocity loss thresholds, like 10% and 20%, to maximize kinematic outputs and reduce neuromuscular fatigue. Therefore, we thought that a 20% velocity loss wouldn't overly fatigue the players before their games. Conversely, for the Tuesday strength sessions, we aimed to increase the training volume and degree of fatigue somewhat more. According to Weakley et al. (2020b), using a 30% velocity loss threshold is effective for boosting training volume while avoiding all the way to muscular failure, making it favorable as a stimulus for muscle hypertrophy without substantial accumulation of fatigue.

All 19 strength training sessions were supervised by two practitioners with long experience in resistance training. Faigenbaum et al. (2009) emphasize that having an experienced strength and conditioning coach supervise adolescent athletes during resistance training is recommended for their safety. Furthermore, it has been shown that when sessions are directly supervised, athletes are more likely to stick to their training program and see greater improvements in strength (Smart & Gill, 2013).

2.4 Measurements

2.4.1 Back squat 1RM

McCurdy et al. (2004) and Tagesson and Kvist (2007) both reported that one repetition maximum (1RM) testing for squats is a highly reliable test. McCurdy et al. (2004) included 30 untrained participants (22 women, 8 men) and 22 trained participants (12 women, 10 men), who had at least a year of lower body training experience. Participants performed the 1RM test with a 48-hour rest between tests. A subset of 20 participants also completed a third session of the 1RM test three days after the posttest to further assess reliability. The study found that 1RM tests were highly reliable across all groups (Trained men: r=0.98, Untrained men: r=0.99, Trained women: r=0.99, Untrained women: r=0.97). Additionally, a systematic review by Grgic et al. (2020) found that the 1RM test was reliable and reported a median coefficient of variation (CV) of 4.2%, regardless of the participant's resistance training background, the number of familiarization sessions, the specific exercise performed, the body part assessed, and the sex or age of the participants. Consequently, they concluded that practitioners could use the 1RM test as a reliable measure of muscular strength. However, Lindberg et al. (2022) noted that the 1RM squat test showed the most variability in test-retest results among different lower body strength tests. Taken this to consideration, the back squat 1RM might not be as consistent and could possibly produce more varied results when repeated from pre- to post-test.

It should be noted that the squat depth was standardized, with the femur positioned at a 90-degree angle parallel to the floor. A practitioner provided verbal feedback to signal when this depth was achieved, allowing participants to begin the concentric phase of the lift. However, during the pre-test, time constraints prevented us from conducting the 1RM test for all participants simultaneously. Therefore, we had to split the group, with one subset performing their 1RM test with the physical coach. Upon entering the 1RM test room, we observed that a few participants did not reach the standardized squat depth. To address this, we instructed all participants to ensure that they matched their pre-test squat depth during the post-test.

2.4.2 isometric Mid-thigh pull

Using the 1RM test has been shown to effectively translate to performance and has demonstrated its reliability (Grgic et al.,2020). However, performing a 1RM test can be tiring and may increase the risk of injury (Comfort et al., 2019). An alternative way to measure lower body strength is the isometric mid-thigh pull (IMTP), which has proven to be reliable for strength testing (De Witt et al., 2018). However, a systematic review by James et al. (2023) investigated the longitudinal associations between isometric and dynamic assessment of maximal lower body strength and found high levels of variations (CV% = 109.27) between the two types of strength measurements. They concluded that isometric and dynamic strength measurements are not related over time and measure different aspects of strength. Although practioners might consider using the IMTP test instead of a dynamic strength test, this approach could lead to misleading information if the goal is to assess dynamic strength (James et al., 2023). Considering this, it raises the question of whether isometric strength is less related to sports performance.

Additionally, we were concerned that grip strength would potentially affect the IMTP test results. Rhodes et al. (2020) found that grip strength influences IMTP performance, suggesting that it is important to consider this factor when using the IMTP for strength assessments. To address this, we made sure that participants used liquid chalk to keep their hands from slipping of the handles. This helped them maintain a better grip and potentially helped them to demonstrate their actual lower body strength more accurately.

