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Benefits of crank moment sonification in cycling

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Abstract

In sports, the provision of augmented feedback is an important means to accelerate learning of new movements. Traditionally, concurrent augmented feedback has been provided verbally or visually. However, more recent studies have shown sonification of data during the movement, i.e. the mapping of a measured variable to parameter of sound, can be very effective to learn temporal aspects of a movement or movement patterns. In this pilot study, it was investigated if learning of complex pushing-pulling action applied to clipless pedals of a cycling ergometer can be enhanced by sonification of the crank moment. Three novice and three experienced cyclists were invited to train a reference crank moment pattern for two consecutive days (a total of twelve training sessions of 60 s each). However, in contrast to the results found in studies on rowing, the applied sonification did not enhance learning compared to visual and verbal instruction only. The lack of learning might be due to an inappropriate sonification design, short training sessions or the high task complexity. Extended studies are needed to draw more significant conclusions.

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Keywords: Augmented feedback; auditory feedback;sonification; complex motor learing; cycling

1. Introduction

In sports, many methods have been developed to accelerate learning of motor skills. Using technology to measure and evaluate performance has a long tradition. Many trainers and athletes use recorded data offline to identify potential aspects to improve. More recently, technical advancements allow the immediate display of kinematic and kinetic data which can also serve as the basis of concurrent augmented feedback. It has been suggested that the effectiveness of concurrent augmented feedback depends on different aspects such as skill level, movement characteristics, and feedback variables but further experimental work is needed to elaborate these assumption [see 1-2]. Therefore, In this study, the effectiveness of concurrent augmented auditory feedback in the form of movement sonification, i.e. the mapping of a measured movement variable to a parameter of sound, to learn a complex crank moment profile on a cycling ergometer is investigated.

In rowing [3] and swimming [4], movement sonification has been shown to be beneficial, which can be explained by audio-motor coupling [5]. When both the auditory and the motor systems are learned to be related, they are activated even when only the movement or only the sound are produced [6-10]. For learning sweep rowing in a simulator (body-arm rowing with one oar), the sonification of the oar movement in addition to visual feedback was more beneficial to learn a complex velocity profile than visual feedback only or visuohaptic feedback [11]. The sonification of the reference oar movement was displayed in one ear via headphones, whereas the sonification of the participant’s own oar was displayed in the other ear. Matching the sound frequencies that depended on the reference and own oar angles resulted in the correct movement velocity. It was concluded that the sonification facilitated the perception, retention, and recall of the velocity profile as it could be remembered as a song in mind.

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However, it has remained unclear if this approach can also be transferred to learning other cyclic movement patterns, such as a moment pattern when pedaling with clipless pedals on a bike.

Professional cyclists are able to apply a complex bipedal pushing-pulling action to the pedals that results – in an optimal case from a mechanical point of view – to only positive crank moments. In praxis, learning of this pedaling movement is typically attempted with verbal and visual instruction as well as verbal and visual feedback provided after a session, i.e. with so called terminal feedback. In this study, in order to learn such a crank moment pattern, augmented concurrent feedback was applied. As the movement is fast and cycling does not enable watching a screen while performing, auditory feedback was selected as the feedback modality. The auditory sense has a high temporal resolution [12-13] and the feedback can easily be provided by headphones while sitting on the bike. In an earlier study on cycling with clipless pedals, participants were encouraged to avoid negative moments through auditory feedback in the form of error sonification [14]. Positive crank moment was mapped to pitch, i.e. the pitch of a harmonic sound increased with increasing moment. Negative moment, i.e. the error, was mapped to noise, whereby the volume of the noise increased linearly with decreasing moment. Indeed, the participants improved during training, however, the performance dropped when the feedback was withdrawn.

Therefore, in this study, instead of error sonification, movement sonification was applied to facilitate the recall of the correct movement even when feedback was withdrawn. In contrast to error sonification, movement sonification is believed to be more beneficial for recall, as the correct "melody" is directly related to the correct movement [1, 11, 15]. The goal was to learn a reference crank moment pattern produced at the left pedal. It was hypothesized that displaying sonification of the own crank moment in the left ear and the reference crank moment pattern in the right ear accelerates learning – similar to the observations made for body-arm rowing [11].

