The sonic instructor: a music-based biofeedback system for improving weightlifting technique

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Abstract

Functional coumpounds movements as in weighlifting and powerlifting disciplines are becoming increasingly popular. The

Crossfit and gymnastic exercising are becoming increasingly popular. Functional movement are the the base of such exercises and

usually these kind of movement require specific technique for movement improvement and

Introduction

Biofeedbacks have been used for over fifty years in the domains of sports [1] and motor rehabilitation [2, 3]. These are used to provide the subjects with information about physiological or biomechanical parameters that that would otherwise be unknown [4]. The main goal of such systems is to let the subject automatically improve the performances at subconscious level, without explicit instructions by a trainer or therapist.

Traditionally biofeedback are presented to the subject via visual displays , acoustic or vibrotactile feedback. Recent technological developments have opened the possibility to provide such bio-feedback in real-time during physical activity, this opened the possibility for using

A recent development in rehabilitation is exercising in a gaming or virtual reality (VR) environment, thus providing a novel form of immersive biofeedback.

In this paper we describe the design and validation process of a bio-mechanical biofeedback system for improving weightlifting movements.

Weightlifting is an ancient sport which appeared in the Olympic Games in Athens already in 1896. Weightlifting movements are becoming increasingly popular in the sport world, as new sports as Crossfit (founded in year 2000 by Greg Glassman) combine elements of Olympic weight lifting with power lifting and other disciplines. Although researchers have proven the benefits of such functional weightlifting movements [5], clear knowledge of the exact technique is required in order to maximize movement efficency and minimize the chance of injuries.

In this work we focused on a specific movement called *deadlift* which is one of the three discipline of power lifting movements but it is widely used in weightlifting training and rehabilitation practices.

According to the handbook of the powerlifting federation [] a deadlift consists of grabbing a barbell from the floor with hands, then raising the weight by extending the knee, hips, and back while holding the arms downward. On completion of the lift, the knees must be locked in a straight position and the shoulders pulled back. McCuigan *et al.* investigated the kinematics of deadlift comparing different techniques: the sumo and conventional style deadlifts. Due to the fact that the deadlift is a closed chain exercise, it is often used in the prevention of and rehabilitation after anterior cruciate ligament (ACL) reconstruction to improve strength of the muscular structures that surround the knee and hence dynamic stability of the joint

However, a wrong technique during deadlift lift-off may predispose the spine and back musculature to an increased risk of injury [6, 7]. The exercise is often made unsafe by the lifter rounding his back and bending over too far at the hips just before lifting. Holding the bar away from your body instead of right against it is another way to injure your back. With the presented system we aim at providing a real-time feedback using auditory displays, i.e. sonification. The quantities being sonified and on which the participant gets feedback are the spine curvature and the barbell horizontal displacement, as these quantities are directly related to back loads and injuries. Usually coaches spend time in the first phase to teach the right technique and provide feedbacks to the performers. Having continuous feedback by a coach is not feasible while training in public gyms or at home. Therefore there is need to develop portable systems able to guide towards the right movement technique.

The use of sonification in weightlifting has been shown to increase average exertion of power compared to silent condition [8]. The work of Fritz *et al.* [9] showed that music agency stimulated by sonification is able to decrease perceived exertion during workout, indicating that musical agency may actually facilitate physically strenuous activities. These results further indicated that the positive effect of music on perceived exertion cannot always be explained by an effect of diversion from proprioceptive feedback. The most typical strategy pertains to a goal-driven approach. This approach requires that the learner has an explicit representation of the target behavior, i.e., the goal. Sonification then functions as mere information carrier, allowing people to monitor their behavior, compare it to the target behavior, and adapt their behavior if required [2?4].