2.4.3 Countermovement jump

The countermovement jump (CMJ) is a popular test for measuring an athlete's explosive lower-body power and it is widely used by coaches and researchers to get an indirect measure of lower limb power (Dias et al., 2011). The CMJ is recognized as a reliable and valid measure of lower body explosive power and is considered the most reliable test for assessing lower body power when compared to other common jump tests like the squat jump, sergeant jump, and standing long jump (Markovic et al., 2004). Furthermore, Markovic (2004) reported a CV of 2.8% for the CMJ, while Souza et al. (2020) demonstrated a CV of 5.8% for jump height in the CMJ test. The participants in the present study were instructed to keep both hands on their hips during the entire test. Studies have shown that using an arm swing during the CMJ can improve performance by about 10% or more (Cheng et al., 2008). Cheng et al. (2008) also pointed out that since most people are used to jumping with their arms, performing jumps without arm swing might not be optimal. However, since the participants in the present study were familiar with the exercise, we chose to exclude the arm swing. This decision was made to minimize potential improvements in technique and to focus solely on measuring their true lower body power. While in the air, the participants were instructed to maintain full extension in their hip, knee, and ankle joints to prevent them from gaining any extra flight time by bending their legs (Markovic et al., 2004).

2.4.4 Keiser leg press

Redden et al. (2018) found no significant differences between consecutive tests and demonstrated acceptable reliability of all measured strength and power variables during the 10-repetition Keiser leg press test. In the present study, we used theoretical maximal strength and power measures, which was extrapolated from a force-velocity curve from the 10-repetition test. When examining the reliability between sessions, the Keiser leg press has shown strong reliability for both the Fmax value (CV of 3.7% - 4.2%) and the Pmax value with a CV of 4.2% (Lindberg et al., 2021). Each participant maintained the same seat position from pre- to post-test to ensure that the knee angle (90-degree) was the same in both tests. During the pre and post-tests, we encountered a total of seven incidents where the Keiser leg press device shut down between repetitions 2 and 5. Each time this happened, we had to repeat the test, which could potentially lead to fatigue for the affected participants. Fortunately, the shutdowns occurred relatively early in the testing sequence before the hardest repetitions. This suggests that fatigue did not significantly impact the participants' performance. Despite these interruptions, we were able to manage the situation and continue with the testing. Nonetheless, these incidents highlight the potential effects of unexpected technical issues on test outcomes.

3.4.5 Muscle size

Muscle thickens of the vastus lateral was measured with ultrasound imaging from the LogicScan 129 CEXT 1-Z REV; B, which has been commonly used in other studies (Bjørnsen et al., 2016, Bjørnsen et al., 2021). We chose the real-time B-mode ultrasound because it is user-friendly and safe, eliminating the need for invasive methods (Koppenhaver et al., 2008). Additionally, we had the equipment readily and available. This type of measurement has been widely researched for its reliability and validity. Betz et al. (2021) demonstrated that B-mode ultrasound is a reliable method for assessing the size of the vastus lateralis muscle. Moreover, a systematic review by Pretorius and Keating (2008) found that ultrasound can provide valid measurements for skeletal muscles. Herbert et al. (2009) noted that using the average of multiple measurements improves reliability. Based on this, we measured the thickness of the vastus lateralis muscle at three different points and used the mean of these measurements for our analysis. Furthermore, Herbert et al. (2009) concluded that reliability improved when experienced examiners performed the ultrasound testing. Therefore, one practitioner underwent 10 hours of training before the intervention started. Although this might not be a lot of time, the practitioner received thorough guidance and practice, ensuring he was well-prepared and comfortable performing the ultrasound measurements.

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Part 3

Appendices

Appendix 1: Ethical approval application for the research project

UiA Universitetet i Agder

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
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FAKTURAADRESSE:
UNIVERSITETET I AGDER
FAKTURAMOTTAK
POSTBOKS 383 ALNABRU 0614 OSLO

Appendix 2: Approval from the Norwegian Centre for Research Data

NSD NORSK SENTER FOR FORSKNINGSDATA

NSD sin vurdering

Prosjekttittel

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

Referansenummer

464080

Registrert

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

Behandlingsansvarlig institusjon

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

Prosjektansvarlig (vitenskapelig ansatt/veileder eller stipendiat)

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

Type prosjekt

Forskerprosjekt

Prosjektperiode

15.02.2020 – 31.12.2023

Status

31.05.2021 – Vurdert

Vurdering (2)

31.05.2021 – Vurdert

Appendix 3: Signed written consent from the participants

Vil du delta i forskningsprosjektet eksplosiv styrketrening i sesong for ishockeyspillere?