2. Method

2.1. Participants

Six participants (21-27 years) took part in the study. Participants declared to be healthy and not to have any impairment that could influence the study. Three participants were expert cyclists (racing cyclists with more than 4 hours training per week) and had prior experience pedaling with clipless pedals. The other three participants were novices, i.e. they had no specific cycling experience and were not used to pedaling with clipless pedals. Two experts and two novices were allocated to the sonification group. One expert and one novice were allocated to the control group, i.e. they trained without sonification. The study was approved by the ethics commission of ETH Zurich (EK 2014-N-21).

2.2. Task and setup

The goal was to learn a reference moment pattern (reference movement) applied to the left crank at 140 W and 80 rpm which required a complex bipedal pushing-pulling action on a cycling ergometer (ergo_bike, 8008 TRS, daum electronic gmbh, Fürth, Germany) (

Fig. 1). The prescribed reference moment pattern was deduced from existing literature investigating elite athletes' performance [16-18]. As the goal of the study was to evaluate the potential benefits and effectiveness of sonification in cycling and not to find the optimal pedaling technique, the reference moment pattern resembled a complex pattern that could potentially be trained by cyclists using clipless pedals. This pattern might not be optimal from a biomechanical point of view.

Fig. 1. Instrumented ergometer with a cyclist wearing headphones

The ergometer was instrumented with custom-made pedals (Institute for Biomechanics, ETH Zurich, Switzerland) that measured the two-dimensional pedal forces in the sagittal plane, pedal angle, and crank angle. Cycling shoes for each rider could be clipped into the pedals (using Shimano SPD cycling cleats). Force sensors were based on strain gauges with an error of ± 2-4 % after crosstalk compensation. Absolute pedal angles were measured with non-contact hall effect sensors. Crank angle was detected every 4° by the use of diffuse contrast sensors with a pulsed red laser diode (OZDK 10P5101/5351, Baumer Electronics, Frauenfeld, Switzerland). Data was processed and logged with Matlab (MathWorks, Natick, MA, USA) at 200 Hz. Data was computed and sent to Pure Data (open source: www.puredata.info) at 60 Hz for sonification. Sonification was displayed through standard stereo headphones (Sennheiser HD 518, Sennheiser electroncic GmbH, Germany; frequency range: 14 Hz - 26000 Hz).

2.3. Sonification

The signal through the right earphone represented the reference moment pattern, whereas the signal through the left earphone represented the own moment produced on the left crank. The crank moment was linearly mapped to the frequency of a violin sound, e.g. higher crank moments resulted in higher frequencies. The frequency of a violin sound of the reference moment pattern ranged from 65.4 Hz (~C2) to 130.8 Hz (C3), i.e. spanned one octave. The goal was to match the frequency from the left earphone (representing the own moment applied with the left leg) to the frequency heard in the right earphone (representing the reference moment) using the frequency differential as feedback. The crank moment applied with the right leg was not sonified.

2.4. Experimental protocol

The experimental protocol included test or training sessions on three consecutive days. Each session was performed at 80 rpm and 140 W and lasted 70 s, where the first 10 s were used to accelerate to 80 rpm at 140 W. Each day started with a general instruction and a warm-up on the ergometer. After the warm-up on Day 1, participants were asked to perform their natural pedaling movement (baseline 1). Thereafter, the reference moment pattern was introduced by the instructor. The instructor verbally explained and presented the reference moment pattern to the participant (Fig. 2). Furthermore, the participants were introduced to the reference moment by showing a video animation pedal movement. This video coupled the sonification to the reference moment pattern for the sonification group – enabling the participants to associate frequencies to the crank angles. The video included two replays of a cycle at a lower velocity (~8 rpm) and four replays of a cycle at the real velocity (~80 rpm). The control group watched the video without sound (Fig. 2). The participants were asked to learn the reference movement on their left leg only – to reduce complexity of the task and feedback. However, it was explained that they could only produce the correct moment if they also performed the pattern correctly on their right leg as the cranks are coupled.