Recently, a promising alternative strategy is being explored, drawing upon basic principles from the reinforcement learning paradigm. Reinforcement learning is rooted in the idea that people act and behave so as to maximize outcome reward. Hence, when coupling a reward to a desired behavior, people are likely to exhibit this behavior spontaneously, without needing to be told explicitly what to do. In this context, music and sound are particularly relevant as they might be rich sources of reward and pleasure (for an in-depth discussion, see [1])

In the present experiment we developed a sonification strategy which exploits the positive effects of music of music. Several authors reported the positive effects of music in sports and physical activities. In particular, music was shown to distract from fatigue and discomfort (Bood, Nijssen, Van Der Kamp, & Roerdink, 2013;Yamashita, Iwai, Akimoto, Sugawara, & Kono, 2006), enhance work output (Edworthy & Waring, 2006; Rendi, Szabo, & Szab, 2008), increase arousal (Szabo, Balogh, Gaspar, Vaczi, & Bosze, 2009; Karageorghis & Priest, 2012; Karageorghis & Terry, 2011), and boost mood states (Edworthy & Waring, 2006; Shaulov & Lufi, 2009).

As formulated in the theory of embodied music interaction [10, 11], listening to music generates motor coordination-inducing schemes that respond to external sensory sources in such a way that it allows auditory-motor alignment and even prediction of musical events.

We developed a system that uses music quality as reward, i.e. the correctness of the movement is rewarded by an improving of the audio quality of the feedback. More specifically in this specific case the unwanted movements: spine forward bending and barbell forward displacement with respect to initial position are mapped ,respectively into: a down-sampling of the music played and a forward panning and reduction of the active loudspeakers. Our hypothesis is that such system could be comparable to the verbal instructions by and instructor in terms of performances and that would be more motivating than standard verbal instruction because of the reward mechanism.

Apart from learning the technique the system could be used for advanced sporters to further improve their technique by discovering minor aspects of their movement that are not fully visible by eye.

Participants were randomly split into 2 groups: one group received only verbal feedback and the other group only sonic feedback during 10 deadlift repetitions. We compared them with a control taken as reference for the participant movement.

Results show that athletes can take advantage of the stimulus we provided, evidencing a higher average exertion of power in the experimental condition, compared to the control condition. Concluding, the results suggest that auditory perception can be a productive field of research in developing experimental strategies to improve athletes? skills.

Materials and Methods

Participants

Twenty-eight participants (11 women) took part in the experiment. The age range was 20 to 42 years (mean = 27.8). An exclusion criterion was having had injuries within the last six months previous to the tests that precluded sport activities. All the participants were trained in sports. In particular, 11 participants mentioned to have more than 2 years of experience with deadlift movements, 12 between 6 months and 2 years and only 3 declared to have less than 6 months of experience with it. The majority of participants (16) declared to mostly use music while training, 6 to train without music and 6 equally with and without music. Thirteen participants (46 %) declared to have received music education in their life.

The study was approved by the Ethics Committee of the Faculty of Arts and Philosophy of Ghent University, and all procedures followed were in accordance with the statements of the Declaration of Helsinki. All participants voluntarily participated; They were informed about the physical effort required for the experiment and that questionnaires could have contained personal questions. Participants received a voucher for a soft drink at the cafeteria of the library as small compensation.

Apparatus

The experiment took place at the IPEM-IDLab Art&Science Lab in De Krook library in Ghent. The lab has dimensions: 10 m x 10 m x 7 m height and is instrumented with an immersive sound system of 64 speakers, distributed all around the room at two different heights and ceiling. Eight Qualisys® infrared cameras were used for the motion capture (Mocap) recordings. A male barbell with 20 kilo's weights was placed at the center of the room on two protective hard foam pads. The cameras detected passive reflective spherical markers of 2.5 mm radius. Participants were equipped with a full body markers set-up, consisting of a total number of 22 markers. Trousers with a fixed configuration of 6 markers were provided to the participants (two different sizes were made available). Two straps with a single marker were placed on the wrists; a headset with 4 fixed markers and adjustable width was used for the head. A total of 10 markers were attached directly on the skin of the participant, using a biocompatible double sided tape by 3M®. Specifically 4 markers were attached on the spine at the height of the vertebras: L4, T12, T7 and C2. The larger spacing between the last two markers was chosen to account for the presence of sport tops used by female participants. Markers were also attached on the elbows and shoulders and on the front part of the feet. Four markers were placed on the barbell: two at the extremities and two on the clap next to the weight on one side only. Asymmetry was chosen to improve barbell model recognition. See images in Fig. 1 for visualization of the full positioning of the markers

