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MUSIC-DRIVEN BIOFEEDBACK FOR ENHANCING DEADLIFT TECHNIQUE.

Sports Science

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ABSTRACT

This paper presents the design and validation of a bio-mechanical biofeedback system aimed at enhancing dead lift technique through real-time sonification and music-based rewards. Weightlifting, particularly dead lift exercises, is essential for both sports and rehabilitation, but improper technique can lead to severe injuries. The system addresses this by providing continuous auditory feedback on key biomechanical parameters, specifically spine curvature and barbell displacement, which are crucial for injury prevention. By integrating sonification and reinforcing correct movements with improved music quality, the approach leverages the positive effects of music in physical activities. This method not only enhances performance but also reduces perceived exertion, making it an effective tool for athletes and individuals training in various environments, including public gyms and home settings. The system offers a novel solution to the challenge of maintaining correct form without the constant presence of a coach, thereby promoting safer and more efficient weightlifting practices.

KEYWORDS

Posture, postural correction, effect of music on posture, dead lift, sports performance, biomechanics of dead ligting, Biofeedback.

INTRODUCTION

Biofeedback has been extensively applied in various fields such as sports performance enhancement [1] and rehabilitation therapies [2]. These systems provide real-time feedback to users about physiological or biomechanical parameters that would otherwise remain unnoticed [3]. The primary goal is to allow users to improve their performance unconsciously without direct intervention from trainers or therapists. Traditionally, biofeedback has been delivered via visual cues, auditory signals, or tactile feedback. With the advancement of technology, real-time biofeedback during physical activities is now possible, paving the way for more dynamic applications in training.

A new trend in rehabilitation involves the integration of gaming or virtual reality (VR) environments for exercise, which provides an innovative form of immersive biofeedback [4].

In this paper, it introduces the design and validation of a biomechanical biofeedback system aimed at improving weightlifting techniques. Weightlifting, an ancient sport included in the Olympic Games since 1896, has gained popularity, especially with the rise of hybrid disciplines like CrossFit, which combines Olympic weightlifting,

Power lifting and other fitness modalities [5]. Despite the popularity, effective technique remains crucial for maximizing performance and reducing injury risks. This study focuses on the dead lift, a key component of power lifting, widely used in both strength training and rehabilitation [6]. The proper execution of the dead lift is essential to avoid stress on the lower back and prevent injuries [7]. A common challenge with dead lift technique is the potential for spinal misalignment, which can lead to serious back injuries. Incorrect lifting form, such as rounding the back or bending excessively at the hips, increases the risk of injury [8]. The system aims to offer real-time feedback on spinal alignment and barbell trajectory, both of which are linked to injury prevention. The use of auditory feedback (sonification) in weightlifting has shown promising results, enhancing athletes' performance and motivation [9]. Previous studies have demonstrated that auditory cues can stimulate greater exertion, even when compared to silent conditions [10]. Additionally, studies like Fritz et al. [11] have highlighted how music-induced agency can reduce perceived exertion and improve performance during physical tasks. Moreover, current research in reinforcement learning suggests that integrating reward-based feedback, such as sonification of movement quality, could enhance spontaneous behavioral improvements without explicit instructions [12]. Music and sound have been identified as key motivators in this process, enhancing engagement during physical tasks [13].

This paper proposes a sonification-based system for dead lift training that rewards proper movement by improving audio quality. Spine misalignment and improper barbell movement trigger down sampling of the music and reduction in speaker activity, providing clear, motivating feedback for users to adjust their form. Participants were divided into two groups: one receiving verbal feedback, and the other receiving only sonic feedback. The experimental group demonstrated a higher exertion of power compared to the control group, suggesting that auditory feedback can be an effective strategy for improving weightlifting technique and performance.