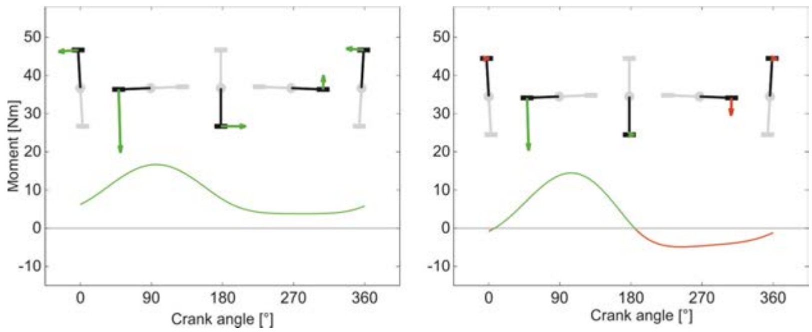

Fig. 2. Crank angle – moment plots used to instruct the participants to the reference moment pattern (reference movement). Crank and pedal are displayed in black (left) and grey (right); The magnitude of the moment at the current crank angle is indicated by arrows (vectors). Green arrows indicate positive moments, red arrows negative moments. The same abstraction of the crank, pedals and arrows was animated for the video instruction. Left: The reference moment pattern is plotted as a green line. Right: Example of a realistic but mostly incorrect performance.

After the instruction, a second baseline test was performed, where the participants were asked to reproduce the instructed reference pattern (baseline 2). After baseline 2, a familiarization session was conducted in which the sonification group was given 30 s of pedaling with hearing the reference sonification only followed by 30 s of hearing both, reference and own sonification. The control group was allowed to try to produce the pattern for 60 s without sonification. Thereafter, three training sessions, a retention test, another three training sessions and another retention test were conducted. The same procedure was repeated on day 2 after a retention test (excluding the familiarization). On day 3, a retention test was performed as well as a transfer test, where participants were asked explicitly to reproduce the reference moment pattern on the right pedal (Table 1).

Table 1. Experimental protocol. WU: Warm-up; BL: Baseline; INST: Instruction of reference moment pattern; FAM: Familiarization; TR: training session; RE: Retention test; TF: Transfer test to right leg. Each session as well as breaks between each session lasted 60 s.

Day 1	WU	BL1	INST	BL2	FAM	TR1	TR2	TR3	RE1	TR4	TR5	TR6	RE2	
Day 2	WU			RE3		TR7	TR8	TR9	RE4	TR10	TR11	TR12	RE5	
Day 3	WU			RE6										TF

2.5. Data analysis

Cycles beyond 80±5 rpm as well as the first 20 cycles and last ten cycles were removed from the analysis in order to only evaluate cycles in steady state pedaling. The error between the reference moment and moment produced by the participant was calculated at each crank angle, i.e. every 4°. Results from a previous pilot test as well as feedback from the participants of the current study revealed that participants tend to focus more on certain phases of the pedaling cycle than on others. Therefore, cycles were further divided into quadrants. The "+ division" cut the cycles at 0°, 90°, 180°, and 270°. The "x division" cut the cycles at 45°, 135°, 225° and 315°. The mean error of the entire cycle ("error entire cycle") and quadrants was calculated for each cycle. Due to the small group sizes in this pilot study, statistical analysis was not performed. The statements of the participants regarding the experiment and feedback were protocolled.

3. Results

3.1. Moment error entire cycle

Two of the six participants decreased the error from baseline 2 compared to the subsequent retention tests, i.e. the novice participant in the control group (Fig. 3a) and one expert participant in the sonification group (Fig. 3e).

The two novice participants in the sonification group reduced their error entire cycle from baseline 1 to baseline 2 distinctly, i.e. from pedaling without previous instruction (except for frequency, i.e. 80 rmp) to pedaling after the introduction to the reference moment pattern (Fig. 3b, Fig. 3c). They did not improve with further training (Fig. 4).

