

The Sound of Strength: Auditory Feedback Enhances Squat Performance in Resistance- Trained Females

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ABSTRACT

Introduction: Kinematic feedback during resistance training (RT) can improve performance, but most research has focused on males. Since conscientiousness levels related to feedback may differ between genders, this study examined how auditory and visual kinematic feedback affects squat performance in resistance-trained females. **Methods:** Seventeen resistance-trained females (21.2 ± 2.4 years; 3.8 ± 2.3 years training experience) performed three sets of 10 repetitions barbell back squats at 75% of 3RM under three randomized conditions: no feedback (CON), auditory feedback (AUD), and visual feedback (VIS). Average (AV) and peak (PV) concentric barbell velocity were measured using a PUSH band, and enjoyment was assessed using the Exercise Enjoyment Scale. **Results:** Feedback x rep interaction were found for both AV ($p = .004$, $\eta^2 = .02$) and PV ($p < .001$, $\eta^2 = .03$). Simple-slope comparisons showed AUD produced a less negative decline than CON for both AV ($p = .002$, $d = 0.82$) and PV ($p < .001$, $d = 0.94$). Main effect for percentage velocity loss (from rep 1–10) were found in feedback for AV ($p = .015$, $\eta^2 = .23$) and PV ($p = .021$, $\eta^2 = .21$). AUD had significantly less reduction in AV (9.5%) and PV (6.9%) vs CON (AV 23.1%, PV 19.0%). No significant differences were found between the other conditions in either slope or velocity loss comparisons ($p = .068$ – $.449$). Furthermore, both VIS ($p < 0.05$, $r = 0.65$) and AUD

($p < 0.05$, $r = 0.69$) feedback were rated more enjoyable than CON, with no difference between AUD and VIS ($p = 0.57$, $r = 0.14$). When asked about preferences, 70% of the participants favored AUD. **Conclusion:** Feedback helps preserve barbell velocity, reducing velocity loss across repetitions in resistance-trained females. Auditory feedback emerged as particularly effective for maintaining barbell velocity compared to no feedback and was the preferred feedback condition.

Keywords: Feedback, Resistance training, Squat.

INTRODUCTION

Resistance training (RT) is a crucial aspect of enhancing muscle strength, power, and muscle mass (Folland & Williams, 2007; Orange et al., 2022; Schoenfeld et al., 2014). These improvements are vital not only for athletic performance (Suchomel et al., 2016) but also for everyday activities (Maestroni et al., 2020). However, maximizing the effects of RT can be difficult due to various challenges, such as neuromuscular fatigue (Weakley et al., 2017), low motivation (Weakley et al., 2019), or a lack of encouragement (Weakley et al., 2020). These factors can compromise training execution and adherence, and may reflect acute performance outputs such as reduced barbell velocity, which can be used to quantify changes in neuromuscular status during RT (Nagata et al., 2020). To overcome

these challenges and maximize the benefits of resistance training, it is important to counteract these various challenges.

In RT, feedback can be in the form of verbal or visual cues that provide feedback on the individual's form and technique (Stien et al., 2023), but also kinematic and kinetic data such as force, velocity, and power (Weakley et al., 2020). This information can help individuals improve their performance and prevent injuries (Napier et al., 2019), as well as increase effort and competitiveness (Campenella et al., 2000). Feedback can be a powerful motivator and can help individuals stay focused and engaged during their training sessions and, therefore, enhance training quality (e.g., maintaining maximal velocity in each repetition throughout a set).

Previous research demonstrated that the use of feedback, whether it be verbal or visual, led to a significant increase in concentric barbell velocity (1.3-6.6%) during exercises such as the bench press and squat (Argus et al., 2011; Weakley et al., 2020). These enhancements are believed to arise from an external focus of attention that leads to an increased motor unit efficiency (Wulf et al., 2010), as well as athletes perceiving an active interest in their training, which leads to increased effort (Keller et al., 2014). These results indicate that incorporating either verbal or visual feedback in training sessions can enhance both the immediate work output and, therefore, training quality.