MATERIAL AND METHOD:

Participants

Thirty participants (15 women) participated in the experiment. Their ages ranged from 22 to 38 years (mean = 27.1). The exclusion criterion involved any participant who had sustained an injury in the last six months that would prevent participation in physical activities. All participants had some background in sports. Specifically, 14 participants reported over two years of experience with strength training, 12 had between 6 months and 2 years of experience, and 4 had less than 6 months of experience. Of the participants, 18 preferred listening to music during their training, 7 trained without music, and 5 alternated between the two. A total of 15 participants (50%) reported receiving formal music education.

All participants provided written informed consent and were made aware of the physical demands of the experiment, as well as the potential inclusion of personal questions in the surveys. Participants were compensated with a voucher for a beverage at the university café.

Apparatus

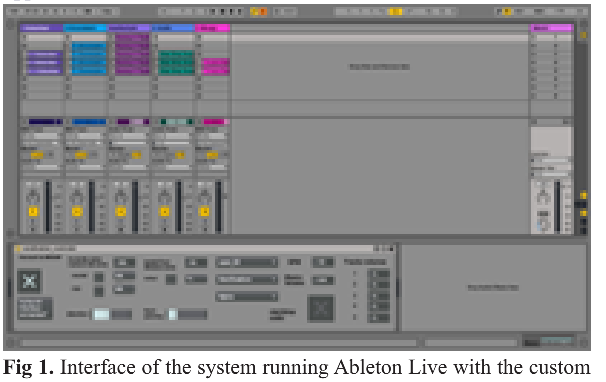

Fig 1. Interface of the system running Ableton Live with the custom Max4Live controller

The experiment was conducted at the Technology and Innovation Lab. The lab's dimensions are 12 m x 12 m x 6 m and is equipped with a high-fidelity sound system comprising 48 speakers arranged at various points around the room. The motion capture system used was a combination of infrared and marker less tracking, with eight high-speed cameras positioned to capture a 3D representation of the participants' movements.A standard barbell weighing 20 kg was positioned at the center of the lab, resting on a set of foam pads for stability. The cameras tracked spherical markers (2 mm radius), and participants wore a full-body marker setup. The marker system comprised 24 reflective markers, including 6 on the participant's pants (with two size options), 2 wrist markers, 4 markers on the headband,

and 10 markers applied directly to the skin using medical-grade tape. Specific markers were placed at anatomical landmarks, including the spine (L4, T12, T7, and C2 vertebrae), shoulders, elbows, and feet. The barbell was equipped with 4 markers for improved tracking, including asymmetry for better model recognition.

The motion capture data were processed using a custom software system running on a Windows PC. The system recorded the 3D positions of the markers at 120 Hz and transmitted them in real-time to a custom Max4Live plug-in within Ableton Live®, which controlled the audio feedback based on the physical performance data. The system also collected and stored data for subsequent analysis.

A screenshot of the software interface is shown in Fig. 1. Spinal curvature
1) The total of consecutive Euclidean distances between spinal markers: $spinal curvature = d0 + d1 + d2$ Barbell-to-foot (B-F) distance
2) The 2D distance measured from the line connecting the ends of the barbell to the markers on the front of the foot.

The smallest value between the two possible distances was used. These measurements are depicted in the diagram of Fig. 2.

