The effect of adding and removing feedback:

Visual augmented feedback improves movement velocity even when feedback is no longer provided.

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Bachelor thesis in Psychology

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Stavanger, 25.04.2023

Universitetet i Stavanger

«Det samfunnsvitenskapelige fakultet, Institutt for sosialfag»

Word Count: 5351

Overview

Abstract

English:

Maximizing potential gains of resistance training (RT) is beneficial for both top athletes and their coaches, clinicians, and rehabilitation patients, as well as the regular gym goer. The use of augmented feedback on velocity-based training (VBT) has shown to be beneficial for different RT goals, whether it be strength, speed, or power (Argus et al., 2011, Harries et al., 2012, Keller et al., 2014, Zhang et al., 2021), whichever might be suited for the type of athlete or goal in mind. However, whether the increased performance when adding feedback is a lasting effect is not established. What happens when feedback is removed? To examine this question this study measured lifting velocity in the squat through sets of 5 repetitions, with the test group (Feedback group=FG, N=18) receiving visual augmented feedback in their second set, while set one and three were done without feedback. The control group (CG, N=11) did all three sets without feedback. Power was also measured to look for tendencies. Paired sample t-tests revealed a significant increase in velocity from Set 1 to Set 2 in the FG, and from Set 1 to Set 3, while no significant change from Set 2 to 3, showing the effect of feedback and that removing feedback did not reverse the effect. The paired t-test in the CG found a significant decrease in velocity for each set added. Changes in velocity from Set 1 to 2 and Set 1 to 3 were then compared between groups. There was a significant difference between groups from Set 1 - 2 ($p = 0.001$) and from Set 1 - 3 ($p = <0.001$). These results show that (1) adding visual augmented feedback increase lifting performance, and (2) that the effect of the feedback last beyond the initial set where feedback was provided.

Keywords: Feedback, Visual Augmented Feedback, VBT

Norwegian:

Det å finne måter å øke effekten av styrketrening på er viktig for både toppidrettsutøvere og trenere, behandlere og pasienter, og ikke minst for den vanlige Ola Nordmann som trener på treningssenter for å få en sterkere kropp og bedre helse. Det å bruke «Augmented feedback» (Utvidet tilbakemelding direkte oversatt) på hastighetsstyrt trening (VBT) har vist seg å være gunstig for uansett hvilken kvalitet utøveren skulle ville utvikle, enteno om det er fart, styrke eller power (Argus et al., 2011, Harries et al., 2012, Keller et al., 2014, Zhang et al., 2021). Hvorvidt denne effekten varer utover de settene man mottar feedback på er ikke fastslått. Hva skjer når man så tar vekk tilbakemeldingen? For å undersøke dette målte studiet løftehastighet i knebøy gjennom 3 sett med 5 repetisjoner. Testgruppen (N=18) fikk visuell feedback på løftehastighet på sitt andre sett, mens sett 1 og 3 ble utført uten feedback. Kontrollgruppen (N=11) gjorde alle tre sett uten feedback. Power ble også målt for å ha et ekstra mål å se etter trender på. Resultatene viste at testgruppen økte hastighet signifikant fra sett 1 til 2 og 1 til 3, mens fra sett 2 til 3 var det ingen signifikant forskjell. Kontrollgruppen derimot sank signifikant for hvert sett lagt til. Når endringene fra sett 1 til 2 og 1 til 3 ble sammenlignet med hverandre så fant man signifikant forskjell (S1-2: $p = 0.001$, og S1-3: $p = <0.001$). Dette tyder på at (1) den prestasjonsøkende effekten av å gi visuell feedback på løftehastighet øker prestasjon, og (2) effekten påvirker settet etter selv når man ikke lenger mottar feedback.

Introduction

«How to improve performance» will always be an important topic for coaches and athletes. Resistance training (RT) for athletes is used to improve performance in their individual sport (Harries et al., 2012). Different methods are used depending on the goal or demands of the sport — whether that be strength, power, or speed. Variables in training like intensity and velocity are specific, which means that athletes get better at what they do in training and therefore it's crucial to perform RT with the right load and velocity for the goal in mind (Zhang et al., 2021). The ability to exert high force rapidly is an important skill in most sports, and to improve this skill, athletes should do part of their RT with the intent of lifting with as high velocity as possible. Most athletes cannot accurately estimate velocity themselves, therefore, feedback from coaches and technology can be useful. Current literature suggests that feedback on lifting velocity improves both intent in lifting, and movement performance, especially when given after each repetition and set (Jiménez-Alonso et al., 2022, Lauber & Keller, 2012, Nagata et al., 2018, Randell et al., 2011). What happens when feedback is no longer available? Will the performance enhancement from feedback in one set also affect the sets after when feedback is no longer given?

Background on training methodology: Why velocity-based training?

The traditional way of planning the loads in a resistance training program is by a percentage-based model based on an earlier measured one repetition maximum (1RM) usually given in kilograms. A drawback in these methods is the lack of attention to the daily variations in strength (Włodarczyk et al., 2021). 1RM can vary as much as 10-20 % within a given training week, and therefore using a percentage-based program could prescribe a too light, or too heavy load for the training goal (Zhang et al., 2021). This can lead to a higher risk of injury or a lack of progress from the bout of training. In sports where resistance training is used mainly to improve qualities for some other movement, for example in sprinting or basketball, it is essential to minimize potential risk and maximize the potential gain from RT. In contrast, the newer wave of auto-regulated training prescribes load based on the objective or subjective level of fitness for the day. This makes it possible for athletes, trainers, and others performing resistance training, to train with the optimal load for that day (Zhang et al., 2021).

