TESTING DIFFERENT VERSIONS OF FUNCTIONAL SONIFICATION AS ACOUSTIC FEEDBACK FOR ROWING

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ABSTRACT

A concept for providing online acoustic feedback during on-water rowing training sessions was developed, empirically investigated with elite athletes and a training procedure was successfully implemented into the technique training of the German Rowing Association. The sound sequence of the sonified boat-acceleration-time-trace presented was proven to be functional and supportive for rowing strokes within the regular basic training frequency (±20 str./min.). But it was found, that with higher stroke frequencies (>24 str./min.) its acceptance for use in training decreases due to the pitch-related direct data-to-sound-mapping. Simplified: with increasing boat acceleration, tone-pitch increased as well.

This paper describes the use of three different sonification versions and their perception and acceptance when presented offline to elite athletes. The mapping of the original sound version used so far in technique training of elite athletes was taken on the basis of a dataset from the German men's Eight at stroke frequency 24 str./min. and modified to two further sound versions for producing a sound sequence that could be used as well for higher stroke frequencies. Special focus was set on reducing the very high tone-pitches that occur during the drive phase of the rowing cycle when the boat acceleration markedly increases. The results of the post-produced sound were described and elite athletes were asked about their subjective perception of its impact on them.

1. INTRODUCTION

The theoretical basis for the concept of acoustic feedback in high performance rowing as well as a specially developed training procedure for on-water rowing training with *Sofirow* - the acoustic feedback system- has previously been described and was empirically investigated with the German national rowing team [1]. Thus, the rhythm of the rowing cycle was provided audibly by sonifying the boat acceleration-time trace using a direct data-to-sound-mapping related to tone-pitch. In doing so, the tone-pitch of the sound sequence increased the more the boat was accelerated [2]. Tiny changes, normally invisible to observation of the boat traveling through the water, became manifest in the sound owing to the characteristics of the auditory sensory system. In comparison, processes of observation are limited in this regard as it is in principle very difficult to detect visually dynamic aspects. The forces originating from movements can only be estimated qualitatively by kinematic observations such as changes in displacement or location and material deformations. Although the differences were tiny within the context of the rowing movement, they affect the boat motion importantly [3]. By acoustic presentation of the boat's acceleration-time trace, the information contained in the captured-data became intelligible to the athletes, directly and intuitively, and athletes perceived the single rowing cycle as a short sound sequence. Periodic recurrence of characteristic sections within the rowing cycle represented the rhythm of the rowing cycle and awakened sensitivity for details in the sequence without further explanations needed.

Recent investigations of sonification of boat acceleration mainly focused on the recovery phase of the rowing stroke cycle as the sonification was found to be especially supportive for it as the most critical phase of the rowing cycle in terms of the boat run as there is no propulsion by the blades. By coordinated movements of the athletes, the boat is released to run forward during the recovery after the athletes extract the blades from the water and slide on the seat in the direction opposite to the boat's forward motion. Thus, the whole system is decelerated during the recovery. Sonification can provide detailed information about the athletes' movements and its execution during the recovery as well as for the time needed for execution of the reversal points (catch/finish turning points in the rowing stroke cycle). The acoustic feedback makes it possible for the athletes to adjust the movement more precisely.

The practical and supportive effectiveness of the concept have been proven for rowing stroke cycles at a regular basic training frequency (approximately 20 str/min. up to a maximum of 22 str/min.) [4]. It was found though, that with higher stroke frequencies (>24 str./min.) the acceptance (and thus the effectiveness) for use in training of the acoustic feedback decreases. This is because of the data-to-sound mapping. Higher stroke frequencies correlate with an increase in boat acceleration and thus, with a higher tone-pitch which reaches its maximum in the middle of the drive phase. Up to now, the high pitched sound during the drive phase of stroke frequencies >24 str./min. is disadvantageous because it was perceived from the athletes to be unpleasing and irritating.

This paper describes the exploration of two sound sequences that were modified from the original version used so far in technique training of elite athletes. On the basis of a dataset from the men's German Eight at stroke frequency 24 str./min. the modified sound sequences aimed at producing a sound sequence that could be used as well for higher stroke frequencies. Special focus was set on reducing the very high tone-pitches that occur during the drive phase of the rowing cycle without losing the functionality and effectiveness of the resulting acoustic sequence, whilst trying to eliminate the above mentioned unpleasant aspects of the sound. It was found in earlier studies that for the athletes, prevailed over aesthetic aspects among the athletes. When using sonification as an acoustic feedback in technique training of elite rowers, it is important to represent the measured data and its structure meaningfully without losing any inherent information.

