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EXPLORING FUNCTION AND AESTHETICS IN SONIFICATIONS FOR ELITE SPORTS

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ABSTRACT

The potential for real-time sonifications to enhance attention for specific movement sections in athletics has led to a growing interest from the elite sports community. Early examples of sonifications for swimming and (ergometer) rowing have demonstrated the functionality of this idea. These pioneering sport sonifications use simple sine-tones to achieve real-time responsiveness. However further improvements in technology will enable more complex sounds to be synthesised, opening up the design possibilities. During the COST-SID workshop on sonification, different design possibilities were explored using the rowing movement and data as a case study. The results identify the potential to include the motivational and physiological aspects of music and the richness of natural sounds. In further related work the initial sine-wave sonification was trialed in action with rowers on the water with improvements in speed demonstrating the effectiveness. Responses to a questionnaire about the sound indicate that functionality is a primary dimension in the aesthetics of a sonification in elite sports. The results from the workshop combined with the questionnaire identify many issues and raise many questions about function and aesthetics in sonifications designed specifically for elite sports applications.

1. INTRODUCTION

Michael Phelps (multiple gold medallist winner in Athens and Beijing) listens to music as part of his preparation for a race.

"I like to get in my own world. When I'm getting ready for a meet, I always have headphones on, listening to rap music to get myself fired up".

Athletes listen to music prior to competition to relax, metnall prepare [1], and to facilitate a state of "flow" [2]. Music has physiological effects on heart rate and adrenalin levels, and can be a stimulant [3]. Music can be motivating and extend endurance during an exercise session (for example during a marathon run) [4], diverting attention from fatigue and altering perceptions of exertion during workouts. Music is integral to the sequencing of routines and coordination of team activities in gymnastics, competitive dancing, and synchronised swimming.

Movement and sound are naturally bound together [5] athletes often use these sounds as sources of information. For example a tennis player can anticipate the speed of the return volley from the sound of the opponent's stroke. Elite rowers listen to the boat moving through the water to adjust their motion sequence, and there was a reduction in performance when they wore earplugs [6], [7]. Sound also animates movement in time to a beat. The high temporal resolution of human hearing [8] enables humans to hear very specific information about the timing of movements, and to synchronise movements with sounds [9]. The ears lead the eyes, and people respond to sudden sounds behind them by turning to see what happened. Humans listen all the time in order to navigate through the environment. The sounds of moving things and kinetic events are a "natural music" that could be thought of as "the soundtrack of everyday life".

Technological developments have enabled simple sounds to be synthesised in real-time on mobile devices. This in turn has allowed information from sensors such as accelerometers, GPS, force, flex, heart-beat and breathing to be sonified in real-time. The potential to use these sonifications to enhance attention in athletics has led to a growing interest from the elite sports community. Early examples of interactive sonifications for swimming and (ergometer) rowing have demonstrated the effectiveness of this idea [5]. Recent advances in audio technology make it now possible to synthesise more complex sounds on mobile devices, opening up a wide space of possible sonification designs.

This paper describes a workshop in which eight researchers produced different sonifications of data from a study with elite rowers. The sonifications were not constrained by the current technological limits of mobile devices, and serve to explore designs that could be deployed on mobile platforms in the future. The following section provides background on the state of the art in the sonification of rowing. The following sections describe the sonification workshop and the sonifications that were produced. The discussion compares and contrasts the different sonifications, and identifies different theories and approaches. This analysis lays a foundation for furthering the theory and method of sonification design with a particular focus on applications in elite sports.

2. BACKGROUND

A pilot study was conducted with elite junior athletes (*N*=8) and their coaches. In the first part of the study the athletes and coaches were shown a video of a training run synchronized with the sonified sound sequence.