Dette er en forespørsel til deg om å delta i et forskningsprosjekt hvor formålet er å undersøke effekten av to hastighetsstyrte styrketreningsprogram på fysisk prestasjonsevne hos ishockeyspillere i sesong. I tillegg vil det undersøkes om det finnes sammenheng mellom ens autoregulering og prestasjonen på den hastighetsstyrte styrketreningen I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Formål

Formålet med denne studien er å undersøke effekten av eksplosiv styrketrening på muskelstyrke, power (effekt/eksplosivitet), muskelstørrelse hopp og sprint prestasjon under sesong. Dere blir tilfeldig fordelt til et av to knebøy programmer som er integrert i det eksisterende treningsprogrammet for konkurranseperioden. Det ene knebøyprogrammet vil trene med et standardisert hastighetsfall på 30% i hver serie. Det vil si at man løfter knebøy så raskt man klarer på vei opp, og treningserien stoppes automatisk når skjermen foran dere lyser rødt, som er når hastigheten har sunket med 30% fall fra beste repetisjon. I det andre knebøy-programmet trener man ved å få oppgitt selve løftehastigheten på skjermen, og forsøker å løfte så raskt man klarer på vei opp i alle repetisjoner. En instruktør vil si ifra når man skal avsluttet serien i denne gruppen. Forskning har vist at begge disse programmene hver for seg kan ha god effekt, men ingen studier har sammenlignet de direkte på ishockeyspillere på høyt nivå i sesong. Før treningsprogrammet startes vil dere bli testet for baseline maksimal styrke, eksplosiv styrke og readiness i perioden før sesongstart og er integrert med treningsplanen deres.

Problemstillinger:

- Vil det være forskjell mellom styrketrening med tilbakemelding på 30% hastighetsfall, versus styrketrening med tilbakemelding på hastighet i hver repetisjon, på endring i styrke, sprint, spenst og muskelvekst prestasjon hos ishockeyspillere på høyt nivå i sesong?
- Vil det oppstå en autoregulering ved treningsvolum basert på løftehastighet og readiness i forhold til baseline fra treningsøkt til treningsøkt ved hastighetstyrt styrketrening blant ishockeyspillere på høyt nivå i sesong?

Hvem er ansvarlig for forskningsprosjektet?

Universitetet i Agder (UiA) er ansvarlig for prosjektet. Prosjektansvarlig 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 mannlige ishockeyspillere på høyt nivå i alderen 16-20 år med god helse.

Hva innebærer det for deg å delta?

For å delta krever det at hver deltaker oppgir navn, fødselsår og kontaktinfo. Videre innebærer deltakelse at hver person gjennomfører fysiske tester ved klubbens treningslokaler i Stavanger og ved Olympiatoppen Sørvest (Vikinghallen). Etter første testrunde blir man randomisert (tilfeldig fordelt) i en av to knebøy-program som trenes i 10 uker under kampsesong. Tidspunkt for testing og trening er planlagt for høsten 2023.

For å kunne delta er det ønskelig at hver deltaker:

- Gjennomfører fysiske tester før og etter treningsperioden fordelt på totalt 2 dager
  - Tester tar 2-4 timer per oppmøte
  - Testene må gjennomføres i utvilt tilstand før og etter treningsperioden. Uthvilt tilstand betyr uten å ha gjennomført hard anstrengende trening de siste 48 timene og unngå all *uvant* trening de siste 72 timene.
- Gjennomfører knebøy-programmet som er blitt utdelt under hele treningsperioden. Det planlegges 2 knebøyøkter per uke med cirka 4 serier per økt.

Testene som utføres før treningsperioden og underveis i treningsperioden

Før oppstarten av treningsperioden vil du utføre baseline-testinger for svikthopp, squatjump, kontinuerlige svikthopp (RSI), en isometrisk/statisk beinøvelse og subjektiv restitusjon fra 1 – 10. Baseline testing vil skje mellom 2 – 8 økter i ukene før treningsperiodens start/sesongstart 19. september.

I starten av hver økt vil du, utføre 2 svikthopp, 2 squatjumps, 11 kontinuerlige hopp (RSI) og en isometrisk/statisk beinøvelse på Alphatek sin kraftplattform, samt gi din subjektive opplevelse av restitusjon (1 – 10).

Testene som utføres både før og etter treningsperioden:

- Høyde og vekt
- Muskelstørrelse av samme lårmuskulatur med ultralyd.
- En kroppsscan (Inbody) som måler din totale muskelmasse i kroppen.