Subjective vs objective ways of autoregulating load

One way of auto-regulating to daily form is by using self-reported Rate of Perceived Exertion (RPE) or Repetitions in Reserve (RIR) scales, although it may not be a reliable way of adjusting as it highly subjective and not possible to assess objectively. For some athletes, like powerlifters who compete in the squat and very well know their limits in the exercise it is used effectively, but for athletes who are not as familiar with their limits in the exercise it may not be optimal. We also see that RPE and RIR measures are highly unreliable when it comes to lighter loads or more than 2RIR. This makes the subjective auto-regulation methods less useful for the training of power and speed, as it is often trained with light loads, and every set is stopped far shy of failure (Larsen et al., 2021).

Velocity-based training, or VBT, is a relatively recently developed way of auto-regulation is the use of velocity as an objective measure of daily form. The maximal concentric velocity in a lift correlates to percentage of the 1RM on the given training, and a loss in velocity within a set correlates well with the proximity to failure. As an example, a velocity below 0.5 m/s is considered effective for training maximum strength (Zhang et al., 2021).

The measured velocity can therefore be used both to find the perfect load/intensity for the workout based on daily form and ensure that the athlete is training to the desired level of fatigue. This may result in a higher training effect of every set, every session, and ultimately the effect of each training period (Włodarczyk et al., 2021). A randomized controlled trial comparing VBT and the traditional percentage-based training (PBT) method found favorable adaptations in strength and explosivity in the VBT compared with the PBT. This was despite a significantly larger training volume in the PBT group, meaning that VBT can be a way of maximizing results while managing fatigue and lowering the risk of injury in resistance training (Dorell et al., 2020). According to Shaw et al. (2023), individuals cannot accurately estimate changes in velocity without being provided with feedback, which is where the tool of feedback comes in handy.

The effect of feedback

Augmented feedback (AugFb) is feedback from an external source on knowledge of the result, for example information about movement outcome, or knowledge of performance, for example movement execution (Nagata et al., 2018). AugFb is most effective when providing information adding on to the intrinsic feedback, providing feedback on velocity in VBT is one such example, as well as jump height or run time. It can be given as visual feedback, auditory, or both (Weakley et al., 2020). Several studies have shown the positive effects of adopting an external focus on strength or force production as well as efficiency in movement patterns (Wulf & Dufek, 2009, Wulf et al., 2010).

Research: Enhancing performance with feedback

Several studies have shown that providing feedback adds an increase in motor performance, in multiple tasks (Lauber & Keller, 2012, Randell et al., 2011). Jiménez-Alonso et al. (2022) found that feedback on velocity increases training performance in both strenght and power sessions, and stated that feedback improves performance in resistance training regardless of the type of session. Campenella et al. (2000) compared force production in quadriceps and hamstrings between four test groups, one without feedback, one with visual feedback, one with verbal encouragement, and the last one with both visual and verbal feedback. They found higher force production in the visual feedback and combined feedback group, compared to no feedback and verbal encouragement only. The results from a study by Argus et al. (2011) also indicate that feedback produce acute improvements in upper-body power in athletes, and found that the effect was especially high in the latter sets. In sum, this means that by adding feedback one can potentially improve training quality for every repetition done, and thereby produce a greater long-term result (Argus et al., 2011, Keller et al., 2014).

Research: Short- and long-term effects

Weakley et al. (2019) investigated how feedback affects velocity within a set by comparing a 10-repetition squat set with or without feedback, and found that feedback was beneficial to maintain barbell velocity within a training set. One study done on drop jumps by Keller et al. (2014) evaluated the immediate and long-term effects of feedback in training. They compared three groups that were provided with AugFb on jump height at different frequencies: 100%, 50%, or 0%. The study revealed a significant in-session effect in both feedback groups, and a long-term effect of a 14 % increase in jump height in the 100% group, 10 % in the 50 %, and only a 6% increase in the 0% group. Nagata et al. (2020) also found that providing immediate feedback after every rep in the squat was more effective than after each set. They conducted a 4-week long VBT intervention consisting of 3 sets of 5 repetitions of loaded squat jumps, comparing four groups receiving either immediate feedback (ImFb), visual feedback (ViFb), average feedback (AvgFb), or no feedback (NoFb). The ImFb group received AugFb on lifting velocity after every rep, while the AvgFb received only after each set. The Visual feedback group received visual kinematic feedback after every set. The ImFb group had significantly greater measures than all other groups both during training and in the post-test.

Why does feedback increase performance?

Andreacci et al. (2002) tested Vo2maks in three groups receiving feedback in the form of verbal encouragement at different frequencies (20 seconds, 60, 180, and no feedback). There was no significant difference between the no feedback and the 180-second group, but the 20-second and 60-second groups had significantly higher values at their second test, indicating that high-frequency feedback leads to significantly greater effort (Andreacci et al. 2002). This is especially important in velocity-based training where we know that intention to move with maximum speed is crucial to ensure the maximal output of RT (Nagata et al., 2018). Furthermore, feedback improves performance by keeping athletes accountable to their performance (Włodarczyk et al., 2021).

Wilson et al. (2017) point out that part of the effect of real-time performance feedback comes from improvements in motivation and mood, and how the use of technological methods might be beneficial not only in sports science but in fields like exercise adherence and rehabilitation as well. Other studies have found greater interest and task enjoyment with feedback (Trewick et al., 2022).