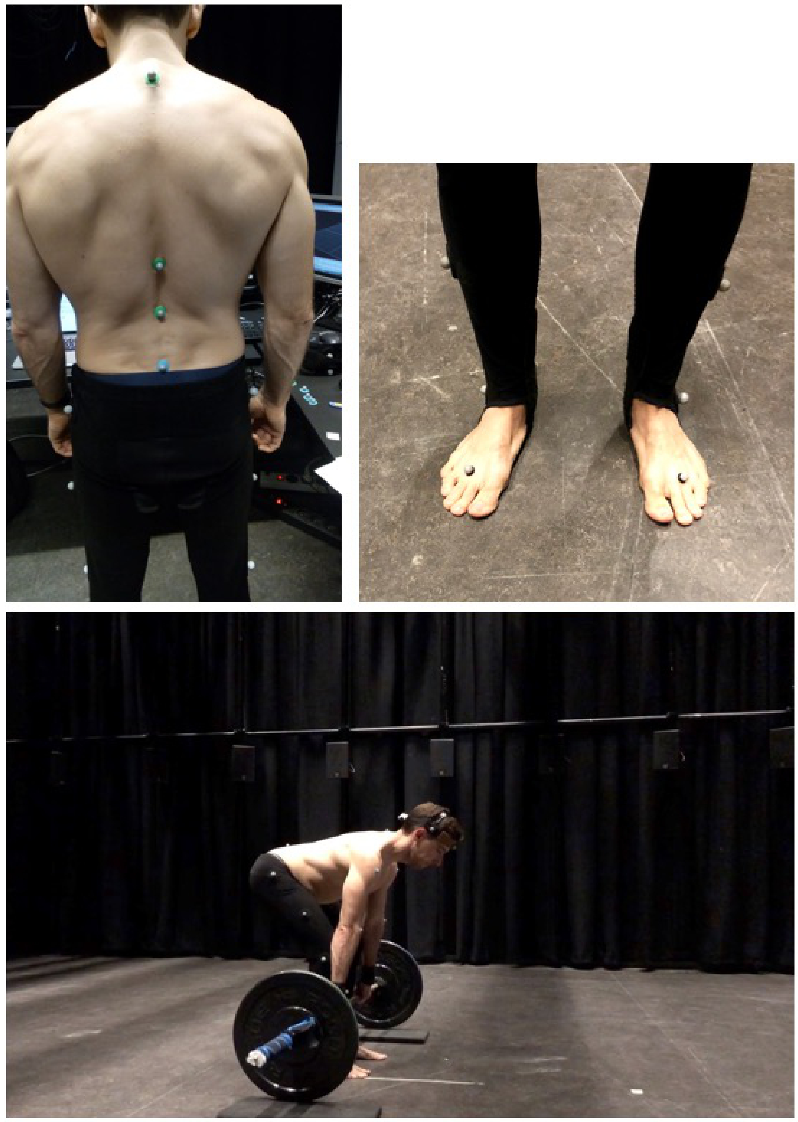

Fig 1. Mocap markers positioning

Mocap recordings were performed on a dedicated Windows computer. The system evaluated the 3D markers positions at a frequency of 100 Hz. These position were transmitted in real-time as OSC message to a custom-build Max4Live implemented as audio effect within Ableton Live® . The Max4Live patch was responsible for starting and stopping the music, providing the sonification based on the physical parameters and storing the data. A picture of the interface is provided in Fig 2

The Max4Live patch calculated the following quantities, used for the analysis and for

Fig 2. Interface of console computer running Ableton Live with house developed MAX4Live controller effect

sonification:

Spine bend The sum of the consecutive euclidean distances between spine markers: $spinebend = d0 + d1 + d2$

Barbell- foot (B-F) distance The planar distance between the line connecting the extremities of the barbell and the markers on the front part of the foot. The smaller of the two distances was considered.

These are shown in the sketch of Fig. 3.