Deretter er det en 10 minutters lang oppvarming etterfulgt av 3 forsøk for hver test og med 3 minutter pause mellom hvert forsøk:

- 30 meter sprint (med splittider) av og på is.
- Svikthopp og knebøyhopp.
- Styrke og power (effekt/eksplosivitet) tester i bein.

Treningsgruppene

Selve treningsprogrammet og antall serier i knebøy utarbeides sammen med fysisk trener Dennis Sveum, imens måten knebøyseriene blir justert på i begge grupper er utarbeidet i fra tidligere forskning på lagspillutøvere for å maksimere eksplosiv prestasjon.

Deltakerne vil bli tilfeldig delt inn i to treningsgrupper. Knebøytreningen i den ene gruppa vil bestå av to økter i uken hvor hver serie stoppes ved et hastighetsfall på 30% som kommer opp på skjermen rett foran knebøystativet. Den andre gruppen vil trene de samme to øktene med knebøy samtidig som man får oppgitt selve løftehastigheten på skjermen. En instruktør vil si ifra når man skal avsluttet serien i denne gruppen. I begge gruppene forsøker man å løfte så raskt man klarer på vei opp i alle repetisjoner.

Begge gruppene vil trene sentrale muskelgrupper ~2 ganger per uke under hele prosjektperioden utarbeidet sammen med fysisk trener, ved siden av lagtreninger og kamper.

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 og masterstudenter har tilgang til koblingen mellom måleresultatene og dine personopplysninger. Opplysningene vil anonymiseres når prosjektet avsluttes/oppgaven er godkjent, noe som etter planen er 31.12.2025. 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 31.12.25 og da vil kodelisten destrueres, noe som betyr at innsamlet informasjonen er anonymisert og ingen opplysninger kan spores tilbake til deg. Anonymiserte resultater vil bli sendt inn til fagfellevurderte forskningsjournaler i etterkant og er en del av masteroppgaver ved Universitetet i Stavanger. 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 og masterstudenter 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:

- Masterstudent Vegard Ege Bjelland, epost: ve.bjelland@stud.uis.no, tlf: 414 93 887
- Masterstudent Henrik Vormeland Paulsen, epost: hv.paulsen@stud.uis.no, tlf: 995 78 519

- Prosjektmedarbeider og Førsteamanuensis Håvard Myklebust, epost: havard.myklebust@uis.no, tlf: 994 12 463
- Prosjektansvarlig og Førsteamanuensis Thomas Bjørnsen, epost: thomas.bjornsen@uia.no, tlf: 986 19 299

- Kontakt vårt personvernombud ved Universitetet i Agder:
  - Rådgiver Trond Hauso (trond.hauso@uia.no, 936 01 625)

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

Vegard E. Bjelland
(Masterstudent)

Henrik V. Paulsen
(Masterstudent)

Dennis Sveum
(Fysisk trener Oilers)

Håvard Myklebust
(Veileder/Førsteamanuensis)

Thomas Bjørnsen
(Prosjektleder/Veileder/Førsteamanuensis)

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet styrketrening i sesong for mannlige hockeyspillere, og har fått anledning til å stille spørsmål. Jeg samtykker til:

- ☐ å gjennomføre alle fysiske prestasjonstester (styrke, power, sprint, hopp)
- ☐ å gjennomføre målinger av muskelstørrelse (ultralyd) og kroppssammensetning (Inbody)
- ☐ å gjennomføre spørreskjemaer underveis i studien
- ☐ Å gjennomføre knebøy-programmet man blir trukket til å gjøre

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

----

(Signert av prosjektdeltaker, dato)

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

Author Guidelines

Sections

1. Submission
2. Aims and Scope
3. Manuscript Categories and Requirements
4. Preparing the Submission
5. Editorial Policies and Ethical Considerations
6. Author Licensing
7. Publication Process After Acceptance
8. Post Publication
9. Editorial Office Contact Details

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- The title page of the manuscript, including:
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        - ethics approval statement
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3. MANUSCRIPT CATEGORIES AND REQUIREMENTS
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Word limit: **Page charges will apply to articles exceeding 8 pages**. Please see the Publication Process after Acceptance section.

Abstract: 250 words maximum.

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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

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Letters to the editor should pertain to crucial scientific aspects, such as the interpretation of data or methods related to a recent article in the journal, including reviews and opinion articles. The content must remain focused on scientific aspects, avoiding any derogatory language. The authors of the referenced article will be able to respond, and their response will be published. Letters should not introduce new data, although such data can be presented in the response. If any original article author chooses not to participate in the response, this should be mentioned as a note at the end of the rebuttal letter. The letter to the editor may also present a short opinion piece or address a controversial issue of recent relevance in Sports Sciences or Sports Medicine or submit a comment on a single case study.