One expert participant in the sonification group reduced the error from baseline 2 to the retention 1 test after the first three trainings (Fig. 3e). Thereafter, the error increased again slightly and continuously towards the end of the study (Fig. 3).

The moment error on the right leg, in general, seemed to neither increase nor decrease along the training sessions. However, the error seemed to drop marginally in five of six participants when they were asked to focus on the right leg in the transfer test compared to the last retention test just before, where the focus was on the left leg.

3.2. Moment error quadrants

One novice participant and one expert participant in the sonification group tended to improve from baseline 2 on day 1 to the retention test on day 3 regarding the error in the quadrants 180°-270° and 135°-225°. No further effect of training group or learning was observed.

3.3. Participants statements

Some participants were commenting on the study and sonification (Fig. 3). Two participants stated that performing the pushing-pulling action at 80 rpm and 140 W is unnatural, i.e. the movement is too slow and the resistance too low (Fig. 3a and Fig. 3e). The novice participant in the control group (Fig. 3a) and an expert in the sonification group (Fig. 3e) focused more on the timing of the peak moment than on the magnitude of the peak moment or entire pattern. Two of four participants in the sonification group (one novice, Fig. 3b, and one expert, Fig. 3f) reported that the sonification was not very motivating. For the same novice, the training sessions with the sonification were too short to be able to profit (even though he performed quite well, Fig. 3b).

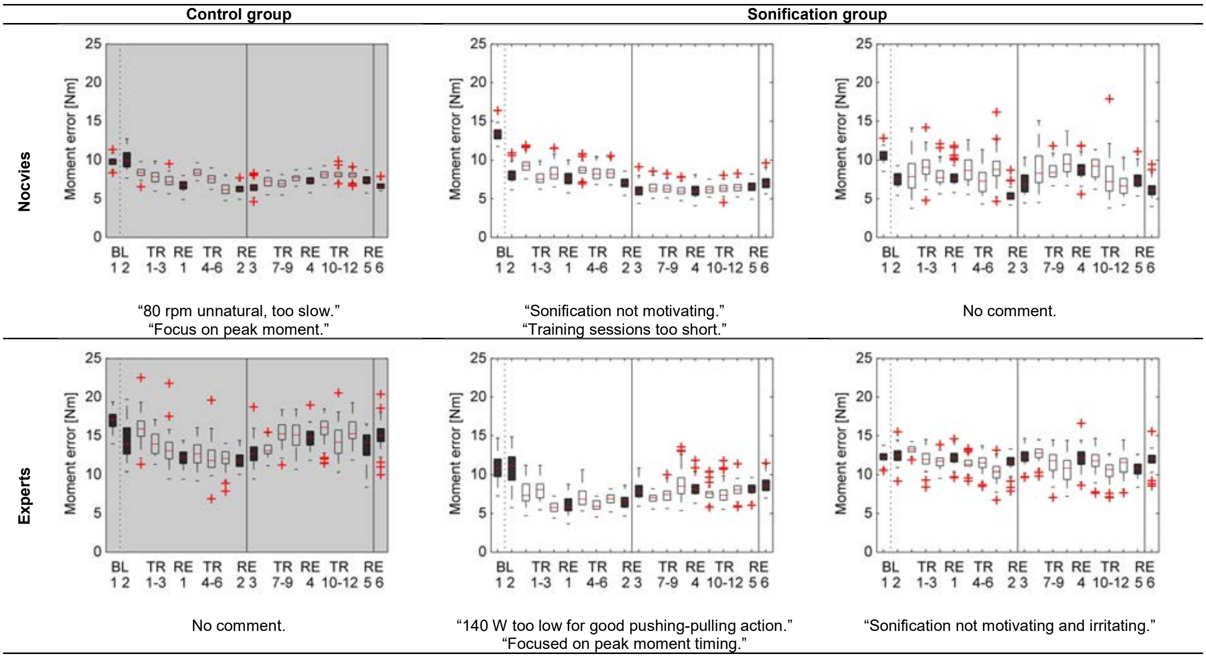

Fig. 3. Error entire cycle from the left pedal of all six subjects of all sessions of the three days including subjects statements after the study. Top row: Novices; Bottom row: Experts; Gray background: Control group; White background: Sonification group. Black boxplot boxes: Baseline and retention tests; Clear boxplot boxes: Training sessions.