In addition, Weakley et al. (2020) reported negative correlations between conscientiousness, a personality trait related to self-discipline and goal pursuit, and responses to kinematic feedback. More precisely, individuals higher in conscientiousness tended to show smaller effects of both verbal ($r = -0.24$) and visual ($r = -0.44$) kinematic feedback. Practically, this suggests that more conscientious participants may rely less on external technique cues, whereas less conscientious individuals may benefit more from additional feedback during training. However, Weakley et al. (2020) only included males, and the findings may not necessarily be generalized to females. Previous research (Costa Jr et al., 2001; Feingold, 1994) has shown that conscientiousness tends to be higher in females, but this finding has not been consistent in the literature (Weisberg et al., 2011). Of great importance, Tarnas and colleagues (2020) demonstrated gender-based preferences for feedback conditions during a motor task. Specifically, they found that males tended to prefer

visual feedback, while females showed a preference for auditory feedback. Given the potential difference in conscientiousness and feedback preferences between the genders, the present study aimed to investigate the influence of kinematic feedback, both verbal and visual, on velocity and enjoyment in resistance-trained females during the squat exercise.

We hypothesize that kinematic feedback during a training set will improve training quality, as evidenced by higher velocity and enjoyment for each feedback condition compared to no feedback. Second, we hypothesize that the female participants will show a higher velocity and enjoyment using the auditory feedback compared to the visual feedback.

METHODS

In this study, a within-subjects and counterbalanced cross-over design was performed to examine the acute effects of different feedback conditions (control, auditory, and visual) on resistance-trained females. The participants were asked to perform 10 repetitions of the free-weight back squat exercise under three randomized conditions: without any feedback (control), with auditory kinematic feedback, and with visual kinematic feedback. All three conditions were conducted on the same day. Differences in average and peak concentric velocity and enjoyment during each feedback condition were then compared with each other.

Participants

A convenience sample of seventeen resistance-trained females (age 21.2 ± 2.4 yrs.; height 169.4 ± 4.2 cm; body mass 70.4 ± 11.5 kg, and 3 repetition maximum (3RM) back squat 66.9 ± 11.1 kg), with 3.8 ± 2.3 years of resistance training experience, completed the study. To be included in the study, participants had to be over 18 years old and female and not have any injuries or pain that prohibited maximal exertion. Exclusion criteria included inability to perform the barbell back squat at an estimated 1 repetition maximum (1RM) equal to their body weight or unfamiliarity with the barbell back squat. Prior to enrollment, participants were thoroughly informed, both orally and in writing, about the potential risks associated with the study and provided written informed consent. They were also assured of their right to withdraw from the study at any time without any obligation to provide a reason. All participants were instructed to refrain

from resistance training for at least 48 hours before all testing sessions. The study received approval from the Norwegian Centre for Research Data (639101) and adhered to the latest version of the Declaration of Helsinki.

Procedures

Participants attended a strength test laboratory on two occasions, which were separated by 48 hours. On the first occasion, participants were familiarized with the testing protocols, including a 3RM test in back squat, each feedback condition, and what the feedback represented (i.e., m/s), and information about the Exercise Enjoyment Scale. Before conducting the 3RM test, a general warm-up, consisting of five minutes on a self-selected aerobic exercise (i.e., treadmill, cycling, rowing), was performed with moderate intensity. This was followed by a specific warm-up protocol that included 10, 8, 5, and 3 repetitions in the barbell back squat at 20%, 50%, 70%, and 80% of their self-reported 1RM, respectively. After the warm-up, participants were given five attempts to achieve their 3RM, with each attempt involving an incremental load ranging from 2.5 to 10 kg. A rest period of three to five minutes was provided between each attempt (Grgic et al., 2018). 3RM was determined when the participant and primary researcher agreed that no more weight could be lifted or that a failed attempt occurred.

On the second occasion, participants returned to perform the experimental protocol. After the general five-minute aerobic warm-up, the participants conducted a specific warmup consisted of two sets of ten repetitions with a 20 kg barbell (Eleiko, Halmstad, Sweden) in the back squat. The testing protocol consisted of three sets of 10 repetitions at 75 % of 3RM, where each set included one of the feedback conditions (control, auditory, and visual) performed in a randomized, counterbalanced order. The chosen intensity and repetition scheme was based on previous studies using kinematic feedback on resistance training performance (Weakley et al., 2019, 2020; Wilson et al., 2017). In the verbal kinematic feedback condition (AUD), the lead researcher, positioned perpendicular to the participant, verbally communicated the average concentric barbell velocity (in m/s) loudly for each repetition, which was recorded on a tablet (2016 Apple Inc., Cupertino, CA, USA) (Argus et al., 2011; Weakley et al., 2020). For the visual kinematic feedback condition (VIS), participants performed 10 repetitions while the tablet, positioned

approximately 1 meter away at eye level, displayed the average concentric velocity (in m/s) for each repetition (Weakley et al., 2020; Wilson et al., 2017). Lastly, for the control (CON), no type of feedback was given.

