# COMPARISON OF SPEED-BASED AND POSITION-BASED AUDITORY FEEDBACK IN ECCENTRIC STRENGTH TRAINING

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## ABSTRACT

Eccentric training, which involves muscle lengthening under tension, requires controlled movement speed to maximize effectiveness. However, muscle fatigue often leads to unintentional acceleration, reducing training effectiveness. This study proposes SpeedFB, a speed-based auditory feedback system that provides real-time auditory cues to regulate movement speed. Specifically, we developed a prototype system for eccentric biceps curls that employs a "charging sound," inspired by sci-fi games, to provide feedback on movement speed. We conducted two experiments to evaluate the effectiveness of our system: (1) The first experiment compared SpeedFB with a numerical count method and a no-feedback condition. Results showed that SpeedFB effectively prevented acceleration and prolonged the eccentric phase. (2) The second experiment compared SpeedFB with a position-based feedback method (PositionFB). The results showed that SpeedFB promoted a more consistent movement duration, whereas PositionFB led to slower movements with increased variability. These findings suggest that speed-based auditory feedback is a promising approach for improving movement regulation and ensuring consistent eccentric training.

## 1. INTRODUCTION

Sonification has been widely applied in sports training and rehabilitation to enhance motor learning through real-time feedback [1, 2, 3]. By transforming movement data into auditory cues, sonification enables users to perceive information without relying on visual feedback, which is particularly beneficial in situations where maintaining visual attention is limited. Previous studies have demonstrated that sonification enhances complex motor skill acquisition [4] and improves performance in rehabilitation tasks [5].

Among various strength training exercises, biceps curls are widely practiced to develop the biceps brachii muscle. In particular, the eccentric phase, during which the muscle lengthens while exerting force, plays a crucial role in improving muscle strength and inducing hypertrophy [6, 7, 8, 9]. Eccentric movements are generally recommended to be performed at a controlled pace of 3 to 5 seconds to maximize their effectiveness[10]. However, as performing the eccentric phase over 3 to 5 seconds imposes a high-intensity demand on the muscles, movement speed during eccentric contractions tends to increase with successive repetitions. Consequently, this unintended acceleration diminishes the effectiveness of training.

We propose SpeedFB, a speed-based auditory feedback system designed to help users perform eccentric movements at an appropriate speed, preventing unintentional acceleration. This system provides real-time auditory cues that dynamically adjust based on movement speed, guiding users to regulate their execution accordingly. Specifically, when the movement speed is within the desired range, a "charging sound," inspired by sci-fi games, is played to represent energy accumulation, leading to more stable speed control. If the movement exceeds the desired speed, a sound representing energy dissipation is played, prompting the user to decelerate to the appropriate level. This design enables users to rely on auditory cues to naturally regulate their movement speed, thereby helping maintain control and prevent unintentional acceleration.

The first experiment compared three conditions: (1) SpeedFB, (2) a numerical count method, and (3) a no-feedback condition, with 10 participants. This experiment aimed to evaluate the effectiveness of different feedback approaches for regulating movement speed. The second experiment compared SpeedFB with a position-based feedback method (PositionFB) to investigate their respective effects on movement speed regulation, involving 21 participants. Position-based auditory feedback, as introduced by Yang et al. [11], has been proposed as an alternative approach. However, the effects of this approach on movement speed have not been directly examined under high-load strength training conditions. Therefore, this experiment was conducted under high-load conditions to compare the two methods and examine their effects on movement speed regulation.

The contributions of this study are as follows:

- We developed an auditory feedback system to help users maintain appropriate movement speed and prevent excessive acceleration during eccentric training, implementing it on Apple Watch for portability and usability.
- We demonstrated the effectiveness of the proposed system through an experiment with 10 participants, showing that it significantly prolonged the eccentric phase duration under high-load conditions.
- We compared speed-based and position-based auditory feedback methods in a study with 21 participants. The results

showed that speed-based feedback significantly reduced movement speed variability compared to position-based feedback, enabling users to maintain a more consistent movement speed.

## 2. RELATED WORK

### 2.1. Studies on Training Support through Form and Posture Improvement

Several studies have explored support systems aimed at optimizing movement execution and form during training. Khan et al. [12] proposed a system utilizing Kinect to analyze athletes' movements in real time, detecting form errors to enhance training effectiveness. This system measures and analyzes joint positions, angles, and movement speed, focusing particularly on how speed variations affect form stability in exercises such as the push press. Their findings demonstrated that beginners exhibited greater speed variability and that repeated training led to more stable movements. Similarly, Chen et al. [13] developed Pose Trainer, a system integrating OpenPose-based pose estimation with machine learning to identify form errors and deliver corrective feedback during training. This system estimates joint positions from training videos and assesses form accuracy. Their experiment successfully classified four exercise types with high precision, demonstrating the system's effectiveness in improving form.

While these studies focus on form and posture correction, our research takes a different approach by emphasizing movement speed regulation. By ensuring an appropriate movement speed, our method aims to enhance the effectiveness of eccentric training.