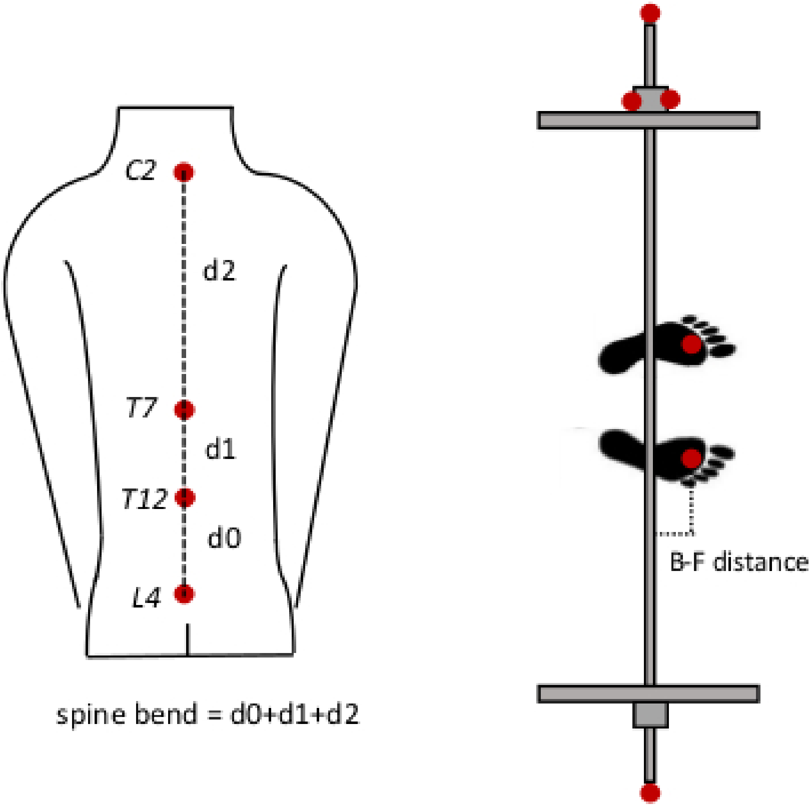

Fig 3. Mocap markers positioning

Experimental procedure

Once in the lab, participants received a written description of the experiment. They were asked to sign an informed consent form and fill in a questionnaire with general information about: gender, age, level of experience with weightlifting, music education, injuries. After that, a video was shown of an expert performing 10 deadlifts, in front and side view. It was explained that the focus of the experiment was on the neutrality of the spine during the movements and verticality of the barbell path.

Participants were then equipped with the markers set-up. The Qualisys software made used of a pre-trained skeleton model to recognize the body parts across different subjects. The correct markers labelling was checked at this stage.

One of the authors is certified Level 2 crossfit trainer and functioned as instructor during the experiments. A warm-up routine was provided by the instructor to all participants prior to the tests.

Before starting performing deadlift, reference parameters for each subject were recorded, specifically:

Neutral spine Participants were asked to grab the bar and keep spine in unloaded neutral position.

Max spine bend Participants were asked to grab the bar and slightly bend forward. The instructor was helping them finding this position letting them bend the spine up to incorrect but stil not dangerous position

Initial B-F distance Participants were asked to grab the barbell on the ground as they would start the movement and they were instructed that the barbell needed to be approximately in the middle of the foot. The initial distance between the barbell and the feet was then recorded.

Based on these values the Max4Live patch calculated in real-time the following non-dimensional quantities:

$$sb = \frac{spinebend - neutralspine}{maxspinebend - neutralspine}$$

and the non-dimensional barbell-foot distance:

$$bfd = \frac{BFdistance}{initialBFdistance}$$

Participants were informed that for correctness of the movement they were requested to keep the spine in the measured neutral position throughout the movement and that the barbell should remain at the same distance from the feet as measured by Initial B-F distance to ensure verticality of the barbell path.

The actual tests started with a serie of 10 deadlifts at own tempo, middle-low pace. This was taken as control condition for the analysis. Afterwards participants were randomly split into two groups, as homogeneous as possible in terms of gender, experience level and age (see sketch in Fig. 4).

One group of participants received verbal feedback by the instructor the other group received sonification as feedback. The groups are hereafter called *instructions group* and *sonification group*.

Participants of both groups were asked to perform 10 deadlifts for each of the following Points of Performance, in randomized order: *Spine*,*Barbell* and *Combination*

The test leaders informed the participant to only focus on the specific point of performance and that continuous feedback (either as verbal instructions or as sonification) would have been given if the movement was deviating from correctness.