The effects of different sonification versions on athletes listening to them offline (not whilst in action) in comparison to the original version were explored and elite athletes were asked about their subjective perception of the sensation.

2. METHOD

2.1. Characterization of the rowing stroke cycle

Owing to the athletes' movements, the rowing stroke cycle is divided into two main phases: drive and recovery during each phase different forces acting on the system (boat and athletes). The measured acceleration-time trace of the boat reflects all forces acting externally on the boat during its travel through the water, including more specifically aerodynamic and water forces as well as muscular forces by the athletes. Its influence on the mean boat velocity is important as it reflects propulsive and decelerating forces. Propulsion occurs solely during the drive phase when the oar-blades are placed below the water surface and the athletes exert a net accelerating force on the boat. This dynamic framework determines the characteristics of the boat-acceleration-time trace and its separation into the different phases. The result is a clear increase in the boat acceleration as a consequence of the athletes-generated forces acting on swivel, foot-stretcher and sliding seat as well as external forces by the oar-blades. This net process accelerates the whole system (boat and athletes) in the propulsive direction up to the point of maximum boat acceleration in the middle of the drive phase, in which the high tone-pitch sound occurs.

Figure 1 illustrates the sound-critical section (highlighted) within the rowing stroke cycle according to the structure of the acceleration curve.

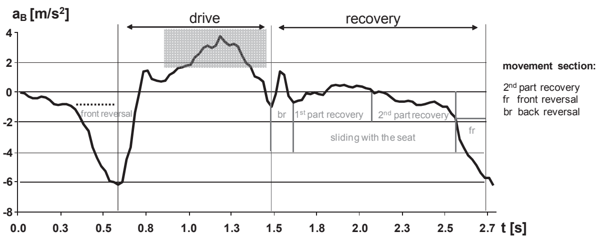

Figure 1: Intra-cyclic characteristics of the boat acceleration-time trace with the sound-critical section (highlighted).

2.2. Participants

The athletes (*N*=41) participating in the questionnaire were members of the German Rowing Association (DRV) in different squads (belonging to the A-squad (National Team), B, C, DC and S-squad).

2.3. Design of the sound sequences

On the basis of the original sound sequence, that was created as an acoustic representation of the kinematic parameter of the boat acceleration-time trace with its characteristic and recurring events within the rowing cycle, the resulting sound was presented as continuous acoustic feedback rather than presenting audibly only single events such as minima and maxima, etc. Thus, the sound result was created by an algorithmic transformation of the boat's acceleration-time-trace (measured with an MEMS-acceleration sensor), derived from its physical parameter using the sonification method of Parameter Mapping [4] with the software Pure Data (pd) [5]. Parameter attributes (frequency, amplitude, etc.) were mapped by numeric values of the given data vector. Thus, each piece of acceleration data was related to a specific tone on the MIDI-scale and related to tone-pitch. Every integer (whole number) equated to a specific semitone. The point of zero acceleration was at middle C on the tone scale (261.63 Hz). Consequently, tone pitch changed as a function of the measured boat's acceleration-time trace [6]. The original sound sequence was labelled in this paper as *Sofi_post_norm* (*norm* referring to the standard version) for a distinction between the two other versions.

Both modified versions were created according to the same procedure that was used for *Sofi_post_norm* but solely as post-produced sounds (offline mode). Creating a more musical sounding acoustic result would include multiple overtones (harmonics) and thus it would obliterate differences in the underlying data as changes in tone pitch would be interpreted as changes in the acceleration-trace. Thus, the original sound version was minimally modified using defined filters and sound version 1 and 2 were created. The three sound versions are briefly described below.

2.3.1. Modified sound version No.1

The first modified sound version, labelled as *sofi_post_min* (*min* referring to minimum), a threshold value was defined, that cuts all tones exceeding this data limit. Several options were explored with thee chosen athletes to find an accepted threshold value according to their aesthetic preferences. Finally, the limit was set at the value of 800 (frequency). When the threshold value was exceeded, a continually sounding threshold tone was emitted as soon as the data crossed the defined cut-off-point. The advantage here is that the timbre lies within the useful range (below the threshold) and does not change.

2.3.2. Modified sound version No.2

The second modified version was labelled as *sofi_post-lp* **(***lp* referring to low pass**)**. Therefore, a classical low pass filter was implemented to dampen the acoustical signal (cut-off frequency). The advantage of this version is that the signal curve (tone-pitch) corresponded exactly to the acceleration curve without the unpleasant high tone-pitches.