Technological feedback

Technological ways of providing feedback is becoming increasingly popular. An example of one such device is a new patented way of providing feedback on velocity through a force plate could be an effective and more user-friendly way of implementing VBT in resistance training. The Alphatek force plate (Alphatek, Stavanger, Norway) provides acute augmented visual feedback on lifting performance by measuring force against the plate (See Appendix A for visual presentation). A recent review of VBT users found that the users want systems to be easy to use (Thompson et al., 2022). The most important feature is the feedback, it should be robust, instant, and efficient. The feedback itself could be the driver of intent, motivation, and internal and external competition and could also be used as a tool for monitoring performance improvements and education of the athletes. Drawbacks of most systems could be logistics of use, with log-in /log-out, the creation of user profiles, too much data, or simply erroneous data (Thompson et al., 2022).

The Alphatek force plate measures the velocity of the center of mass (COM) of both the lifter and the barbell instead of the barbell velocity. This seems to be a more precise measure, especially in movements like the squat where technique changes like leaning forward with increasing load will affect the barbell velocity (Lake et al., 2012, Larsen et al., 2022).

Research focus and prediction

In this article, the researcher is particularly interested in evaluating whether the acute effect of feedback is lasting or not. From recent literature, we anticipate that lifters do get a positive acute effect on lifting performance when being provided with feedback, but little research has been done on whether the effect transfers to the next movement, exercise, or working set. Therefore this study aims to explore velocity changes in three sets of the squat movement with and without feedback. The test group will have the first set without feedback, then one with feedback, and the last without feedback. The control group will have all sets without feedback.

It seems like being presented with acute augmented feedback improves performance by increasing motivation and the lifters' intent which we know has an important role in the effect of strength training (Nagata et al., 2018, González-Badillo et al., 2014). It is expected that the feedback group will be able to keep their reps at a higher velocity throughout the sets, whereas the control is expected to have a drop in velocity.

The most interesting comparison to see whether there is a lasting effect of feedback even when it is taken away will be the between-group change from set 1 to set 3, for example by increasing intent. If it has, then the test group should have a higher mean velocity on set 3 than set 1 compared to the control group.

Methods

Experimental design

A quantitative observational method comparing between-group differences. The study was conducted across 3 weeks through a quasi-experimental design. The aim of researching how feedback affects performance in resistance training was measured by providing acute visual augmented feedback on lifting velocity as a measure of performance in the squat. The experiment consisted of participants executing three sets of 5 repetitions of the squat movement on a force platform measuring lifting velocity, with a 3-minute break in between sets. 29 participants were divided into two groups one being the feedback group (FB, N=18) consisting of 1 set without feedback, 1 set with augmented visual feedback on every repetition, and lastly 1 set without feedback. The control group (CG, N=11) went through three sets without feedback. The effect of feedback was then measured as the change in mean propulsive velocity from set to set in each group to look for «trends» of change. Each participant also answered questions about age, sex, estimated 1RM, experience in the squat (noted in years, and x per week), experience with VBT, and if they were athletes; what kind of sport. A variety of participants participated, from «gym rats», to long-distance runners and junior powerlifters. Working-weight in the squat was also noted. Figure 1 shows a visual presentation of the design, and figure 2 presents each variable.

Figure 1

Visual presentation of the study design.

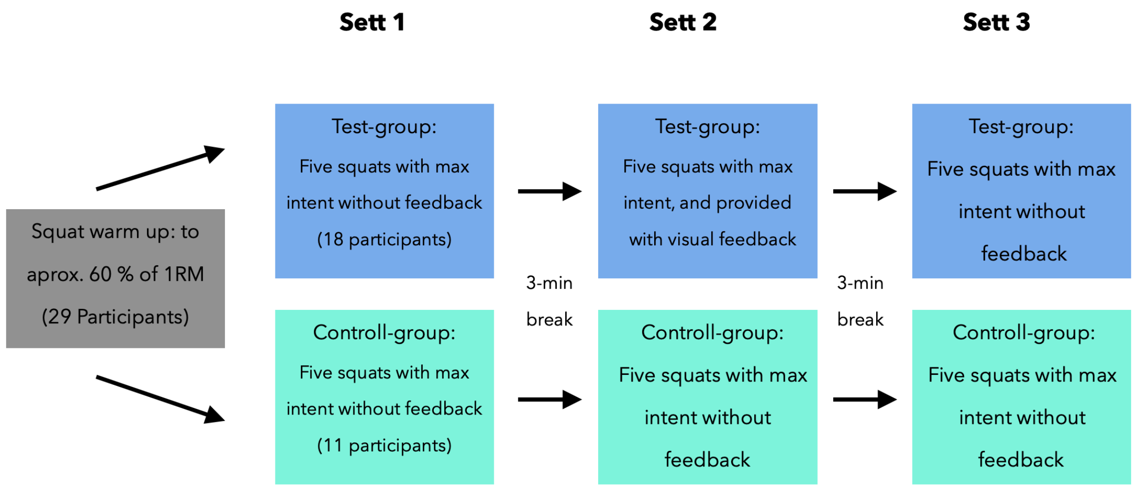
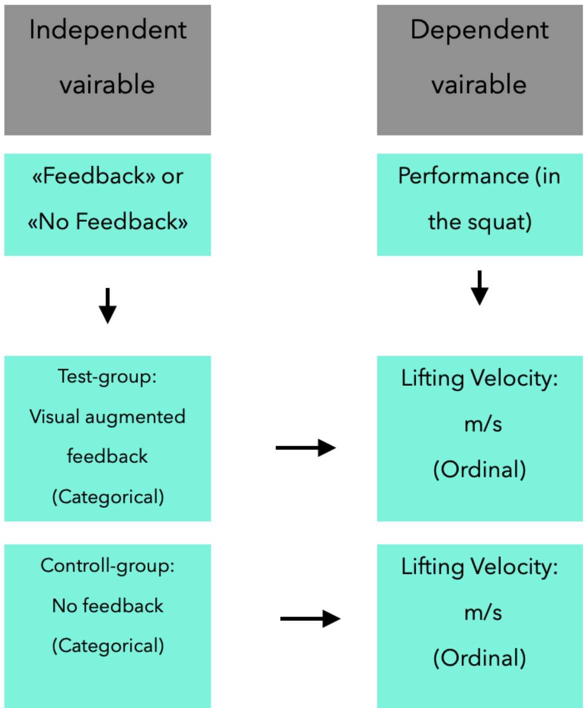