Average (AV) and peak (PV) concentric velocity were quantified using a PUSH band, a smartphone-compatible wearable device engineered to monitor movement velocity across various resistance exercises. The PUSH band is equipped with a 3-axis accelerometer and a gyroscope, offering six degrees of freedom in its coordinate system with a sampling rate of 200 Hz. During the back squat exercise, the band was set to "bar mode" and securely positioned around the barbell (just inside of the 81 cm ring), outside of the participant's grip. Participants were explicitly instructed to refrain from adjusting or moving their grip to ensure that the band kept its position throughout the testing. The data collected by the PUSH band was processed using a Butterworth filter, which served to smooth the acceleration data. Subsequently, the vertical velocity was computed by integrating the vertical acceleration over time. For a more detailed explanation of the specific calculation methods, readers are directed to Balsalobre-Fernandez et al. (2016). The PUSH band was synchronized with the PUSH application via a Bluetooth 4.0 LE connection, which facilitated the recording of the measured data.

In both the familiarization and experimental protocol, participants performed the back squat with the barbell positioned on their upper trapezius. They descended until the femur was parallel with the floor, a position verified visually by the lead researcher. To control the depth of each repetition, an adjustable step platform (Reebok, England) was used during all testing, which participants touched lightly with their glutes in the bottom position. Throughout the exercise, participants were instructed to keep their heels grounded and their torso upright. The descending phase of the squat was executed for 2 seconds, followed by a 1-second pause at the lowest point of the movement. For the ascending phase, the participants were directed to exert as much force and power as possible to achieve the highest possible velocity for each repetition. A rest period of three minutes was provided between each set.

The level of enjoyment experienced by the participants after each feedback condition was quantified using the Exercise Enjoyment Scale (EES).

This scale ranges from one to seven, where one signifies “not at all” enjoyable and seven represents an “extraordinary” level of enjoyment. Participants were asked the question: “Use the following scale to indicate how much you are enjoying this exercise set”. The question was slightly modified to fit our purpose, where the word «set» was used instead of «session» to quantify enjoyment for each feedback condition. The scale was anchored as follows: “a score of 1 indicates that you found the exercise set to be among the least enjoyable you have ever undertaken, while a score of 7 suggests it was one of the most enjoyable”. The validity of the EES scale has been previously established (Stanley & Cumming, 2010).

Lastly, ten minutes after the final testing condition, participants were asked which of the feedback conditions they preferred.

Statistical analysis

The data are presented as means \pm standard deviation (SD) (Figure 1) or median \pm interquartile range (EES data). The velocity data were checked and confirmed for normality using the Shapiro-Wilk test ($p = 0.21-0.68$). To examine the effect of the different feedback conditions on the overall average and peak barbell velocity, a linear mixed-effects model with Gaussian error distributions was used. Linear mixed-effects model was fitted with Feedback (AUD, VIS, and CON) and Rep (1-10) as fixed factors and their interaction (Feedback \times Rep). Participants were entered as a random effect with a random intercept to account for repeated measurements within individuals. An identical analysis was used for velocity loss (% decrease from rep 1 to 10), where feedback served as a fixed factor and participant as a random factor with intercept.

When significant main or interaction effects were detected, post hoc pairwise comparisons were performed with appropriate adjustment for multiple testing (Holm). For the non-parametric variable (EES), the Friedman test was used to detect differences between the different conditions of feedback. If differences were detected, the Wilcoxon signed-rank test was used to identify where the differences lay.

Effect sizes for linear mixed models were calculated and reported as partial eta squared (η^2) and Cohen's d for the pairwise comparisons to quantify the magnitude of observed effects in addition

to p -values. An effect size of 0.01-0.06 was considered small, 0.06-0.14 moderate, and >0.14 large for partial eta squared. Regarding Cohen's d , we interpret 0.2, 0.5, and 0.8 as small, medium, and large effects, respectively (Cohen, 1988). For the non-parametric variable (EES), the product-movement r (r) was used for effect size. R was calculated using the following equation $r = z/\sqrt{n}$, with z being the z -value from the Wilcoxon signed rank test and n being the number of participants. A r -value of 0.10 – 0.29 was considered small, 0.30 – 0.49 medium, and > 0.50 large (Cohen, 1988).