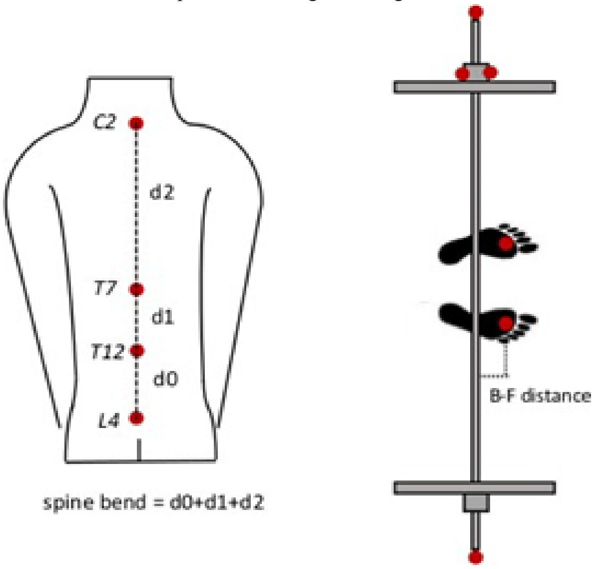

Fig 2. Positioning of motion capture markers

Experimental setup
Upon entering the lab, participants were provided with a written overview of the study. They were asked to sign a consent form and complete a questionnaire covering details such as: gender, age, weightlifting experience, musical background, and any prior injuries. Next, participants watched a video demonstrating an expert performing 10 dead lifts from both the front and side perspectives. The focus of the experiment was explained to them: ensuring a neutral spine position during the lift and maintaining a vertical barbell trajectory. Participants were then fitted with the marker setup. The Qualisys system employed a pre-trained skeleton model to track body movements across different individuals. The placement of the markers was verified at this stage. Prior to testing, a warm-up routine was guided to the participants. Before participants began the dead lifts, baseline measurements for each individual were recorded, including:

1) **Neutral spine position**: Participants were instructed to grab the bar and maintain a neutral spine in
a non-loaded position.
2) **Maximum spine curvature:** Participants were asked to slightly bend forward while holding the bar. The instructor assisted in reaching this position, ensuring the spine was bent in a way that wasn't dangerous but deviated from the neutral alignment.
3) **Initial B-F distance:** Participants were directed to grip the bar as if preparing to start the lift, ensuring the barbell was positioned approximately in the middle of the foot. The initial distance between the bar and the feet was recorded.

From these measurements, the Max4Live patch computed the following dimensionless quantities in real-time:

$$SC = \frac{spinal\ curvature - neutral\ spine}{\text{maxspine curvature - neutral spine}}$$

and the non-dimensional barbell-to-foot distance:

$$\text{bfd} = \frac{\text{B} - F\ \text{distance}}{\text{initial B - }F\ \text{distance}}$$

Participants were instructed to maintain the neutral spine position throughout the movement and to keep the barbell at the initial distance from the feet to ensure proper verticality of the bar path. The actual trials began with 10 dead lifts performed at a comfortable pace, considered the baseline for analysis. Participants were then randomly assigned to one of two groups, balanced for gender, experience, and age.

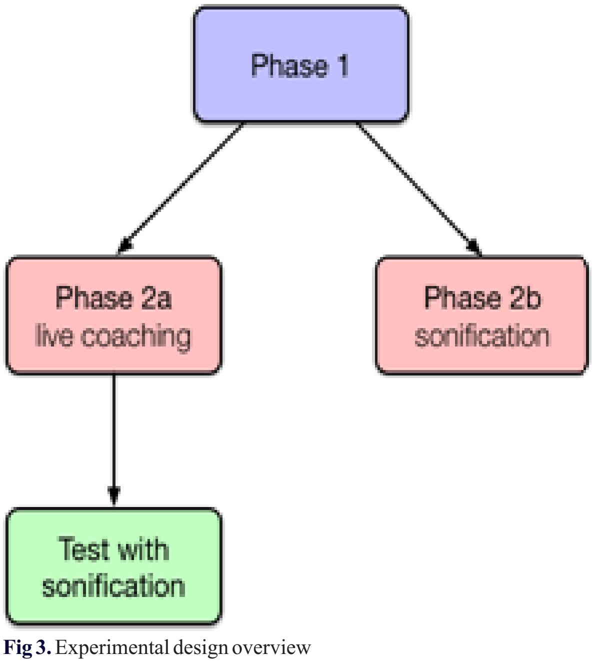

Fig 3. Experimental design overview

One group received verbal feedback from the instructor, while the other group received auditory feedback via sonification. These groups are referred to as the *instruction group* and the *sonification group*. Each participant in both groups performed 10 dead lifts for each of the following performance points, in a random order: *Spine*, *Barbell*, and *Combination*. Participants were reminded to focus exclusively on the specific point of performance, and were informed that feedback (either verbal or sonified) would be provided if their movement deviated from the correct form. The feedback provided to the participants was as follows, tailored to each group and point of performance:
a) Verbal feedback: For the *instruction group*, the instructor provided the following guidance:
1) *Spine*: Feedback focused on the positioning of the spine. If any curvature was detected, corrections were provided.
2) *Barbell*: The feedback will now shift to the position of the barbell.
3) *Combination:* This feedback combines both spine and barbell positions, using the same cues as previously mentioned.

b) *Feedback through Auditory Cues:*
1) *Pelvis Tilt*: Participants.
2) *Dumbbell*: auditory cues
3) *Hybrid*: synchronization of rhythm based on initial movement speed of the subject.