Figure 2

Presentation and description of variables.



Subjects

An easy accessible convenience sample of 29 healthy adults who are regular gym goers with squatting experience from 1 to 20 years (mean ±SD; 5.4 +/- 4.2 years) 12 female and 17 male from ages 20 to 55 (mean ±SD; age: 28.17 ± 8.0 years) from two gyms at Norwegian Universities (SiS sportssenter & Norges Idrettshøyskole). Participants were recruited through asking people who were already doing squats at the gym. Sampling technique does not provide external validity as the sample available as the specific times and locations ensures generalizability to all gym goers, but the sample might still be fit to look for tendencies in the wanted population.

Minimum 12 months of training including the squat movement minimum once a week was a minimum requirement for joining, ensuring familiarity with squat technique. All participants had to be of age 18 and older. Researcher also ensured that participants had a satisfying squat technique.

Data was collected without a connection to name or other personal data. Each participant freely participated and was instructed on the study's aim. As the project did not gather any sensitive data, it was not necessary to register the project with Sikt (Norwegian Agency for Shared Services in Education and Research).

Materials/ Equipment

A standard squat rack, barbell, and weights were used, and velocity and power was measured with an «Alphatek» force plate (Alphatek, Stavanger, Norway). See Appendix A for a visual presentation. Feedback was provided with the screen connected to the platform, but was turned off for all sets without feedback. An extra screen (iPad) only visible to the researcher was connected to the platform to record and monitor power and velocity output. The researcher noted data from the questions during the experiment and later noted output from screen recordings of the platform in use. The velocity measure used was the mean-propulsive velocity of center-of-mass (m/s) and power based on the peak propulsive velocity (W).

Procedures

Participants were asked to do warm-up sets the way they usually did in training, up to around 60 % of their self-estimated 1RM. The researcher monitored the velocity of these sets to ensure that velocity was in the power zone (0.50 m/s to 1.0 m/s), aiming to start the experiment at around 0.60 to 0.70 m/s. The participants did not get feedback on the warm-up sets. When the right load was found, one set of 2-3 reps was done at that weight as a preparation for the working sets, and the participant was told to lift with intent and maximal concentric force.

In set 1 both groups had the same regime. They were told to do 5 reps with intent and maximal concentric force, and then they would get 3 minutes of rest. In set 2 the feedback group was shown the screen on the Alphatek device that gives acute augmented feedback on every rep by showing mean propulsive concentric velocity in a large font on a screen. Peak propulsive power was shown. They were reminded to lift with intent and maximal concentric force. In the feedback group's last set, set 3, feedback was removed. The control group was instructed with the same protocol in sets 2 and 3 as the first set. They did not get feedback or information about lifting velocities in any of the sets. The protocol lasted for about 20-30 minutes per participant. For all participants, the researcher counted their reps out loud, and before rep 4 they were again encouraged to lift as fast as possible. Velocity and power measures were documented by screen recording on the iPad only visible to the researcher, which showed the same info as the TV that was turned on and off. Photos of the summary screen after each repetition was taken to ensure data. Then the data was plotted into Numbers by Apple.

Statistical Analyses

Statistical analyses were conducted in SPSS 28 by IBM with 29 participants in total, with no data excluded and no drop-outs as it was a one-day test. All measurements were plotted into the program, and the analysis started with creating means for velocity and power in each set. First, a normality assessment was done to ensure normal distribution in the relatively small sample, and to apply the appropriate statistical method. A Shairo-Wilk normality test was run on each set in each condition to evaluate significance greater than 0.05 (Mishra et al., 2019), ensuring no sign of non-normality.

Every set from each group had satisfactory significance values, meaning data is normally distributed. The FG has a statistic of .957 (p-value = .551) in set 1, .886 in set 2 (p-value = .123), and .989 in set 3 (p-value = .997). The same was seen in the CG with .908 in set 1 (p-value = .234), .935 in set 2 (p-value = .234) and .946 in set 3 (p-value = .587). This is shown in Table 3. Histograms of distribution were also taken into consideration, and all groups had a roughly clear bell-shaped distribution and most dots on the normal Q-Q plots were on the line. Kurtosis measures are not deemed fit for the small sample size and are therefore not included (Mishra et al., 2019).

To examine differences between conditions or correlations between pairs of variables, both paired t-tests, and independent t-tests were run. Data is described in the «results» section, and for full tables from SPSS output see Appendix B. The results section describes this further.

Table 1

Table showing Shapiro-Wilk`s test of Normality in both groups for each set.