The provided feedbacks corresponded to, respectively for the *instruction group* and the *sonification group* and for the specific point of performance:

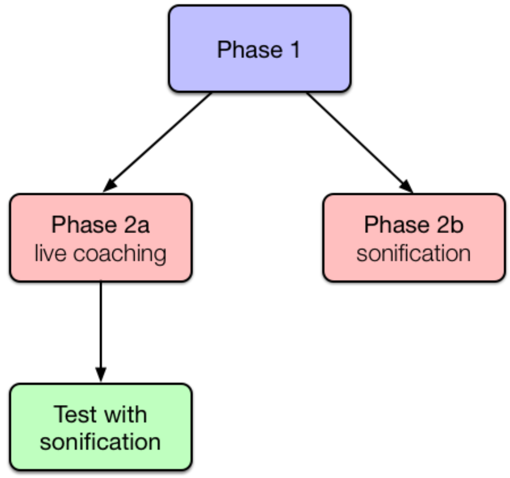

Fig 4. Scheme of the experiment design protocol

Instructions feedback In this case the instructor informed the participants as follows

I DO REALLY THINK THIS IS FOR YOU JACOB!

Spine: You will receive feedback on your spine position. If the curvature of the spine. remember the two cues you will receive are:

Barbell: Feedback will now be on. sonification remember the two cues you will receive are:

Combination: This is a combination of the two and you will receive feedback on both parameters the cues are the same as before

Sonification feedback

Spine: You

Barbell: sonification

Combination: a tempo synchronization condition based on the initial SPM of the runner

After each serie of repetitions, a break of 5 minutes was introduced to enable the participant to recover sufficiently. During the break they were asked to fill out a Rating of Perceived Exertion (RPE) questionnaire [13] and indicate how heavy the effort had been during the exercise, ranging from 6 ("no exertion at all") to 20 ("maximal exertion"). In addition, they rated the level of physical enjoyment of the previous run on the 8-item version of the Physical Activity Enjoyment Scale (PACES) [14], a single factor scale to assess the level of enjoyment during a physical activity in adults across exercise modalities. In order to test the motivational properties of the feedback, participants also performed a modified version of the Brunel Music Rating Inventory 2 (BMRI-2) test [15]. In this test, they were asked to rate on a 7-point Likert scale: clarity, pleasantness, accuracy, motivational properties and usability of the presented audio feedback. All questionnaires were implemented as Google forms on a dedicated Apple computer within the same room, only used by the participant.

Stimuli

Music In all conditions the same music track was played. The piece was specifically composed for this experiment by the authors. The music was composed respecting the following requirements:

- to be unknown, to avoid personal affection
- to be instrumental (no lyrics), to avoid focus on content
- to have a clear beat, in order to stimulate repetitive movements.

Sonification The sonification group received feedback on their movement performance through alterations of the baseline music track

More specifically, the implemented feedbacks consisted in:

spine bend Continuous variations of the sampling rate of the track music. Specifically, the non dimensional spine bend value *sb* was mapped into the following Sigmoid function.

$$y = 1 - expr1/(1 + pow(2.7182, -10 * (x - 0.2)))$$

The resulting value between (comprised between 1 and 0) provided the input of the effective sampling size of the "degrade " object implemented in Max4Live. The slope and ramp value of the Sigmoid function were determined in preliminary tests to ensure enough responsiveness of the feedback and margin for movement execution without distortion.

BF distance feedback Change in panning and number of effective speakers. The *bfd* was mapped through the following Sigmoid function

$$1 - expr1/(1 + pow(2.7182, -15 * (x - 0.6)))$$

The two stereo channels outputs of the Ableton Master track were mapped to different speaker configuration using Dante Controller software, using a Rednet connection The right channel was mapped to a speaker configuration surrounding the participant, while the left channel was mapped to only the 3 speakers in front of the participant. The output of the Sigmoid function in this case determined the gain of the Ableton right and left channels. This implied that if the value *bfd* moved towards 0 (i.e. barbell toward the foot) the gain of the left channel (linked to the three speakers in front only) was increased while that of the right channel (linked to the all surrounding speakers) was decreased. This implies volume reduction and directionality change, giving the effect to the participant that if the barbell moved forward only the forward speakers were active.