The sonification was produced from kinematic parameters (propulsive boat acceleration and horizontal boat velocity) measured during training sessions. An acceleration sensor and global positioning system (GPS) were used to measure the movement of the boat at different stroke rates. The acceleration traces were converted into auditory information using a measurement and feedback system called Sofirow (BeSB GmbH Berlin) [7], [10]. This system maps numerical data values to pitches in the western music scale using a technique known as parameter mapping sonification [11]. As the acceleration increases the pitch of the sine tone increases, and as the acceleration decreases the pitch decreases. The point of zero acceleration is at MIDI note 60 (or Middle C = 261.63 Hz) so that positive acceleration varies above this pitch and negative below.

The rowing stroke, as a cyclic motion, has characteristic repetitive phases in the acceleration trace that divide into four sub-phases: front reversal (fr), drive (d), back reversal (br) and recovery (r). Figure 1 shows two acceleration traces for six selected rowing strokes at 36 and 24 strokes per minute in which the curve characteristics became evident. The stroke rate steps (18-36 strokes per minute) differ significantly (p=0.00). Therefore the acceleration trace differentiated the rhythm of the rowing cycle according to the intensity: with increasing stroke rate the boat velocity increased as well (3.9 – 5.4m/s) (table 1).

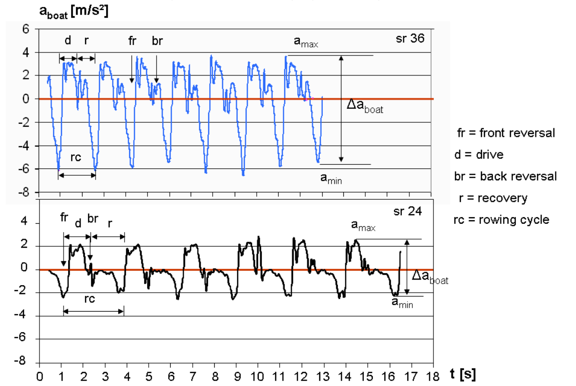

Figure 1: Acceleration traces of six selected strokes (36 and 24 strokes per minute).

Table 1: Selected stroke rate steps: stroke rate (s) and boat velocity (v).

	sr [strokes/minute]		v_{boat} [m/s]	
sr-steps	mean	sd	mean	sd
18	20.6	0.3	3.9	0.5
20	21.1	0.9	4.0	0.5
22	21.8	0.9	4.2	0.6
24	23.8	1.6	4.4	0.6
30	29.3	2.1	5.0	0.8
36	35.1	1	5.4	1

The athletes commented they could hear reversals in the acceleration trace that were not visible in the video. These reversals produce an inefficient transfer of energy that slows the boat. The athletes generally agreed that real-time sonification feedback could enhance awareness of the reversals and allow better coordination of movements to reduce this effect [7].

Although these comments indicate the potential for sonification in this domain there are also other considerations that arise from longer-term experience. In his analysis of his early studies in the sonification of sports Effenberg comments that “A sound quality must be realized which is individually perceived as pleasant. If possible, the targeted person’s musical taste has to be accommodated for.” Following this suggestion, Henkelmann proposed that “more aesthetically acceptable audio results are a necessity if sonification is to gain a wide acceptance as a common tool in data exploration. In the context of sonifying motion data this is even more pressing. If sonifications are to be used as regular tools in rehabilitation for physically impaired persons, or as an additional training aid for athletes, audio results have to be at least bearable if not enjoyable on a regular basis” [12]. Henkelmann explored a wide variety of sound synthesis algorithms for the sonification of realtime motion data streams that included Subtractive Synthesis, Waveshaping, Frequency Modulation, Formants, Tristimulus Model and Spatial Positioning. He concludes that these approaches do produce more aesthetically pleasing sonifications, but cautions the need for user evaluation of functionality in a task setting. He also notes that there are many other techniques to be tried, such as granular synthesis, and effects such as flanging, phasers and chorus, reverb and echo.