		Statistic	df	Sig.
Mean Velocity Set 1	Feedback group	.957	18	.551
	Control group	.886	11	.123
Mean Velocity Set 2	Feedback group	.989	18	.997
	Control group	.908	11	.234
Mean Velocity Set 3	Feedback group	.935	18	.234
	Control group	.946	11	.587

Results

Descriptive analysis

Variables of means for each set in each condition was created to evaluate central tendency. Looking at the difference, increase or decrease, from set to set within each group can demonstrate whether there is a tendency in either direction before running inferential statistics.

Table 2

Descriptive table of statistics on lifting velocity (m/s) in both the feedback group and control group.

		Minimum	Maximum	Mean	Standard Deviation
Feedback group (N=18)	Set 1	.51	.77	.6431	.07193
	Set 2	.54	.81	.6753	.06813
	Set 3	.49	.77	.6722	.06663
Control group (N=11)	Set 1	.60	.75	.6542	.04835
	Set 2	.56	.69	.6295	.04583
	Set 3	.54	.70	.6016	.04850

Table 2 is showing mean velocity (m/s), minimum and maximum, and standard deviation(SD) for all sets in both groups. This was done by first creating means for every set for each participant. The mean velocity in the Feedback Group (FG) in set 1 was .6432 (SD = .07193), and changed to .6753 (SD = .06813) in set 2 indicating the expected increase in squat velocity when feedback is provided. In set 3 when feedback was removed there was a slight drop in velocity to .6722 (SD = .06663), but still fairly high. In the Control Group (CG) mean velocity for all participants in set 1 was .6542 (SD = .04835), .6295 (SD = .04583) in set 2, and finally .6016 in set 3 (SD = .04850), showing a drop in velocity for each set added. These results show an increase in lifting velocity when feedback was added, whereas the control group had a drop in velocity from their initial set to their second. For the third and last set, where feedback was removed in the test group, participants managed to keep a high velocity, although a small drop from the feedback set, still higher than the first set - whereas the control group has the complete opposite result with a drop for each set added. Figure 3 show a graphical presentation of the mean velocity in each group.

Figure 3

Bar graph of squat velocity in the feedback group and control group for each set.

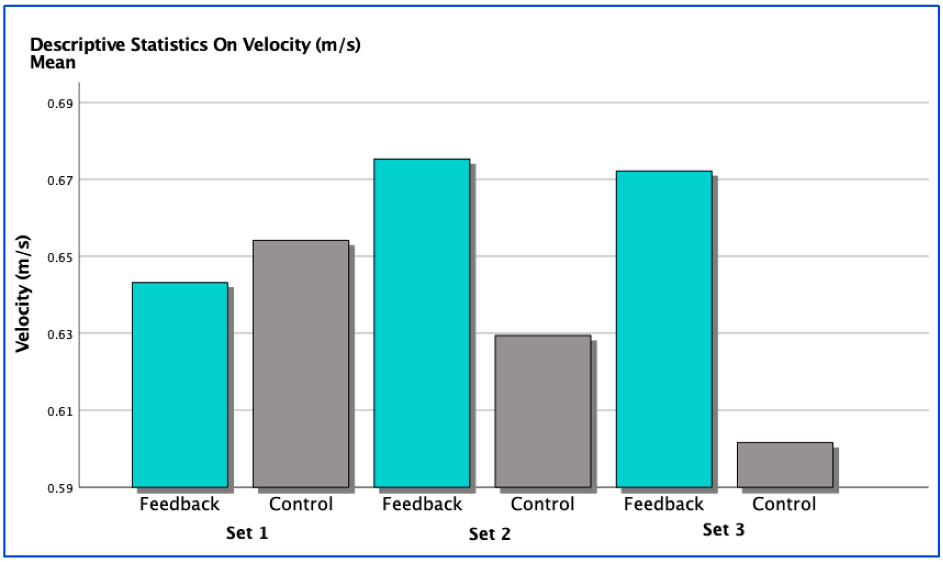


Table 3

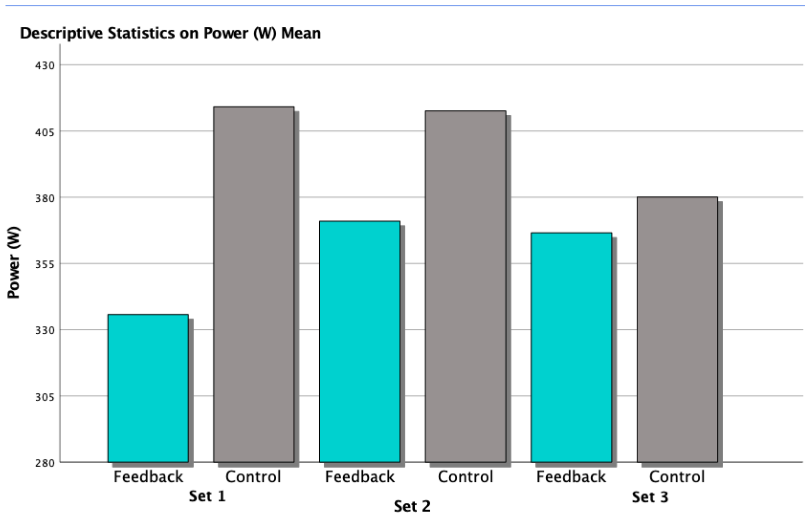
Descriptive table of statistics on lifting power (W) in both the feedback group and control group.