### 2.2. Studies on Sonification-Based Training Support

The use of auditory feedback, particularly sound effects, to support exercise movements has garnered increasing attention in recent research. Yang et al. [11] proposed sonification techniques that translate muscle activity, movement velocity, and arm position into real-time audio cues during dumbbell curls. They tested pitch-mapped position feedback, white noise cues triggered by high speed, and musical note progressions representing movement stages. These methods aided perception, though effects on speed stability and learning remain unclear. Subsequent work [14] reported that auditory feedback improved pacing and user motivation. However, these studies were conducted in low-intensity training settings, and their effectiveness in high-load strength training remains largely unexplored. In high-load training, muscle fatigue often reduces movement stability, increasing speed variability. Therefore, it is crucial to examine whether auditory feedback can improve movement stability and speed control even in high-load conditions. This study investigates whether auditory feedback can improve movement stability and speed control under such conditions.

Sonification-based support has been widely studied beyond strength training. For instance, auditory cues synchronized with movement have been shown to improve average power output in bench press exercises [15]. Similarly, combining auditory and visual feedback enhanced motion accuracy and learning efficiency in basketball jump shots [16]. Similar benefits have been reported in speed skating, hammer throw, and rifle shooting [17, 18, 19]. Building on these findings, this study applies sonification to strength training to enhance movement speed stability and improve training effectiveness.

### 2.3. Commercial System

Auditory feedback has also been adopted in commercial products, most notably "Ring Fit Adventure" by Nintendo. This system includes a "charging sound" that guides users during certain exercises, potentially promoting movement control, particularly during concentric or isometric phases. While the technical details of Ring Fit Adventure are proprietary and its efficacy under high-load eccentric conditions remains unclear, its widespread popularity suggests the practical relevance of sonification in consumer fitness. Compared to such closed systems, our approach emphasizes transparency and reproducibility through open algorithms and experimental data, enabling more rigorous evaluation and replication in academic settings.

## 3. PROPOSED SYSTEM

### 3.1. System Overview

In this study, we developed a prototype system specifically designed for biceps curl exercises, a common strength training movement targeting the biceps brachii. The system operates on an Apple Watch, capturing motion data and delivering real-time auditory feedback. The system generates a "charging sound" when the movement speed remains within the appropriate range and a "power dissipation sound" when it deviates from the target speed. The "charging sound" is an energy-charging effect commonly found in sci-fi games, while the "power dissipation sound" mimics the sound of air escaping from an inflatable object, representing energy loss. To measure movement speed, the system employs angular velocity around the Y-axis, acquired from the smartwatch's built-in motion sensors. The target speed range is defined based on a recommended eccentric training duration of 3 to 5 seconds per repetition. Motion data is sampled at 60 Hz , and the system calculates the average angular velocity over 10 frames to mitigate short-term fluctuations caused by sensor noise and unintended rapid wrist movements, ensuring stable and seamless auditory feedback.

### 3.2. Speed-Based Feedback Algorithm

The auditory feedback system operates in real time, employing a threshold-based approach to determine whether the movement speed is within the desired range. To accommodate individual differences in range of motion, the system records the roll angles at the start and end of the movement to estimate the user's range of motion and to determine an appropriate speed threshold. If a user's range of motion is $120^\circ$, the system sets a speed threshold of $40^\circ/\mathrm{s}$ ($120^\circ/3\mathrm{s}$), triggering feedback when exceeded.

When the angular velocity falls within the target threshold, the system plays the "charging sound," reinforcing the correct movement speed. However, since the charging sound is also triggered for excessively slow movements exceeding 5 seconds, its duration is capped at 5 seconds to prevent prolonged reinforcement of overly slow execution. When the angular velocity surpasses the threshold, the system plays the "power dissipation sound," prompting the user to decelerate.

By dynamically adjusting feedback in real time, the system assists users in maintaining a consistent and controlled eccentric movement speed.

### 3.3. Auditory Feedback Design

The auditory feedback sounds were carefully designed to enhance movement regulation and user engagement during training.

- **Maintaining the target speed:** A "charging sound" was selected to reinforce movement at the appropriate speed. As users focus on muscle activation during training, hearing a sound that represents accumulating power may psychologically motivate them to sustain the movement effectively.
- **Slowing down excessive speed:** A "power dissipation sound" was implemented when the movement exceeded the target speed. When power is perceived as diminishing, users may instinctively recognize a decrease in muscle engagement, prompting them to decelerate.

This feedback system is expected to facilitate stable movement speed regulation even under high-load conditions, thereby ensuring effective eccentric training. Additionally, the accumulating power sound may enhance motivation and training enjoyment, promoting greater user engagement and concentration during exercise. By maintaining user engagement, the system may improve training effectiveness and adherence.