After each set of exercises, a 5-minute rest period was implemented to allow the participant to recover adequately. During this interval, they were asked to complete a Subjective Effort Scale (SES) to rate the intensity of their effort during the exercise, on a scale from 1 ("no effort at all") to 10 ("maximum effort"). Additionally, they evaluated the level of enjoyment during the previous session using the 10-item version of the Exercise Enjoyment Scale (EES), a comprehensive tool to assess enjoyment during physical activities. To assess the

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motivational qualities of the feedback, participants were also asked to complete a modified version of the Music Feedback Evaluation Scale (MFES) .In this evaluation, participants rated on a 5-point Likert scale: clarity, enjoyment, accuracy, motivational impact, and overall usability of the audio feedback. All surveys were conducted using online forms on a dedicated laptop, only accessible by the participant.

Stimuli

a) Soundtrack: A single music track was played in all experimental conditions. This track was specially composed for the study by the researchers. The composition adhered to the following guidelines:
• to be unfamiliar to participants, minimizing personal associations
• to be instrumental (no vocals), avoiding focus on lyrics
• to include a defined beat, encouraging rhythmic movement.

b) Auditory Feedback: The auditory feedback group received real time performance adjustments based on their movement, altered through the baseline music track. Specifically, the feedback mechanisms included:

1) **Spine Flexion:** Continuous variations in the playback speed of the track. The spine flexion value *sf* was mapped to a Sigmoid function:

$$y = 1 - \exp \frac{1}{1 + \exp(-10(x - 0.3))}$$

The output value, ranging from 1 to 0, determined the playback rate of the track, implemented via the ”time- stretch” effect in Ableton Live. The function parameters were adjusted based on prior tests to ensure sufficient responsiveness while avoiding auditory distortion during typical movement ranges.

2) **Movement Speed Feedback:** Variation in stereo panning and the number of active speakers. The movement speed *ms* was mapped using this Sigmoid function:

$$1 - \exp \frac{1}{1 + \exp(-12(x - 0.5))}$$

The two stereo channels of the Ableton Master track were routed to different speaker configurations using a sound management software, connected via Rednet. The right channel was routed to speakers surrounding the participant, while the left channel was directed to speakers placed only in front of the participant. The Sigmoid function output determined the gain of the respective channels, so if the value *ms* decreased (indicating slower movement), the left channel volume (linked to the front speakers) increased while the right channel volume (linked to the surrounding speakers) decreased, creating a directional shift in sound that signaled slower movement.

Data Collection

The positions of the body markers were recorded using a motion capture system. Data was acquired every 10 milliseconds and stored in .txt files on the control computer, containing the following variables:
- 3D positions of the markers
- *sf* and *ms* values
- distortion levels
- audio panning settings

Separate files were maintained for each participant, and each instance of the exercise performance. Questionnaire responses were directly uploaded to the cloud for further analysis.

Data Analysis

The repetitive movements were divided into individual dead lift actions by analyzing the vertical displacement of the barbell. A preliminary assessment of the data's normality using the Shapiro-Wilk test indicated that the data followed a non-normal distribution. Further statistical tests were carried out, including a t-test to evaluate the differences between groups. Power analysis was performed to assess the likelihood of detecting a Type II error, which occurs when a study fails to detect a true difference, such as between experimental and control groups.