		Minimum	Maximum	Mean	Standard Deviation
Feedback group (N=18)	Set 1	203	542	335.72	106.096
	Set 2	229	618	370.98	113.586
	Set 3	236	661	366.53	108.835
Control group (N=11)	Set 1	219	731	414.15	152.613
	Set 2	238	683	412.60	157.908
	Set 3	187	632	380.09	128.695

The third table is showing the same values for power (W). Power measurements are included to have a second measure to show tendency, but will not be further analyzed for statistical significance because of the limit of the task. Mean Power in the FG in set 1= 336, set 2=371, and set 3=366 showing a similar trend as in velocity. The CG had the same where the first set was at 414, set 2= 413 and the last set had 380 as the mean. This is visualized Figure 4. The tendency is that the group without feedback is decreasing throughout the sets, while the FG is increasing.

Figure 4

Bar graph of squat power in the feedback group and control group for each set.



Inferential statistics: T-tests

Paired samples T-test

Firstly, paired samples t-test was conducted to investigate whether in-group changes in velocity were significant. In table 4 paired samples statistics for each set and each group are presented with means and SD for reference.

Table 4

Table of paired samples statistics of velocity (m/s).

			Mean	Standard Deviation	Standard Error Mean
Feedback group (N=18)	Pair 1	Set 1	.6432	.07193	.01695
		Set 2	.6753	.06813	.01606
	Pair 2	Set 2	.6753	.06813	.01606
		Set 3	.6722	.06663	.01571
		Set 1	.6432	.07193	.01695
	Pair 3	Set 3	.6722	.06663	.01571

			Mean	Standard Deviation	Standard Error Mean
Control group (N=11)	Pair 4	Set 1	.6542	.04835	.01458
		Set 2	.6295	.04583	.01382
	Pair 5	Set 2	.6295	.04583	.01382
		Set 3	.6016	.04850	.01462
	Pair 6	Set 1	.6542	.04835	.01458
		Set 3	.6016	.04850	.01462

In Table 5 the results from the paired samples T-test are shown. Means in the FG group for each set were .64, .68, and .67, and .65, .63, and .60 in the CG. In the FG group, there was a significant difference between sets 1 and 2 of .007 with a CI not crossing 0 (95% CI: -.054, -.010). The same was seen for Set 1 and 3, with a p = .013 (95 % CI: -.051, -.007). No significant difference was found between sets 2 and 3 (p = .754, 95% CI: -.017, .023). For the CG p = .032 between set 1 and 2(95 % CI: .002, .047), for set 2 and 3 p = .039 (95 % CI: .002, .053) and for set 1 and 3 p = <.001 (95 % CI: .030, .075).

Table 5

Results of the Paired samples T-test for all pairs (P1-P6) described in table 4.

		Paired Differences				t	Significance (2-sided)
		Mean	Std. Deviation	95 % Confidence Interval of Deviance (Lower, Upper)			
FG (df=17)	P1	-.03211	.04416	-.05407	-.01015	-3.085	.007
	P2	.00311	.04141	-.01748	.02370	.319	.754
	P3	-.02900	.04452	-.05114	-.00686	-2.764	.013
		Paired Differences				t	Significance (2-sided)
		Mean	Std. Deviation	95 % CI of Deviance (Lover, Upper)			
CG (df=10)	P4	.02473	.03285	.00266	.04680	2.496	.032
	P5	.02782	.03883	.00173	.05390	2.376	.039

	P6	.05255	.03299	.03039	.07471	5.283	<.001

Independent samples T-test

Secondly, independent samples t-test was run to analyze the between-group differences. For this test, a new variable of the difference between sets was computed. These difference variables are described in Table 6. The change between FG sets 1 & 2 was then compared with the change in CG set 1 & 2 to establish the effect of adding feedback in the sample. To investigate the research question of what happens when feedback is removed the change between FG sets 1 & 3 was compared with the change in CG sets 1 & 3.

Table 6

Group statistics with mean difference variable for each group used for the independent samples t-test.

		N	Mean	Std. Deviation	Std. Error Mean
Difference between S1 and S2	FB	18	.0321	.04416	.01041
	CG	11	-.0247	.03285	.00991
Difference between S1 and S3	FB	18	.0290	.04452	.01049
	CB	11	-.0525	.03299	.00995

In table 7 the results from the independent sample t-test is shown. The upper part is the between group comparison of the change from set 1 to 2, and the lower is for set 1 and 3. Levene`s Test for equality variances indicate equal variance across the groups in both tests (See appendix B for full test). The difference between the FG and the CG from set 1 and 2 was significantly different with p = .001 (95% CI: .025, .089) and so was the between group difference from set 1 and 3 with p = <.001 (95% CI: .05, .113).

Table 7

Table of the Independent Samples T-test Result.

	95 % Confidence Interval of Deviance (Lower, Upper)		T-test for equality Means		
			t	Mean Difference	Significance (2-sided)
Set 1 & 2 (df=27)	.02516	.8852	3.681	.05684	.001
Set 1 & 3 (df=27)	.04964	.11345	5.244	.08155	<.001

Discussion

Study aim

This project aimed to study the effect of applying and removing visual augmented feedback on squat velocity to investigate whether the performance enhancement from feedback in one set also affects the sets after when feedback is no longer given. This was done by comparing squat velocity between two groups, in which one group (FG) was presented with visual augmented feedback on movement velocity in their second set of squats. The first and last sets were done without feedback. The second group (CG) performed three sets of squats without any feedback.

Primary findings

The primary findings in the study is that performance in movement velocity in the squat is significantly improved when adding visual augmented feedback and that this improvement is maintained even when the feedback disappears. This is shown firstly through the means in each set, visually represented in Figure 3. When comparing within-group changes in the FG group there was a significant increase from set 1 to 2 ($p = .007$), but no significant difference from set 2 to 3 ($p = .754$), showing the increase in performance by adding feedback and the maintenance of movement velocity after being provided with feedback. The results from comparing FG set 1 and 3, measurements before and after feedback (aka treatment condition), show a significant increase with $p = .013$. The CG had a significant decrease in velocity in all three tests.