## 4. EXPERIMENT1: EVALUATION OF AUDITORY FEEDBACK EFFECTIVENESS

### 4.1. Overview

The first experiment aimed to evaluate the effectiveness of the proposed speed-based auditory feedback system in helping users maintain an appropriate movement speed during the eccentric phase of biceps curls. This experiment evaluated three conditions: (1) the proposed auditory feedback system, (2) a numerical count-based method, and (3) a control condition without auditory feedback. We evaluated how these feedback methods influenced movement speed consistency and adherence to the target duration of the eccentric phase (3 to 5 seconds).

The numerical count-based method was selected for comparison because personal trainers traditionally count seconds aloud to guide the duration of the eccentric phase. By comparing the charging sound feedback to this established method, we aimed to determine whether the proposed system provides a more effective approach to movement regulation.

### 4.2. Experimental Conditions

Participants performed eccentric biceps curls under the following three conditions using a within-subjects design:

1. **Charging Sound Condition (Proposed System):** Movement speed-based auditory feedback was provided (see Section 3).
2. **Numerical Count Condition (Baseline Comparison):** A voice prompt announced the elapsed time at one-second intervals (from 1 to 5 seconds) to guide participants in maintaining the target duration.
3. **No-Feedback Condition (Control):** Participants executed the exercise without any auditory feedback.

### 4.3. Hypothesis

We hypothesize that the Charging Sound Condition (proposed system) will enable participants to perform eccentric training at a more appropriate speed and maintain that speed more consistently than the Numerical Count Condition.

### 4.4. Participants and Equipment

Twelve male participants (age range: 21–24 years) took part in the experiment. As most participants had minimal to no prior strength training experience, detailed instructions on proper form and system usage were provided before the experiment.

The experiment used an Apple Watch SE (2nd generation) for real-time motion tracking and auditory feedback. For resistance, participants utilized an adjustable dumbbell with a maximum weight of 24 kg. To account for individual strength differences, each participant's one-repetition maximum (1RM) for biceps curls was assessed prior to the experiment. Since eccentric training generally requires heavier loads, the dumbbell weight was set to 80–90% of 1RM. This 10% range was established to accommodate the limited adjustability of dumbbell weights, ensuring an appropriate load within the available range.

### 4.5. Procedure

Each experimental session consisted of three sets of 10 repetitions of eccentric biceps curls. The experiment adopted a within-subjects design, in which each participant completed all three conditions. To minimize the effects of muscle fatigue, each condition was performed on a separate day, ensuring a minimum interval of 48 hours between sessions. To counterbalance order effects, the sequence of conditions was randomized for each participant.

Participants performed a warm-up before training and completed three sets of eccentric biceps curls with 3-minute rest intervals. The experimenter assisted participants in the concentric phase the upward movement during which the muscle shortens to ensure they could focus entirely on the eccentric (lowering) phase (see Figure 1).

After each experimental session, participants completed a subjective evaluation questionnaire that included a five-point Likert scale and open-ended responses to assess their focus and concentration, perceived training load, ease of movement control, and overall user experience under the corresponding feedback condition.

### 4.6. Measurement Metrics

To evaluate the effectiveness of auditory feedback, we analyzed two key metrics: eccentric phase duration and movement speed consistency.

The eccentric phase duration was examined to compare differences across conditions. Since movement speed directly affects duration, faster movements result in shorter durations, while slower movements extend it. This metric serves as an indirect indicator of movement speed.

Movement speed consistency was evaluated based on speed variation within each repetition. Even if a repetition falls within the 3 to 5 second target range, inconsistent movement such as starting slow and accelerating in the latter half may reduce the effectiveness of eccentric training. Maintaining a stable

Figure 1: A participant performing eccentric training while the experimenter assists in the concentric (lifting) phase.

movement speed throughout the eccentric phase ensures consistent muscle activation and enhances training effectiveness. Therefore, speed consistency was quantified using the standard deviation of movement speed within each repetition, providing an objective measure of movement control.

### 4.7. Results

Of the 12 participants, two were excluded from the analysis due to inadequate recovery from muscle soreness and fatigue, which prevented them from properly performing eccentric training even in the first set, making their data unsuitable for inclusion. Each of the 10 participants completed three training sets per session across three experimental sessions, yielding a total of 90 data samples ($10 \times 3 \times 3 = 90$). However, one sample was excluded due to a recording error, where only 9 repetitions were recorded instead of the required 10. Since this study focuses specifically on the eccentric phase, the eccentric contraction period was defined as the segment in which the angular velocity remained below zero for a certain duration. However, minor fluctuations in angular velocity after movement completion and initial sensor noise may introduce discrepancies between the detected eccentric phase and the actual movement duration. Therefore, rather than focusing on absolute values, our analysis emphasizes differences among conditions.