Significance difference was accepted at $p < 0.05$. The JASP statistical program (version 0.95.4, University of Amsterdam, Netherlands) was used to analyze the data and create the figure.

RESULTS

When looking at the whole set, from rep 1 to 10, no main effect for feedback was detected for average ($F(2,488) = 0.09, p = .914, \eta^2 = .0003$) or peak velocity ($F(2, 488) = 1.64, p = .19, \eta^2 = .006$). Main effects were found for rep in both average velocity ($F(1, 488) = 176.87, p < .001, \eta^2 = .26$) and peak velocity ($F(1,488) = 113.23, p < .001, \eta^2 = .18$). Interaction between feedback \times rep were found for both average ($F(2,488) = 5.69, p = .004, \eta^2 = .02$) and peak velocity ($F(2, 488) = 7.82, p < .001, \eta^2 = .03$).

The slope (average change in m/s per repetition) for average velocity for each feedback condition was: AUD -0.007 m/s, VIS -0.011 m/s, and CON -0.014 m/s (Figure 1A). Post hoc comparisons showed that AUD exhibited a less negative slope than CON ($p = .002, d = 0.82$), whereas AUD did not differ from VIS ($p = .149, d = 0.43$) and VIS did not differ from CON ($p = .149, d = 0.39$). The slope for peak velocity for each feedback condition was: AUD -0.009 m/s, VIS -0.013 m/s and CON -0.022 m/s (Figure 1B). Post hoc comparisons showed that peak velocity AUD exhibited a less negative slope than CON ($p < .001, d = 0.94$), whereas AUD did not differ from VIS ($p = .225, d = 0.29$). Of note, CON exhibited a more negative slope than VIS ($p = .016, d = 0.64$).

To validate the velocity slope, we also analyzed velocity loss (% drop from rep 1 to 10) between the feedback conditions. Main effects were found for feedback in both average ($F(2,32) = 4.80, p = .015, \eta^2 = .23$) and peak ($F(2,32) = 4.34, p = .021, \eta^2 = .21$) velocity loss. AUD showed the lowest percent

velocity loss for both average velocity (9.5%) and peak velocity (6.9%), whereas VIS was intermediate for both outcomes (average 19.6%, peak 12.9%), and CON showed the highest loss for both average and peak velocity (average 23.1%, peak 19.0%) (Figure 1).

Post hoc comparisons showed that for average velocity, %-loss was lower in the AUD than CON ($p = .016$, $d = .072$), while the AUD vs VIS showed the same direction without reaching significance after correction ($p = .068$, $d = 0.54$). CON vs VIS did not differ meaningfully ($p = .449$, $d = 0.19$). For peak velocity AUD showed lower %-loss than CON ($p = .018$, $d = 0.71$), whereas AUD did not differ from VIS ($p = .297$, $d = 0.36$) and CON did not differ from VIS ($p = .297$, $d = 0.36$).

The Friedman test showed that there was a significant difference in perceived exercise

enjoyment between the different types of feedback ($p < 0.01$). Comparing the different conditions, the Wilcoxon signed rank test revealed that both VIS (5 ± 2 vs 3 ± 2 , $p < 0.00$, $r = 0.65$) and AUD (5 ± 1 vs 3 ± 2 , $p < 0.00$, $r = 0.69$) feedback were more enjoyable than CON. However, there was no significant difference between VIS and AUD feedback ($p = 0.57$, $r = 0.14$). When asked about their preference, twelve preferred AUD, five preferred VIS, and none preferred no feedback (i.e., CON condition).

DISCUSSION

The aim of this study was to assess the effects of different feedback conditions: auditory, visual, and no feedback, on barbell velocity in resistance-trained females. Furthermore, the study assessed perceived exercise enjoyment and preference between the different feedback conditions. The