Furthermore, the main test which provides answers to the hypothesis is the comparison between group differences from the independent sample t-test. A *p* = of .001 was found when comparing the result of adding feedback, which states that providing feedback increased squat velocity significantly, and when comparing before and after treatment (set 1 and 3) there was less than 1% chance that the difference is random (*p* = <.001). This result shows that the FG has significantly higher performance in squat velocity after feedback was removed.

Underlying mechanisms

As expected, there was a significant effect of adding feedback. This supports the current literature on the effect of feedback (Jiménez-Alonso et al. 2022, Lauber & Keller, 2012, Randell et al., 2011). The mechanisms behind the effect of feedback are discussed in the introduction with multiple possible mechanisms. One of these is the enjoyment of the task (Trewick et al., 2022). One might find a task more motivating if being provided with an objective way of measuring progression, and knowing how well one performs (Wilson et al. 2017). As mentioned, being provided with visual feedback increases intent to lift with maximal effort perhaps by increasing accountability for their performance, especially when knowing others will see your result (Włodarczyk et al., 2021). Another theory is that being able to lift with intent is a skill you learn, and being provided with feedback then teaches you to do this even when you are not receiving feedback anymore. This is an interesting theory that could be further explored by measuring performance in other movements in addition. Andreacci et al. (2002) demonstrated how being provided with a high frequency of feedback was beneficial, and this might be contributing to the effect here since the FG received acute feedback on every repetition. It may well be that providing feedback after the set, not immediately, would not have provided the same results when, although this is just speculation.

Discussing limitations of the research method

Another factor that might be contributing to both the effect of feedback, as well as the results from this study, is the effect of being evaluated. In general, people tend to increase effort when being evaluated, and as this is an experiment, participants know that they are being watched. Whether this alters participants behavior to a degree that alters the results of the study is on the other hand not known, as both groups knew that they were being evaluated. This might have influenced all participants' efforts in every set, which would then mean that the difference would be even greater, but obviously, this could not be controlled for. When using feedback with athletes and in sports settings they are also knowingly being watched, so it may not affect the practical implication after all. In addition, the significant difference between sets and groups shows that even though there might be an effect of being monitored, there is certainly an effect of monitoring yourself. It is still worth noting that a general weakness of the experimental methods is the fact that the settings are unnatural, and in a quasi-experimental setting like this not all variables can be controlled for. To have less potential noise, the study should preferably have been conducted in a separate laboratory, but then again that would have been even more of an unnatural setting.

The researcher effect, like in most experiments, is also something to take into as a potential influence on the experiment. In this study, measures were taken to try to minimize this effect, for example by specifically noting when and what to comment in the test set, and by ensuring as similar settings as possible in each test. What is unintentional on the other hand cannot be accounted for.

A tendency was expected to be found but it was not expected to provide significant results from such a small sample containing participants with such different backgrounds, for example, some participants being long-distance runners and some powerlifters, etc. Preferably, a more homogenous sample would be expected to have even more clear results, and it was expected to be a too small N to find provide significance results. If adding another type of feedback to compare differences, one might not have been able to find significant differences between feedback groups with this sample. Two provide stronger external validity, a randomly selected sample would be preferred.

Further research

As noted, athletes from different sports attended the study. Some possible tendencies of power and velocity differences were observed, for example long distance runners struggling to lift with velocities matching the power zone. A second potential study investigating tendencies in different types of athletes, both with power and velocity. We could for example speculate that athletes that are not used to lifting with intent would gain the most from training with feedback.

Another study could investigate feedback in different forms. It could be interesting to look investigate whether visual or auditive would be more lasting, similar to how Weakley et al. (2020) investigated the effect of different types. Finding out whether specific types of feedback provide longer-lasting effects could be a study of practical importance.

VBT feedback is usually limited to certain exercises, but if lifting with intent is something you learn then it could potentially be of benefit to other movements as well. For a greater use of VBT, it could be interesting to see if the lasting feedback effect transfers to other tasks, like jumping, or even other exercises, like pull-ups.

Even though this study supports the hypothesis that adding feedback and removing it improves more than just the set where feedback was given, it cannot say anything about how long-lasting this effect is. Is it just for the next set? Does it decrease steadily? Does it last for a day, a week, and or a month and then disappear? How often do you need to add feedback to keep the effect? It would be interesting to learn more about the dose-response in velocity-based training with feedback and how long the lasting effect appears may be another feature of VBT that can change the way coaches use it in the training of athletes, and add to the lists of benefits that VBT can have for sports performance.

Conclusion and practical implication

The current findings show that providing augmented feedback on lifting velocity in the squat improves performance by increasing movement velocity and power and that this effect transfers to later sets done after feedback is removed. This might be an untapped potential for both athletes and regular gym attendees that can potentially significantly increase performance, and therefore long-term effects. It might be an effective way of increasing performance in team sports where one coach cannot provide feedback to all athletes all the time, and especially effective if technological decives are available. In settings with a large number of athletes, one can rotate between groups that alternate between being provided with feedback or not.

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Appendix A

Figure A.1: Digital presentation of the set up.