Figure 2 presents a violin plot of eccentric phase duration for each condition. Each plot is color-coded by deciles, allowing for intuitive visualization of the internal distribution structure, and black horizontal lines indicate the median duration for each group. The results indicate that both the charging sound condition and the numerical count condition led to longer eccentric phase durations than the no-feedback condition. A one-way ANOVA revealed a significant difference in eccentric phase duration among the three conditions ($F = 44.32$, $p<.05$). Post-hoc multiple comparisons further indicated that both the charging sound condition and the numerical count condition resulted in significantly longer eccentric durations than the no-feedback condition ($p<.05$). However, no significant difference was found between the Charging Sound Condition and the Numerical Count Condition, suggesting that the hypothesis regarding movement execution at an appropriate speed was not supported.

Figure 3 illustrates the standard deviation of movement speed during the eccentric phase for each condition. The results indicate that both the charging sound condition and the numerical count condition exhibited lower speed variability than the no-feedback condition, suggesting more consistent movement

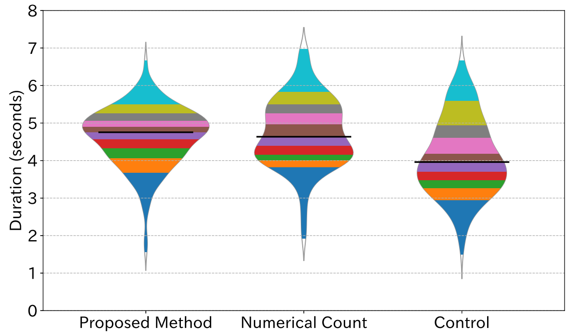


Figure 2: Eccentric phase duration for Charging Sound, Numerical Count, and No-Feedback conditions.

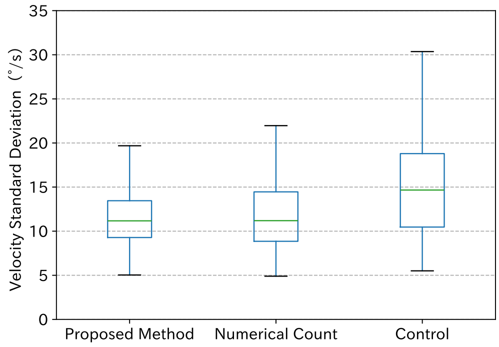


Figure 3: Standard deviation of movement speed during the eccentric phase.

execution ($F = 17.71$, $p<.05$). A one-way ANOVA revealed a significant difference in speed variability among the three conditions. Post-hoc multiple comparisons indicated that both the charging sound condition and the numerical count condition significantly reduced speed variability relative to the no-feedback condition ($p<.05$). However, no significant difference was found between the Charging Sound Condition and the Numerical Count Condition, suggesting that the hypothesis regarding the maintenance of movement speed was not supported.

After each experimental session, a questionnaire was administered to obtain participants' subjective evaluations of the feedback methods. The questionnaire included items assessing participants' awareness of movement speed and motivation, with responses recorded on a 5-point Likert scale ranging from 1 (lowest) to 5 (highest). For the item "Was it easy to maintain a slow and consistent movement rhythm?", the charging sound condition received a mean score of 4.58, the numerical count condition 3.92, and the no-feedback condition 1.83. Additionally, for the item "Did you enjoy the training?", the charging sound condition received a mean score of 4.25, the numerical count condition 3.17, and the no-feedback condition 2.58.

These results suggest that the charging sound condition effectively enhanced participants' awareness of movement speed and contributed positively to their motivation during training.

### 4.8. Discussion

Figure 2 demonstrates that both the charging sound condition and the numerical count condition led to longer eccentric phase durations than the no-feedback condition. The charging sound, synchronized with movement, likely served as a natural pacing cue, aiding participants in slowing down their movements. Similarly, the numerical count explicitly conveyed the elapsed time to participants, reinforcing a slower execution. The absence of a significant difference between the charging sound and numerical count conditions suggests that both methods were effective in preventing unintentional acceleration, resulting in slower eccentric movements than the no-feedback condition.

To further investigate movement speed regulation under high-fatigue conditions, we analyzed the velocity trajectory during the third training set. Figure 4 illustrates velocity changes during the eccentric phase of the third set. The horizontal axis represents the normalized eccentric phase, with each repetition divided into ten segments and averaged across trials. The vertical axis represents angular velocity, where higher values indicate faster movement speed. The results indicate that the charging sound condition led to the greatest reduction in movement speed. This suggests that, particularly in the third set, where muscle fatigue was at its peak, the charging sound feedback effectively encouraged participants to maintain an appropriate movement speed.

Figure 3 shows that both auditory feedback conditions resulted in lower movement speed variability compared to the no-feedback condition. The larger variability in the no-feedback condition suggests that participants may have found it more difficult to maintain a consistent movement speed, likely because they had to count seconds themselves, which may have divided their attention and led to irregular pacing.

A more detailed analysis of training sets in Figure 5 revealed that in the third set, the numerical count condition exhibited greater variability than the charging sound condition. This suggests that, particularly under high muscle fatigue, participants using the numerical count method focused on completing the movement within the designated time, becoming fixated on the numerical count and ultimately failing to maintain a stable movement speed. In contrast, the charging sound condition maintained lower variability even in the third set, suggesting that auditory feedback served as a more intuitive and continuous pacing guide, allowing participants to sustain a stable movement speed despite increasing muscle fatigue.