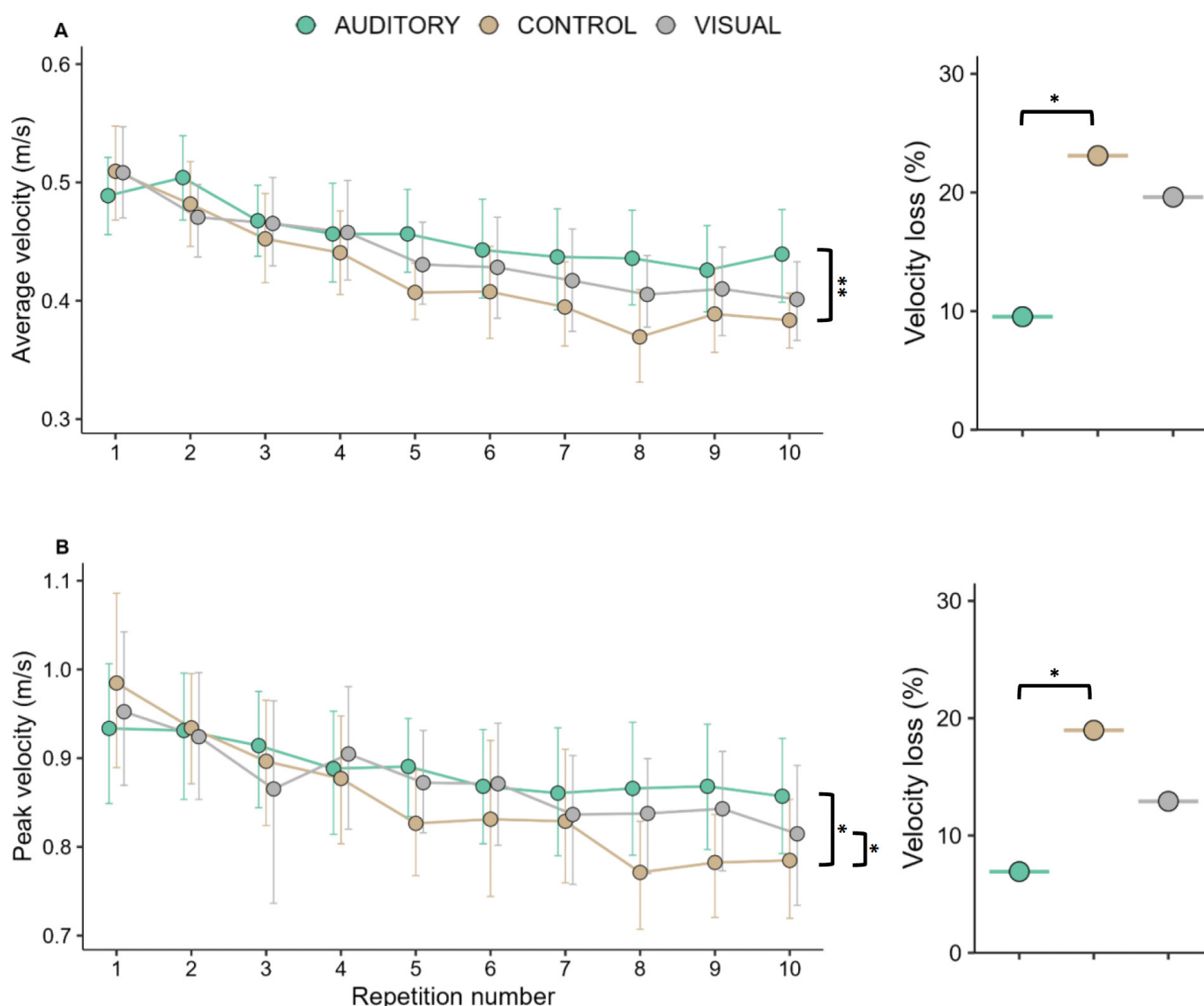


Figure 1. Mean ± CI 95% of average (A) and peak (B) barbell velocity and mean velocity loss (%-loss from rep 1 to 10) during the whole set with different feedback conditions. * $p < 0.05$, ** $p < 0.01$.

main findings in this study were that auditory feedback was significantly better than no feedback for upholding both the average and peak concentric barbell velocity in the squat exercise during a set. Furthermore, feedback is preferable when it comes to perceived exercise enjoyment compared to no feedback; however, descriptively, it seems that the auditory feedback condition is favored for resistance-trained females.

Comparing velocity slopes is challenging because no previous feedback study has reported this outcome in a directly comparable way. Using PlotDigitizer, which has demonstrated good validity and reliability (Aydin & Yassikaya, 2022), to extract data from the most comparable study (Weakley et al., 2020), we estimated declines of 0.009, 0.011, and 0.011 m/s per repetition for auditory, visual, and no feedback, respectively. This is consistent with our own findings (AUD -0.007 m/s, VIS -0.011 m/s, CON 0.014 m/s). The average concentric barbell velocity across the whole set in the auditory feedback condition was 9.2 % higher compared to the control condition. The average velocity is in line with previous research (Argus et al., 2011; Weakley et al., 2020) when comparing auditory kinematic feedback to no feedback, on exercise velocity in resistance-trained participants. Most recently, a systematic review and meta-analysis showed an 8.4 % difference in barbell velocity when comparing feedback (visual and auditory) to no feedback (Weakley et al., 2023). Feedback during multi-joint tasks facilitates self-regulation and instant adjustments, enabling the participants to change their movement velocity based on the feedback output (Rucci & Tomporowski, 2010; Sigrist et al., 2013). Another mechanism highlighted by Weakley et al. (2023) on why improvements in lifting velocity occur during feedback could also be a result of increased motivation and competitiveness. When these factors change, we also see an enhanced velocity output during resistance training (Weakley et al., 2019; Wilson et al., 2017).