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- Acknowledgments;
- Up to eight keywords;
- Main body: formatted as introduction, materials and methods, results, discussion, acknowledgements, conflict of interest statement;
- References;
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- Figures: Figure legends must be added beneath each individual image during upload AND as a complete list in the text.

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References

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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

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2. Been involved in drafting the manuscript or revising it critically for important intellectual content; and
3. Given final approval of the version to be published. Each author should have participated sufficiently in the work to take public responsibility for appropriate portions of the content; and
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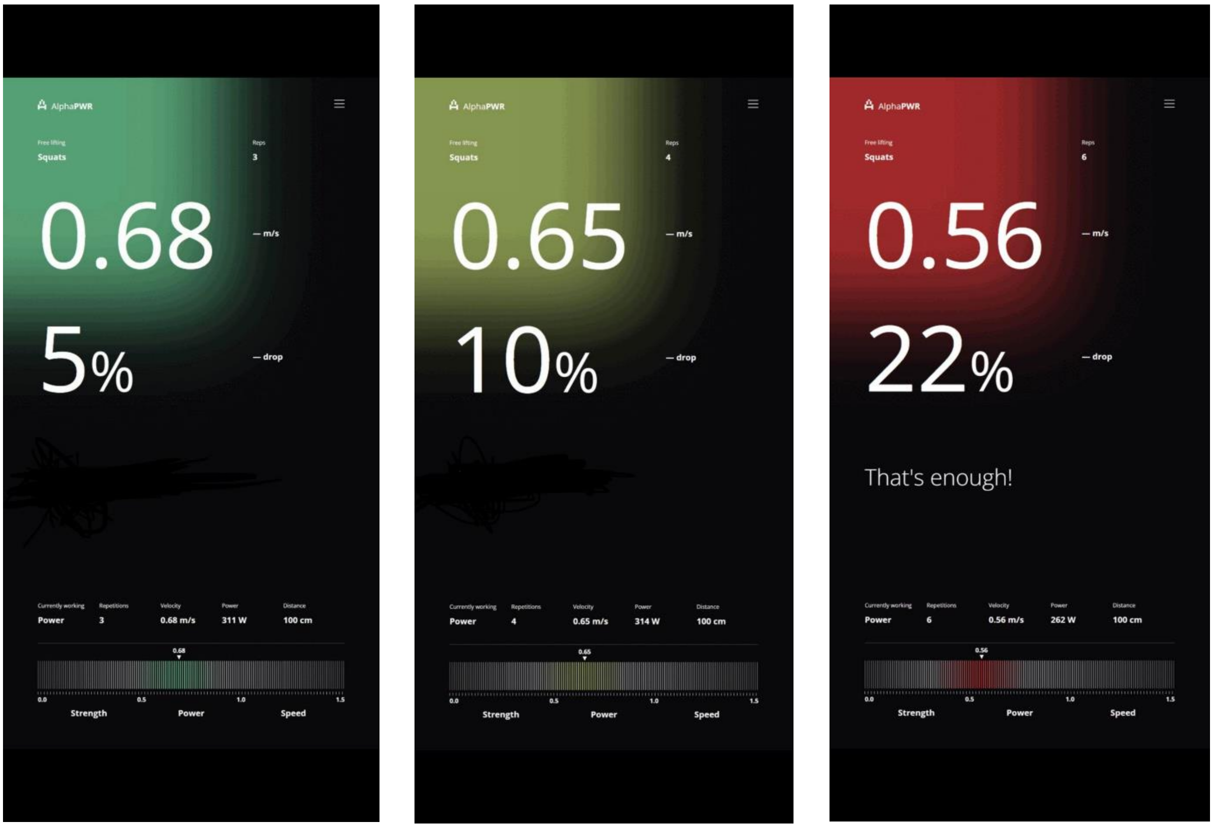
Appendix 5: Detailed outline of the strength training program implemented during the intervention