These findings demonstrate that speed-based auditory feedback effectively extends the duration of the eccentric phase and enhances movement speed consistency, particularly under fatigue. This suggests its potential as a practical tool to support controlled eccentric movement execution in real-world training scenarios.

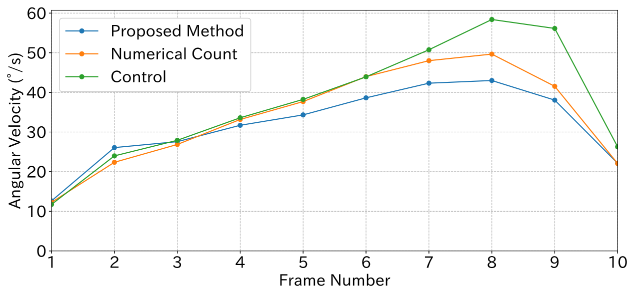


Figure 4: Average angular velocity trajectory in the third set.

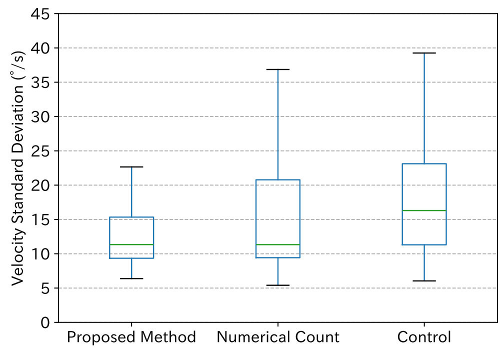


Figure 5: Movement speed variability in the third set.

## 5. EXPERIMENT 2: COMPARISON OF SPEED-BASED AND POSITION-BASED FEEDBACK

### 5.1. Overview

The second experiment examined how SpeedFB, our proposed method, compares to an alternative strategy: position-based auditory feedback (PositionFB). Speed-based feedback dynamically adjusts sound in response to real-time movement velocity, whereas position-based feedback generates auditory cues based on arm position. To compare the characteristics and effectiveness of these two feedback strategies, participants performed eccentric biceps curls under both feedback conditions, and their movement speed and consistency were analyzed.

### 5.2. Experimental Conditions

In this experiment, participants performed eccentric biceps curls under two auditory feedback conditions as follows:

1. **Speed-Based Feedback Condition (Proposed Method):** Auditory feedback was delivered based on movement speed, as described in Section 3.
2. **Position-Based Feedback Condition:** Auditory feedback was generated based on arm position, providing stepwise feedback on movement progression. The movement range was determined by the smartwatch's roll angle and was divided into eight stages. Each stage corresponded to a musical pitch, with frequency increasing as the arm moved downward. At full flexion, the system played C (261 Hz), and at full extension, it played C' (523 Hz).The pitch changed in real time at each stage transition, enabling users to perceive movement progression. By focusing on maintaining a consistent duration for each stage, participants were expected to improve movement speed consistency.

### 5.3. Hypothesis

The hypotheses tested in Experiment 2 are as follows:

1. SpeedFB will result in more appropriate movement durations compared to PositionFB.
2. PositionFB will reduce movement speed variability more than SpeedFB.

### 5.4. Participants and Equipment

24 participants (18 males, 6 females; age range: 20–24 years) were recruited. Before the experiment, all participants completed a training session to familiarize themselves with eccentric training and ensure proper movement execution. If participants reported fatigue following the practice session, the experiment was postponed until they had fully recovered. If fatigue persisted, participants were allowed to withdraw from the study.

Experiment 2 used the same equipment as in Experiment 1 (Section 4.4): an Apple Watch SE (2nd generation) for motion tracking and auditory feedback, and an adjustable dumbbell set at 80–90% of 1RM.

### 5.5. Procedure

As in Experiment 1, each session consisted of three sets of 10 repetitions of eccentric biceps curls. The experiment employed a within-subjects design, in which each participant experienced both feedback conditions: speed-based feedback (SpeedFB) and position-based feedback (PositionFB). To minimize the effects of muscle fatigue, each feedback condition was tested over three separate sessions within 1.5 weeks, with a minimum interval of 48 hours between sessions. Participants underwent a total of six training sessions across three weeks. Each participant completed three consecutive sessions under one feedback condition, then switched to the other condition for the remaining three sessions. The order of feedback conditions was randomized for each participant.

Prior to each training session, participants practiced with the assigned auditory feedback system to familiarize themselves with its characteristics.

In the Speed-Based Feedback (SpeedFB) condition, participants learned how auditory cues responded to their movement speed. As described in Section 3.2, when the movement duration was less than 3 seconds, a “power dissipation sound” was played to encourage slowing down, whereas when the movement exceeded 3 seconds, a “charging sound” was played. To prevent excessively slow movements, the charging sound automatically stopped after 5 seconds, helping participants stay within the 3 to 5 second target range. Participants were instructed to perform multiple repetitions, adjusting their movement speed to naturally recognize how the feedback guided their motion. Through this practice, they developed an intuitive understanding of how to maintain movement within the 3 to 5 second target range.