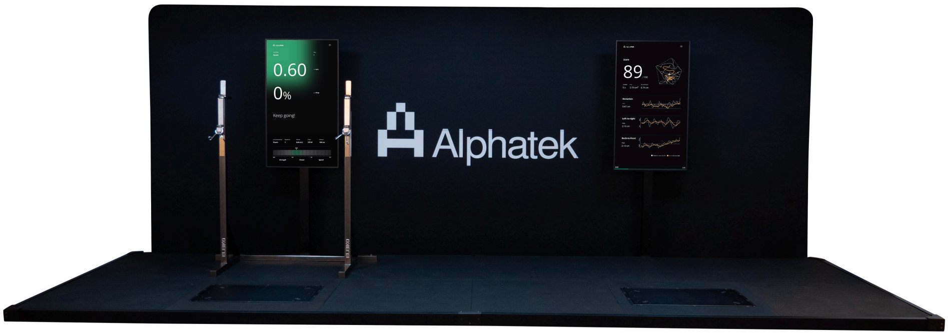

Figure A.2: Demonstrative photo of two people doing squats on the Alphatek force plate and recieving feedback displayed as a large number on the screen.

Appendix B

Screenshot of full SPSS output.

Table B.1: Test of Normality table output from SPSS.

Tests of Normality

	(1=Feedback, 2=Kontroll)	Kolmogorov-Smirnov[a] Statistic	df	Sig.	Shapiro-Wilk Statistic	df	Sig.
Mean Velocity Sett 1	1	.151	18	.200*	.957	18	.551
	2	.252	11	.050	.886	11	.123
Mean Velocity Sett 2	1	.119	18	.200*	.989	18	.997
	2	.188	11	.200*	.908	11	.234
Mean Velocity Sett 3	1	.161	18	.200*	.935	18	.234
	2	.156	11	.200*	.946	11	.587

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table B.2: Descriptive output on lifting velocity in the test- and control group.

Descriptive Statistics On Velocity (m/s)

	N	Minimum	Maximum	Mean	Std. Deviation
V_Feedback_Set1	18	.51	.77	.6432	.07193
V_Feedback_Set2	18	.54	.81	.6753	.06813
V_Feedback_Set3	18	.49	.77	.6722	.06663
V_Kontroll_set1	11	.60	.75	.6542	.04835
V_Kontroll_set2	11	.56	.69	.6295	.04583
V_Kontroll_set3	11	.54	.70	.6016	.04850
Valid N (listwise)	0				

Table B.3: Descriptive output on lifting power in the test- and control group.

Descriptive Statistics on Power (Watt)

	N	Minimum	Maximum	Mean	Std. Deviation
P_Feedback_Set1	18	203	542	335.72	106.096
P_Feedback_Set2	18	229	618	370.98	113.586
P_Feedback_Set3	18	236	661	366.53	108.835
P_Kontroll_Set1	11	219	731	414.15	152.613
P_Kontroll_Set2	11	238	683	412.60	157.908
P_Kontroll_Set3	11	187	632	380.09	128.695
Valid N (listwise)	0				

Table B.4: Table of paired sample statistics of velocity (m/s).

Paired Samples Statistics / Velocity (m/s)					
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	FG – Set1	.6432	18	.07193	.01695
	FG – Set2	.6753	18	.06813	.01606
Pair 2	FG – Set2	.6753	18	.06813	.01606
	FG – Set3	.6722	18	.06663	.01571
Pair 3	FG – Set1	.6432	18	.07193	.01695
	FG – Set3	.6722	18	.06663	.01571
Pair 4	CG –Set1	.6542	11	.04835	.01458
	CG –Set2	.6295	11	.04583	.01382
Pair 5	CG –Set2	.6295	11	.04583	.01382
	CG –Set3	.6016	11	.04850	.01462
Pair 6	CG –Set1	.6542	11	.04835	.01458
	CG –Set3	.6016	11	.04850	.01462

Table B.5: Table of paired sample t-test results.

Paired Samples Test/ Velocity (m/s)										
		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	FG – Set1 & Set2	-.03211	.04416	.01041	-.05407	-.01015	-3.085	17	.003	.007
Pair 2	FG – Set2 & Set3	.00311	.04141	.00976	-.01748	.02370	.319	17	.377	.754
Pair 3	FG – Set1 & Set3	-.02900	.04452	.01049	-.05114	-.00686	-2.764	17	.007	.013
Pair 4	CG – Set1 & Set2	.02473	.03285	.00991	.00266	.04680	2.496	10	.016	.032
Pair 5	CG – Set2 & Set3	.02782	.03883	.01171	.00173	.05390	2.376	10	.019	.039
Pair 6	CG – Set1 & Set3	.05255	.03299	.00995	.03039	.07471	5.283	10	<.001	<.001

Table B.6: Table of group statistics with mean difference variable for each group

Group Statistics / With mean change					
	(1=Feedback, 2=Kontroll)	N	Mean	Std. Deviation	Std. Error Mean
Difference – S1 & S2	1	18	.0321	.04416	.01041
	2	11	-.0247	.03285	.00991
Difference – S1 & S3	1	18	.0290	.04452	.01049
	2	11	-.0525	.03299	.00995

Table B.7: Table of independent Samples T-test Result

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance		Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p			Lower	Upper
Diff_S1_2	Equal variances assumed	.232	.634	3.681	27	<.001	.001	.05684	.01544	.02516	.08852
	Equal variances not assumed			3.956	25.783	<.001	<.001	.05684	.01437	.02729	.08639
Diff_S3_1	Equal variances assumed	1.676	.206	5.244	27	<.001	<.001	.08155	.01555	.04964	.11345
	Equal variances not assumed			5.640	25.828	<.001	<.001	.08155	.01446	.05182	.11127