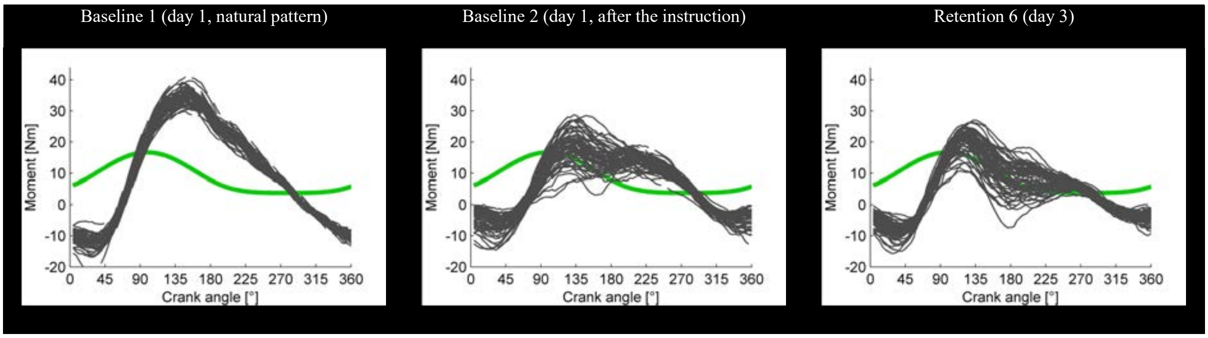

Fig. 4. Exemplary plots showing crank angle to crank moment for each cycle of a session of the participant of the sonification group that rated the sonification not to be motivating (left pedal). Green thick line: Reference moment pattern. Black thin lines: participant's moment pattern.

4. Discussion

Based on own studies in rowing that showed sonification to be very effective to learn movement velocity profiles [sigrist2015], it was hypothesized that sonification is also beneficial to learn a crank moment profile (pattern) in cycling with clipless pedals. However, the similar approach in this study in cycling led to no effect.

One reason for the lack of benefits could be that the pedaling movement in this study was more complex than the previously used body-arm rowing with one oar [11]. The pedaling movement in this study required a bipedal coordination and was much faster. Furthermore, the given resistance at the pedals seemed to be too low for the experienced cyclists. This could result in quite turbulent sonification which might have been hard to listen to and compare to the reference sonification. As a consequence, the reference sonification was hard to be matched by applying required moments, difficult to keep in mind and recall as a "melody" – i.e. the beneficial mechanism of sonification did not come into play. Moreover, for the experts, it might have been challenging to adapt their internalized pattern to the reference pattern – consequently, the errors of the experts were as high as the errors of the novices.

Another reason for the lack of learning with sonification could be the short training time. As stated by one participant, training sessions were too short to understand the sonification and benefit from it. Moreover, it remains unclear how difficult it was to learn the movement. It might be that learning the reference pedaling movement needs *per se* much more training sessions. In future studies, it should be evaluated beforehand which reference pattern is realistic to be learned within a defined number of sessions.

Finally, it could be that sonification in general is not beneficial for learning crank moment patterns, or, the applied mapping functions or sonification design were not adequate. As a first step to learning the complex pedaling movement, it might be more effective to guide the focus to certain aspects of the movement [19], i.e. timing of peak moment or avoiding negative moments. Such a breakdown method could be combined with different auditory feedback designs, which need to be developed.

5. Conclusion

In rowing, sonification of the oar movement has been shown to be effective to learn temporal aspects of a movement. In this pilot study on cycling, the provision of sonification of the crank moment did not further facilitate learning of a predefined moment pattern after a visual and verbal instruction. The study design of this pilot experiment may benefit from an adaption of the pedaling resistance and pedaling frequency, the sonification design, or by selecting other aspect of the pedaling movement to be learned. An improved study design may allow drawing more sophisticated conclusions on the effectiveness of a sonified moment pattern on motor learning.

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