In the Position-Based Feedback (PositionFB) condition, it was essential for participants to understand the pitch changes corresponding to movements performed within the 3 to 5 second range. Therefore, prior to training, they practiced lowering the dumbbell over 3, 4, and 5 seconds while listening to the corresponding pitch shifts. This practice aimed to help participants become familiar with the sounds associated with movements in the target duration and develop a sense of executing the motion within the 3 to 5 second range.

After practicing with the assigned feedback system, participants proceeded with the warm-up and three training sets, following the same procedure as in Experiment 1 (Section 4.5).

After each training session, participants completed a brief questionnaire to subjectively evaluate the feedback method, including perceived difficulty, usefulness, and enjoyment of the movement. Additionally, upon completing all three sessions for each feedback method, participants provided open-ended responses regarding their impressions of the sounds, any discomfort experienced, and overall feedback. This qualitative data was collected to assess user experience and identify potential improvements for the feedback systems.

### 5.6. Results

Among the 24 participants recruited for this experiment, three were excluded due to persistent fatigue reported during the familiarization session, even after an initial postponement of their participation. As a result, 21 participants (16 males, 5 females) completed the experiment. Each participant performed three training sets per session across six experimental sessions. A total of 378 data samples ($21 \times 6 \times 3 = 378$) were collected, of which four were excluded due to measurement errors, resulting in 374 valid samples for analysis. The eccentric phase was identified using the same method described in Section 4.7.

Figure 6 presents a violin plot of eccentric phase duration for each feedback method. Each plot is color-coded by deciles, and black horizontal lines indicate the median duration for each group. The duration was calculated as the elapsed time from the start to the end of the eccentric phase. To examine differences in both central tendency and variability, we conducted two statistical tests. First, a Wilcoxon signed-rank test suitable for comparisons within subjects revealed a significant difference in eccentric phase duration between the SpeedFB and PositionFB conditions ($p$<.01). The median eccentric phase durations were 4.84 seconds for SpeedFB and 4.72 seconds for PositionFB, showing a slight tendency for longer durations in the SpeedFB condition, though the difference was not substantial. Second, an F-test showed a significant difference in variance between the two conditions ($F = 33.11$, $p$<.01), with SpeedFB showing lower variability (variance = 0.375) compared to PositionFB (variance = 0.953). This result supports the hypothesis that SpeedFB facilitates more consistent movements at an appropriate speed.

While both feedback methods effectively guided participants to stay within the 3 to 5 second target range, the greater variability observed in PositionFB suggests more inconsistency in speed control across repetitions and participants.

Figure 7 presents a box plot of the standard deviation of movement speed for each feedback method. The standard deviation was calculated based on the angular velocity data from the start to the end of the eccentric phase. We conducted a Wilcoxon signed-rank test to compare the movement speed variability between the two feedback conditions. The results showed a significant difference between conditions ($p$<.01), with SpeedFB (median = 9.81) exhibiting higher variability than PositionFB (median = 9.04). This finding supports the hypothesis that PositionFB reduces movement speed variability across movements, contributing to improved movement speed consistency. However, due to the small effect size, it remains unclear whether PositionFB truly improves movement speed

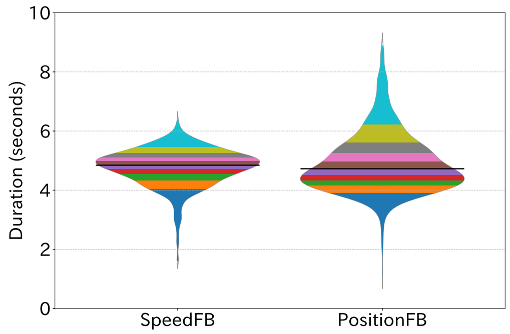


Figure 6: Eccentric phase duration for SpeedFB and PositionFB conditions.

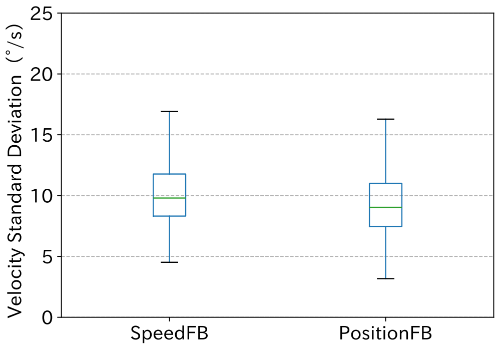


Figure 7: Standard deviation of movement speed for each feedback condition.

consistency over SpeedFB.