3. SONIFICATION WORKSHOP

The COST-SID [13] workshop on sonification was held at the T-Labs (Technical University (TU) of Berlin) in June 2009. The workshop brought together a group of twenty researchers for an intensive three day open ended hands-on exploration of the state of the art in sonification [14]. The sine-wave sonification of rowing data was taken as starting point for a collaborative investigation but one subgroup of researchers. This subgroup began with a presention of the rowing scenario, the sensors and data, and the previous sonification videos of a training session with the responses of the athletes and coaches. The participants then explored different theoretical perspectives, technological approaches and aesthetic responses to the sonification of this data. Together they produced six new soundtracks for the rowing video that can be accessed online at [14]. These sonifications tease apart approaches to sonification that have previously all been considered as parameter mapping. They also raise further questions about the aesthetic aspects of sonification that go beyond pleasantness.

* Xylophone MIDI-fication (Anton Schertenleib, Nina Schaffert, Stephen Barrass)
In this example the sine-tone was replaced by a MIDI Xylophone instrument, but it could have been any of the 128 instruments in the MIDI set. The Xylophone was chosen because it has a short envelope suited to rapid playback. Another instrument could also be used to distinguish negative acceleration from positive. The use of timbre to overlay task related categorical information on a continuous dataset is described in the TaDa method for Auditory Information Design [15]. The introduction of timbre also raises the question of whether a particular musical instrument has an effect on the acceptance or functionality of a sonification? Do athletes in different sports prefer different instruments?

* Ear-Training (Hanna Buhl and Georg Spehr)
The acoustic ecology movement teaches how to attend and observe the soundscape through a technique known as “ear-cleaning”. The training of listening attention could be very helpful in sports activities such as rowing where the eyes are already busy. The audio recording of the rowing skiff on the example site [14] is full of sounds produced by moving through the water: the oars, the rowlocks, the seats and the physical exertions of the athletes. This raises the question of whether training to listen to auditory cues about synchronicity, rowing motion, and acceleration that are natural consequences of rowing could be used to enhance rowing performance?

* Ecological Sonification (John Williamson, Roderick Murray-Smith)
The natural sounds in the boat can provide a basis for ecologically inspired auditory metaphors in a sonification. The example sonification uses simulations of water

splashing, and impacts on wood and metal that convey a the metaphor of rowing. The physically-based sound models of splashes and impacts are triggered by turning points and thresholds in the acceleration data. This sonification is founded on a theory of ecological perception similar to Auditory Icons.

* Techno-Music Probe (Stephen Barrass)
The soundtrack is a piece of techno music artificially generated with 152 beats per minute (bpm) in order to synchronise with the movement of the oars at 38 (x 4 = 152) strokes per minute. The percussion beat syncs with the strokes while the changes in pitch correspond with the drive and recovery phases. This soundtrack demonstrates the possibility to use a pop-music metaphor to convey functional information, whilst also raising the possibility that the sonification could be emotive and motivating. The musical approach also opens up possibilities for sonic branding, personalisation and representation of team or national identity.

* Music-ification prototype (Stephen Barrass)
The Music-ification prototype is a further development of the Techno-music probe in which the data is mapped to an array of synthesiser instruments with more control parameters than sampled musical instruments. This example develops the musical concept further by introducing changes in the sonic mix at the beginning, middle and end to reflect stages in the training run. This narrative approach could involve distinct musical verse/chorus or other structures to organise and sequence a training routine. Alternatively different musical stages could be triggered by a combination of features in the data.

* PAF Streaming (Reiner Gehret and Stephen Barrass)
This sonification develops on Henkelmann's experiment with the Phase Aligned Formant (PAF) synthesiser. The acceleration maps to tone pitch (as before) while in addition, the derivative of acceleration maps to both the width and centroid of a vocal formant. This causes moments of rapid changes in acceleration (or jerking) to emerge as a distinctive figure against the smoother bass ground. This approach begins to move beyond musical ideas of instruments with pitches towards more dynamic perceptual figure/ground as a basis for sonification [16].