	Weekly session 1		Weekly session 2	
	Exercise	**Sets x Repetitions**	**Exercise**	**Sets x Repetitions**
Week 1 - 5	BBsq 80% 1RM	3 x 30% VL	BBsq 70% 1RM	3 x 20% VL
	B1. Barbell alternating step ups	3 x 10 (5el)	B1. Barbell bench press	4 x 6
	B2. Lateral step up jumps	3 x 3el	B2. Line quick feet; forward backward jump both legs	2 x 7 Seconds
	C1. Swissball hamstring curl	3 x 15	B3. Line quick feet; forward backward jump one-leg	2 x 7 Seconds
	C2. Landmine Cossack mobility	3 x 10 (5el)	C1. Pullups (Weighted)	3 x maximum
	C3. Copenhagen plank (partner hold)	3 x 10ea	C2. Line quick feet; lateral jumps both legs	2 x 7 sec
	C4. Landmine rotation (explosive)	3 x 12 (6el)	C3. Line quick feet; lateral jumps one-legged	2 x 7 sec
			D1. Band clean + press	3 x 10
			D2. Bent over reverse flies	3 x 12
			D3. Line quick feet; forward backward sprint	2 x 7 sec
			D4. Line quick feet; in & out jump	2 x 7 sec

Week 6 - 10	A1. BBsq 80% 1RM + 2.5kg (+5kg week 9-10)	3 x 30% VL	A1. BBsq 70% of 1RM + 2.5kg (+5kg uke 9-10)	3 x 20% VL
	B1. Deficit reverse lunge	3 x 8 el	B1. Bench press	4, 4, 3, 2
	B2. Band assisted vertical jump	3 x 3	B2. Suitcase KB march	3 x 10 + 10
	B3. Depth broad jump	3 x 3	C1. Single arm landmine row	3 x 10
	C1. Single leg small hurdle hoops	3 x 3 el	C2. Kneeling biceps curl	3 x 12
	C2. Single leg Romanian deadlift	3 x 10 el	C3. Weighted deadbug	3 x 20
	C3. Calf raise farmers walk	3 x 20 (10 el)		

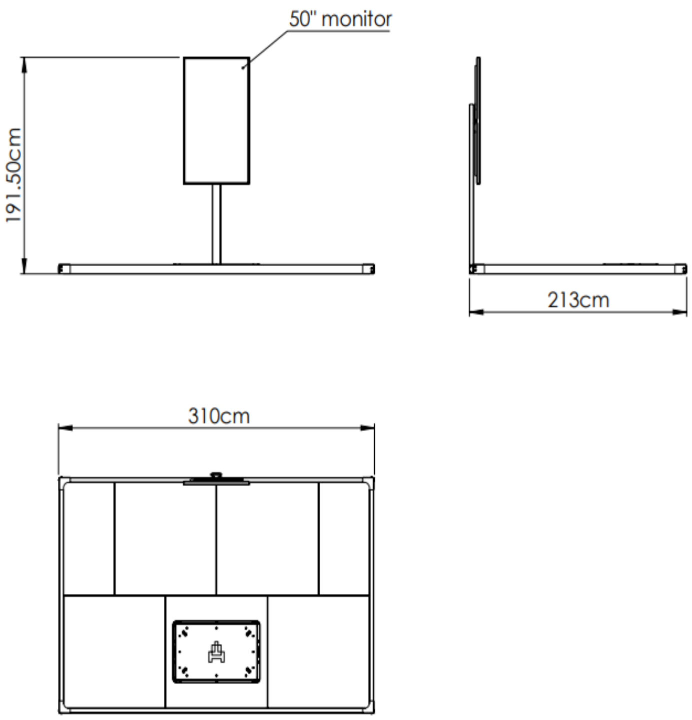
BBsq = Barbell back squat., **el =** each leg.,**ea** = each arm **X1,X2,X3,X4** = Sets performed as a super/giant set back to back without rest., **VL** = Velocity Loss., **+2.5/5kg** = added load from initial 1RM

Appendix 6: Traffic light Group feedback screen



Appendix 7: Velocity feedback group screen

Appendix 8: Alphatek Product Specification



Alphatek

Product specification sheet

AlphaPWR medium

Technical Requirements:

Electrical:
- Input Voltage: 2x AC 100-240 V (50/60 Hz)
- Maximum Power Consumption: 300W

Physical Requirements:
- Surface: Level surface with hard floor (Rubber tiles are acceptable)
- Recommended Roof Height: 275cm
- Dimensions: Refer to the drawing on the left for detailed physical dimensions

Internet Requirements:
- Connection: 2x Ethernet connection (CAT5); Wifi is not supported

Environmental Conditions:
- Operating Temperature: 32 °F – 104 °F (0 °C – 40 °C)
- Humidity: 10% – 80%, non-condensing