After each training session, participants completed a questionnaire to provide subjective evaluations of the feedback methods. The questionnaire included items assessing movement difficulty, feedback usefulness, concentration during exercise, and enjoyment of training, with responses recorded on a 5-point Likert scale. Additionally, open-ended questions gathered participants' opinions regarding their impressions of the sounds, any discomfort experienced, and overall feedback. For the item "Did you feel it was easy to control your movements with auditory feedback?", the SpeedFB condition received a mean score of 4.40, while the PositionFB condition scored 3.97, indicating that SpeedFB facilitated better movement control ($p<.01$). Furthermore, SpeedFB received higher ratings than PositionFB on multiple aspects, including awareness and control of movement speed, concentration, and enjoyment.

In the open-ended responses, a common issue identified for both feedback methods was that participants often focused excessively on the auditory cues, reducing their attention to muscle engagement. Additionally, many participants expressed uncertainty regarding movement accuracy due to unclear criteria for speed judgment and auditory feedback. Nevertheless, participants frequently highlighted positive aspects of auditory feedback, emphasizing its effectiveness in maintaining movement awareness and motivation during training.

### 5.7. Discussion

As shown in Figure 6, both SpeedFB and PositionFB resulted in median eccentric phase durations within the recommended 3 to 5 second range, indicating that both feedback methods effectively guided participants toward the target duration. However, PositionFB showed notably greater variance, suggesting less consistent execution. Figure 8 further illustrates this difference. SpeedFB produced a concentrated distribution within the 3 to 5 second range, while PositionFB had a broader spread, with many trials exceeding 6 seconds. One likely reason is that PositionFB did not provide clear feedback when movements became too slow, making it harder for participants to self-correct. In contrast, SpeedFB limited the charging sound to 5 seconds, helping participants identify and adjust overly slow movements. This suggests that SpeedFB was more effective at keeping durations within the optimal range.

The high frequency of overly long movements in the PositionFB condition may also be due to insufficient resistance. Although resistance was calibrated based on 1RM, some participants may have been underloaded due to inaccurate estimates or strength gains during the multi-week protocol. As a result, they could perform very slow repetitions without fatigue, inflating duration variability.

Overall, SpeedFB reduced variability in movement duration and promoted stable pacing. While PositionFB encouraged slower movement potentially useful in specific training contexts it often lacked precision in timing control. Future studies should improve load adjustment accuracy to allow clearer comparisons.

Figure 7 shows that PositionFB resulted in slightly lower speed variability. This suggests that mapping pitch to segmented arm positions may have helped users maintain consistent speed within each repetition. The discrete pitch changes likely provided intuitive feedback about progress and encouraged pacing regularity. Interestingly, SpeedFB, despite not offering such segmentation, achieved nearly the same level of consistency. Participants may have been strongly motivated to maintain appropriate speed in response to real-time auditory cues, especially the charging sound, which gradually rose in pitch. This continuous feedback likely supported stable movement throughout the eccentric phase.

In summary, PositionFB supported consistent pacing through pitch segmentation, while SpeedFB enabled stable execution via direct, speed-sensitive feedback. These complementary characteristics indicate that each method has unique strengths for supporting controlled eccentric training.

## 6. CONCLUSION

This study evaluated the effectiveness of a speed-based auditory feedback system for eccentric strength training through two experiments. We refer to this proposed method as SpeedFB, which provides real-time auditory cues based on movement speed to support controlled eccentric execution.

Results from Experiment 1 demonstrated that the proposed charging sound feedback significantly prolonged the eccentric phase duration compared to the no-feedback condition, with durations approaching the recommended 35 second range. Additionally, it helped participants maintain a more consistent movement speed, particularly under high muscle fatigue, and showed comparable or superior performance to the conventional

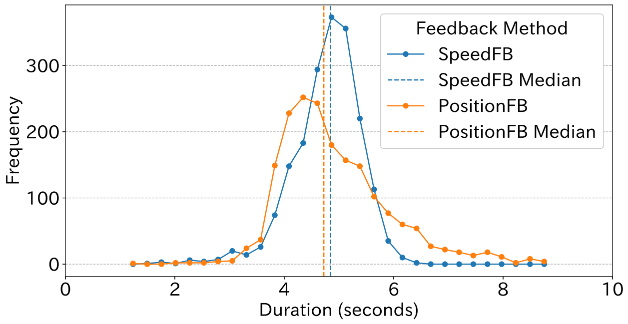


Figure 8: Histogram of eccentric phase duration across conditions.

numerical count method commonly used by trainers.

In Experiment 2, we further investigated how different auditory feedback strategies influence movement execution by comparing the proposed speed-based feedback (SpeedFB) with a position-based feedback method (PositionFB). SpeedFB effectively maintained movement durations within the target range and offered more stable pacing guidance. In contrast, PositionFB encouraged slower movements, which may be beneficial when emphasizing controlled execution. However, it often led to inconsistent pacing, with durations frequently exceeding the target range.

These results highlight the complementary nature of the two feedback strategies: SpeedFB ensures stable pacing and helps maintain appropriate movement durations, while PositionFB promotes slower, more deliberate execution. Future work should explore hybrid strategies that combine these strengths, investigate long-term training effects, and develop adaptive feedback systems that offer personalized, real-time guidance to support effective and engaging strength training.