In contrast to most of the literature (Campenella et al., 2000; Weakley et al., 2019, 2020) on visual feedback, we found no difference between VIS vs CON when looking at the set as a whole (all repetitions) for average velocity. However, we found a difference between VIS and CON in peak velocity, but it was not supported by the analysis on velocity loss, and therefore should be interpreted cautiously. Nonetheless, the pattern in the data can also be visually inspected in Figure 1. It is apparent that the importance of feedback is more

prevalent in the late part of the set compared to the early part, as the velocities were maintained in both feedback conditions. Exercise-induced fatigue will cumulate during a high-effort training set, which will decrease the muscle fibers shortening speeds, relaxation times, and force-generating capacity that cause subsequent reductions in voluntary exercise velocity (Rodríguez-Rosell et al., 2020; Sánchez-Medina & González-Badillo, 2011). Put simply, as fatigue cumulates, lifting velocity decreases, which clearly shows the importance of feedback in the late part of a training set.

Perceived exercise enjoyment also differed between the feedback conditions, where visual and auditory feedback were more enjoyable than no feedback, but with no difference in enjoyment between auditory and visual feedback. Di Bella et al. (2023) demonstrated a clear association between motivation and enjoyment, while Weakley et al. (2023) established that feedback significantly influences motivation. These interconnected relationships provide a plausible explanation for our findings regarding enjoyment and feedback. As a sidenote, when asked 10 min after the session about which type of feedback the participants preferred, 70 % of the participants preferred the auditory feedback and the rest the visual feedback condition. During the data collection several of our female participants expressed an uncomfortable feeling during the squat, in both the control and visual feedback condition due to the “awkward silence” which could be the explanation for their feedback preference. While one might speculate that auditory feedback helps mitigate the potentially uncomfortable atmosphere of lifting weights in a laboratory setting under researcher observation, this interpretation remains speculative and should be considered with caution.

The present study has some limitations that need to be addressed. First, the use of the PUSH band as a measurement tool for velocity could lead to cumulative errors because of its accelerometer-based build. While showing acceptable ICC ($> .70$) and CV ($< 10\%$) values (van den Tillaar et al., 2024) in the barbell squat, it overestimated the average velocity and had a wide limits of agreement (0.122 m/s), indicating inconsistency. This inconsistency was more prevalent at higher loads (Callaghan et al., 2022; van den Tillaar et al., 2024). Importantly, the load used in our study is equivalent to 67.5% of 1RM (3RM = 90% of 1RM (Brzycki formula), $75\% \times 90\% = 67.5\%$), which means that the loads being used in our study are less prone to error when using

the PUSH band. Secondly, our research participants were females with a resistance training background, and the findings cannot be generalized to other populations. Third, we did not assess participants' psychological profiles, particularly regarding motivation and competitive tendencies. Given that previous research (Weakley et al., 2019) has established that psychological factors influence how knowledge of results affects velocity performance, such assessments might have provided valuable insights into the individual variations we observed in feedback response patterns.

In conclusion, feedback helps preserve barbell velocity in the squat exercise by reducing velocity loss across repetitions. Auditory feedback was particularly effective compared with no feedback and was also the preferred condition. Together, these findings support the use of kinematic feedback when the goal is to limit in-set velocity loss in resistance-trained females, which may be relevant for optimizing resistance-training prescription.

DATA AVAILABILITY STATEMENT

All data related to this work is attainable from the corresponding author upon reasonable request.

CONFLICTS OF INTEREST

The authors have no conflicts of interest to disclose.

FUNDING

The authors received no funding from outside corporations for this work.

ETHICAL APPROVAL

The protocols conformed to the latest revision of the Helsinki declaration, followed Norwegian laws and regulations, and were processed by the Norwegian Center for Research Data (reference: 639101).

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