Data acquisition

The body markers positions were acquired by Mocap system on the Mocap computer. Recordings were made every 10 milliseconds and stored as .txt file on the control computer containing the following quantities:

- 3D marker positions
- *sb* and *bfd*
- distortion level
- system panning

A separate file was stored for each participant and each point of performance. The questionnaire information was directly put in the cloud.

Data analysis

The serie of repetitions were split into single deadlift movements by analisys of the vertical barbell displacement.

The mean

A preliminary analysis of normality of the data using Shapiro-Wilk test showed that the data

t-test

speak of power as the probability of not making a beta, or a "Type II" error, which refers to falsely concluding that there was no difference (e.g., between experimental and control groups) when in fact there was a difference, but the study failed to show it.

Results

Differences in performance between feedbacks

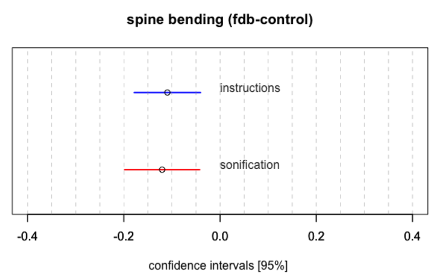

Fig 5. Differences between the instruction and sonification feedbacks

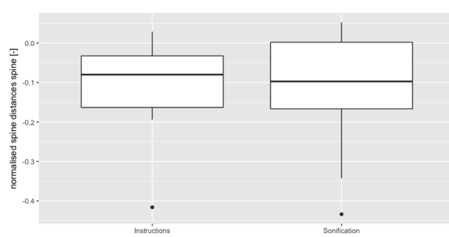

Fig 6. boxplot between 2 feedbaccks

Spine bend differences

Table 1. Comaprison of

	Point of Performance					
	Spine bend		Barbell distance		Combination	
Feedback type	mean	sd	mean	sd	mean	sd
Instructions						
Sonification						

Barbell horizontal displacement

Regression factors

Music education, experience level, gender effect over spine minus control and barbell minus control

A KS-test for normality revealed that g differences for Adaptive sync condition were normally distributed ($p = 0.06$) as well as for the Plus 30% ($p = 0.2$). The conditions Initial sync ($p = 0.022$), Minus 30% ($p = 0.016$) and No music ($p = 0.001$) were not normally distributed. Paired t-tests were performed on the normally distributed pairs, Wilcoxon tests on the non-normally distributed ones. A summary of the results is shown in Table **??** with effect size Cohen d for t-tests and Pearson correlation coefficient r for Wilcoxon tests:

Questionnaires information

Participants were asked to rate pleasantness and motivational effect of the different synchronisation strategies on a 7-point Likert scale.

No significant differences were found across gender and across training level of participants.

Discussion

In this case no effect of arousal produced by the acoustic stimulus was noticed compared to the no sonification condition. E certo se era distorsion!!

Portability of the system could be improved by adoption of current systems for back posture detection ViPerform tm Assessment Modules

Our hypothesis was is that such system could be comparable to the verbal instructions by and instructor in terms of performnces

Fritz *et al.* [9] distortion linked to agency positive feedback?

However no significant differences were found between the two feedbackss across participants in terms of pleasantness and motivational qualities: reasons could be

choice of music (elaborate) people used to having a coach people prefer human feedback

From Tate (2010) NO RETAINING TESTS in his study nor in present experiment Each biofeedback method appeared to result in moderate to large treatment effects immediately after treatment. However, it is unknown whether the effects were maintained. Future studies should ensure adequate randomization of participants and implementation of motor learning concepts and should include retention testing to assess the long-term success of biofeedback and outcome measures capable of demonstrating coordinative changes in gait and improvement in function.

Extend conversation to WELL-BEING also for PhD thesis

Conclusions

An experiment was performed to check the influence of different music synchronisation strategies on runner's foot strike impact. From the analysis, synchronisation seems not to lead to variations in impact level. However, music onset seems to cause an average impact level increase of 17% compared to running without music, irrespective of the synchronisation strategy. No significant difference in pleasantness and motivational effect were observed across the different synchronisation strategies, although phase alignment of the footfalls with music beats seems to be preferred by people with musical background.

Acknowledgments

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