## 7. REFERENCES

[1] T. Hermann, A. Hunt, and J. G. Neuhoff, *The Sonification Handbook*. Berlin, Germany: Logos Verlag, 2011.

[2] G. Dubus and R. Bresin, "A systematic review of mapping strategies for the sonification of physical quantities," *PLOS ONE*, vol. 8, no. 12, p. e82491, 2013.

[3] N. F. Bernardi, D. Müllensiefen, P. E. Keller, and S. D. Bella, "A review on the relationship between sound and movement in sports and rehabilitation," *Frontiers in Psychology*, vol. 10, p. 244, 2019.

[4] A. O. Effenberg, U. Fehse, G. Schmitz, B. Krueger, and H. Mechling, "Movement sonification: Effects on motor learning beyond rhythmic adjustments," *Frontiers in Neuroscience*, vol. 10, p. 219, 2016.

[5] M. Matsubara, H. Kadone, M. Iguchi, H. Terasawa, and K. Suzuki, "The effectiveness of auditory biofeedback on a tracking task for ankle joint movements in rehabilitation," *Journal of the Robotics Society of Japan*, vol. 31, no. 4, pp. 341–348, 2013.

[6] T. Hortobgyi, J. J. Hill, D. Houmard, R. F. Fraser, R. Lambert, and F. H. Israel, "Adaptive responses to muscle lengthening and shortening in humans," *Journal of Applied Physiology*, vol. 80, no. 3, pp. 765–772, 1996.

[7] D. B. Hollander, R. R. Kraemer, M. W. Kilpatrick, Z. G. Ramadan, G. V. Reeves, M. Francois, E. P. Hebert, and J. L. Tryniecki, "Maximal eccentric and concentric strength discrepancies between young men and women for dynamic resistance exercise," *Journal of Strength and Conditioning Research*, vol. 21, no. 1, pp. 34–40, 2007.

[8] B. J. Schoenfeld, D. Ogborn, and J. W. Krieger, "Hypertrophic effects of concentric vs. eccentric muscle actions: A systematic review and meta-analysis," *Journal of Strength and Conditioning Research*, vol. 31, no. 9, pp. 2599–2608, 2017.

[9] S. Sato, R. Yoshida, F. Murakoshi, Y. Sasaki, K. Yahata, K. Kasahara, J. P. Nunes, K. Nosaka, and M. Nakamura, "Comparison between concentric-only, eccentric-only, and concentric-eccentric resistance training of the elbow flexors for their effects on muscle strength and hypertrophy," *European Journal of Applied Physiology*, vol. 122, no. 12, pp. 2607–2614, 2022.

[10] A. Bubbico and L. Kravitz, "Eccentric exercise: A comprehensive review of a distinctive training method," *IDEA Fitness Journal*, vol. 7, no. 9, pp. 50–59, 2010.

[11] J. Yang and A. Hunt, "Sonic trainer: Real-time sonification of muscular activity and limb positions in general physical exercise," in *Proceedings of the 4th Interactive Sonification Workshop*, Erlangen, Germany, December 2013.

[12] M. U. Khan, K. A. Shah, and S. Qadeer, "Weight training analysis of sportsmen with kinect bioinformatics for form improvement," *arXiv preprint arXiv:2009.09776*, 2020.

[13] S. Chen and R. R. Yang, "Pose trainer: Correcting exercise posture using pose estimation," *arXiv preprint arXiv:2006.11718*, 2020.

[14] J. Yang and A. Hunt, "Real-time sonification of biceps curl exercise using muscular activity and kinematics," in *Proceedings of the 21st International Conference on Auditory Display*, July 2015.

[15] M. Murgia, F. Sors, R. Vono, A. F. Muroni, L. Delitala, D. D. Corrado, and T. Agostini, "Using auditory stimulation to enhance athletes' strength: An experimental study in weightlifting," *Review of Psychology*, vol. 19, no. 1, pp. 13–16, 2012.

[16] H. Ramezanzade, K. Khosravani, A. Yalfani, and A. A. Norasteh, "The effect of sonification modelling on perception and accuracy of performing jump shot basketball," *International Journal of Sport Studies*, vol. 4, no. 7, pp. 835–840, 2014.

[17] A. Godbout and J. Boyd, "Corrective sonic feedback for speed skating: A case study," in *Proceedings of the 16th International Conference on Auditory Display*, June 2010.

[18] T. Agostini, G. Righi, A. Galmonte, and P. Bruno, "The relevance of auditory information in optimizing hammer throwers' performance," in *Biomechanics and Sports*, P. B. Pascolo, Ed. Springer, 2004, pp. 67–74.

[19] N. Konttinen, K. Mononen, J. Viitasalo, and T. Mets, "The effects of augmented auditory feedback on psychomotor skill learning in precision shooting," *Journal of Sport and Exercise Psychology*, vol. 26, no. 2, pp. 306–316, 2004.