4. POST WORKSHOP

Since the workshop, a further study with the German junior national team (*N*=21) was conducted using the real-time sine-tone sonification presented over headphones in on-water training sessions (during preparations for the world championship). The rowers responded positively to the headphones and liked the idea of wearing them during the training session. They were also shown the synchronized video of the training run and were given an explanation about how the sound was related to the movement of the boat. In the trials the rowers found that the section of the front reversal was clearly identifiable and tried to keep the moment in which the sound went down in pitch as short as possible. An increase in the velocity of the boat with the sonification indicates that it is providing useful information for the rowing task.

The responses to a questionarre about the sonification were also very positive with almost uniform agreement that the sonification is conveying boat motion, focusing attention, and has application in on-water training as shown in Figure 2.

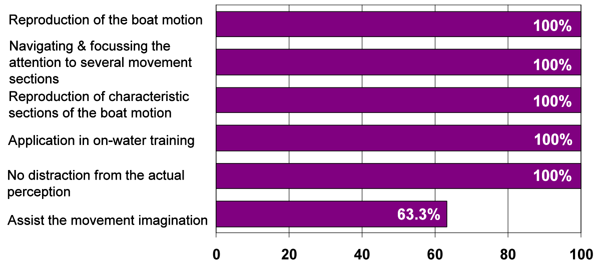

Figure 2: Percentage of answers (athletes' questionnaire).

Individual responses from the athletes included:
Question: Please describe how you perceived the sound result?

"I really liked the sound."

"...it was not displeasing or disturbing."

"... the sound was helpful."

"... new, the feeling for the rhythm was enhanced."

"... it is very easy to link the sound result to the pressure curve during the drive phase."

"The sound represents the movement appropriately – therefore aesthetic aspects are second ranked for me."

"... direct feedback of the boat motion and, because of this, the boat run changed for the better and the total feeling during rowing was better than without the sound."

Question: How would you change the sound?

"Exactly like the one we've heard."

"I wouldn't change it."

"The sound wasn't annoying. I wouldn't wish something else."

5. DISCUSSION AND CONCLUSION

The post workshop study with real-time sonification on the water has demonstrated the functionality of the sine-wave sonification. The recovery and the front reversal were clearly identifiable and well suited for adjusting the movement to extend the sound and make the moment in which the sound run off as short as possible. The resulting increase in boat speed is evidence for the effectiveness of the sonification.

The explorations in the workshop also developed other ways that the sonification could provide additional functionality. The Xylophone MIDI-fication introduces the potential to draw attention to the difference between positive and negative acceleration. The ecologically based sonification explores the idea that important turning points in the data could be emphasised using natural sound metaphors linked to rowing. The music sonifications explore the potential to provide sequential information about different stages of the training run. The PAF sonification explores the potential to provide layers of information that draw attention to jerkiness as well as the stroke phase in a more complex and dynamic way. Further real-time experiments with rowers are needed to evaluate whether these extra kinds of information have an effect on performance.

The athletes in the post-workshop trial also found the sine-wave sonification to be pleasing. These comments indicate that functionality may be a primary aspect in the aesthetic appreciation of sonification in elite sports. This raises the question of whether the correlation between function and aesthetics is particular to elite sports, or does it extend to other competitive sports, and recreational sports as well? What is the difference between the aesthetic appreciation of a sonification before and after actual use in a real sporting situation? Is functionality the only thing that matters? Does the sound affect acceptance? And does it affect longer term usage? Do the aesthetics of sonification include the psychological and emotional effects that music has on athletic performance? Does the way the sonification sounds beyond the information content have any effect on performance? Should sonification have a specific sound of its own that is readily distinguished from music or natural sound? Should sonifications for different countries (or cultures) sound different?

In further work we will present other versions to the athletes. If the information can be conveyed clearly and comprehensibly, a more musical approach opens the possibility to combine the advantages of auditory feedback [9] with listening pleasure, as well as introducing emotive effects, narrative sequencing and other aspects that relate to music in sports.

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** Percentage descriptions must be interpreted in relation to the number of tested subjects.*