III. RESULTS

Comparison of Feedback Methods
a) Differences in Spine Alignment:
b) b) Horizontal Barbell Displacement:

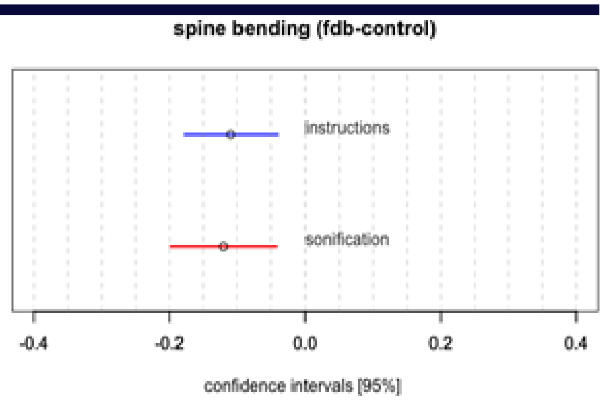

Fig 4. Comparison of spine alignment under different feedback conditions.

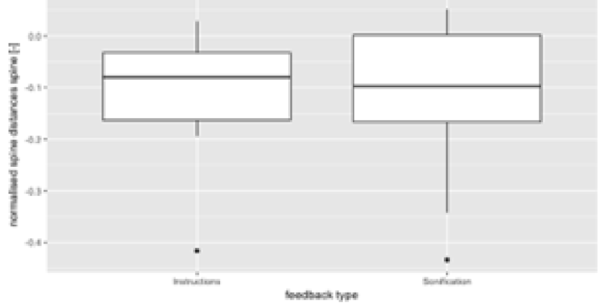

Fig 5. Box plot comparison between instruction and sonification feedback.

Regression Analysis

The effects of variables such as music education, experience level, and gender were analyzed in relation to the spine alignment and barbell displacement. A Kolmogorov-Smirnov test for normality showed that the Adaptive Sync and Plus 30% conditions followed a normal distribution ($p = 0.06$ and $p = 0.2$, respectively). However, the Initial Sync ($p = 0.022$), Minus 30% ($p = 0.016$), and No Music ($p = 0.001$) conditions did not. Paired t-tests were used for normally distributed pairs, and Wilcoxon tests were used for the non-normally distributed pairs. The results, including effect size (Cohen's d for t-tests and Pearson correlation for Wilcoxon tests).

Questionnaire Responses

Participants rated the pleasantness and motivational impact of the various synchronization strategies using a 7-point Likert scale. No significant differences were found based on gender or experience level.

DISCUSSION

No noticeable effect of arousal induced by the auditory stimulus was found when compared to the no sonification condition. Further research is needed to explore potential distortions.

Table I. Comparison Of Performance Metrics Between Different Feedback Types.

	Performance Metrics					
	Spine Alingnment		Barbell Displacement		Combined Metric	
Feed back Type	Mean	SD	Mean	SD	Mean	SD
Instructions	12.4	2.3	15.1	3.1	18.5	2.9
Sonification	11.8	2.0	14.5	2.8	17.9	3.2

The portability of the system could be enhanced by integrating current back posture detection systems, such as ViPerform tm Assessment Modules. Our hypothesis was that the system would perform similarly to verbal instructions given by a coach in terms of effectiveness. However, no significant differences were observed between the feedback types regarding pleasantness or motivation.

Possible reasons for this lack of difference could include:
- The choice of music used during the study.
- Participants' previous experiences with having a coach.
- A preference for human feedback over automated systems.

According to Tate (2010), retention tests were not conducted in his study or in the current experiment. Future studies should incorporate retention testing to evaluate the long-term effectiveness of biofeedback and its impact on motor learning. Further research could also explore the relationship between well-being and performance in similar contexts, particularly in terms of feedback systems for physical training.

CONCLUSIONS

A study was conducted to investigate the effect of various music timing techniques on the posture of dead lift. The findings suggest that music timing does not significantly correct the posture. No notable differences were found in terms of enjoyment or motivational effects across the different music synchronisation methods. Still, participants with a musical background appeared to prefer when their lifting were in sync with the beats of the music.

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