2.4. Investigation procedure and analysis

The different sonification versions were presented offline to the athletes via loudspeaker in the laboratory. They could listen to the versions as often as they wished and needed, for preference evaluation. The original sound version was presented first, followed by the modified sound version Nos.1 and 2.

Acoustic properties of the audio files were analysed in terms of their acoustic properties with spectrograms (also known as sonograms) in order to visualize the spectrum of frequencies in the different sound versions. Spectrograms were commonly used to identify acoustic signals for analyzing their spectral density over time [7]. In the most common format, a graph is displayed with two axes, the horizontal axis representing time and the vertical axis, frequency; a third axis indicating the amplitude of a particular frequency at a particular time is represented by the intensity or colour of each point in the image. The spectrograms were created with the software Adobe Audition 3.0.

Finally, the perception of the different sound versions was requested with standardized questionnaires. The results were analyzed and described.

3. RESULTS

3.1. Acoustic properties of the sound versions

The results of the visual comparison of the three sonification versions with the spectrograms showed different acoustic spectra. The modified sound versions differed from the original sound version in terms of its high tone-pitch section which is represented in the spectrograms with high frequencies during the drive phase (figure 2). In more detail, *sofi_post_min* clearly showed less high frequencies, indicated by more yellow colour in the drive phase, compared to *Sofi_post_norm* due to the defined cut-off point. But *sofi_post-lp* showed the most differences: according to the colour distribution in the spectrogram where high frequency parts in the sound were dampened to lower frequencies. This becomes obvious as the colour spectrum that represents the acoustical spectrum of the sound is limited (almost only three colours are visible) compared to those of *Sofi_post_norm* and *sofi_post_min*.

Listening to the sound versions in comparison, the differences become audible.

3.2. Questionnaire

Ten athletes from the total of 41 requested athletes had experienced the online-sonification during rowing as acoustic feedback. The remaining 31 athletes (75%) heard only from the sonification up to the present. They were instructed in the method and told that the sound represents the boat acceleration-time trace acoustically.

The results of the questionnaires showed that the two modified sound versions dominated over the original sound version in terms of pleasureable aspects when presenting them offline (not within a moving context). In more detail, the first modified sound version *sofi_post_min* was found to be pleasant for most of the athletes (46.3%) followed by the second modified version *sofi_post-lp* (29.3%). The original version *Sofi_post_norm* was rated to be the favorite version in terms of aesthetic aspects for 22% of the athletes.

In contrast, the results of the second question, which of the three sound versions was found to be the least informative in terms of functional aspects, showed that *sofi_post_min* came first (40.5%), followed by *sofi_post-lp* (35.7%). The original version, *Sofi_post_norm*, was found to be the most informative version from 24.4% of the athletes.

Individual answers described the presented versions as *"very digital and electronical"* and as *"very abstract"* sounding. Those athletes who had not experienced sonification as online acoustic feedback during technique training mentioned that it is difficult to imagine rowing with the sound.

4. DISCUSSION & CONCLUSIONS

In this paper the use of three different sonification versions was described and their perception and acceptance when presented offline to elite athletes was requested. It was aimed at producing a modified sound version on the basis of the original version used so far in technique training of elite athletes for rowing stroke cycles within stroke frequencies of approximately 20 str./min. and up to a maximum of 22 str./min., that could be used as well for higher stroke frequencies (>24 str./min.). Therefore, a dataset from the German men's Eight at stroke frequency 24 str./min. was taken and sonified to three different sound versions: *Sofi_post_norm* (as the original version), *sofi_post_min* and *sofi_post-lp*. Special focus was set on reducing the very high tone-pitches that occur during the drive phase of the rowing cycle and to keep the functionality of the resulting acoustic sequence, whilst trying to eliminate some potentially unpleasant aspects in the sound such as the high tone-pitch section during the drive phase of the rowing movement.

Analysis of the acoustic properties of the different sound versions showed that most of the high frequencies in the sound were reduced. Thus, the modified sound sequence No.1, *sofi_post_min* was characterized by a continually sounding threshold tone that occurred as soon as the data crossed the defied cut-off point. It belongs to aesthetic aspects if the threshold sound is pleasing. The second modified version, *sofi_post-lp*, was dampened using a classical low pass filter. This version represented the acceleration curve comparable to the original version, *Sofi_post_norm*, but within a lower tone pitch. Again, it belongs to the individual if this low frequency in sound is pleasing to the ear of an athlete.

But within a practical context in terms of technique training, the question of the sounds' functionality is more important for the effectiveness of the acoustic feedback: does the sound still

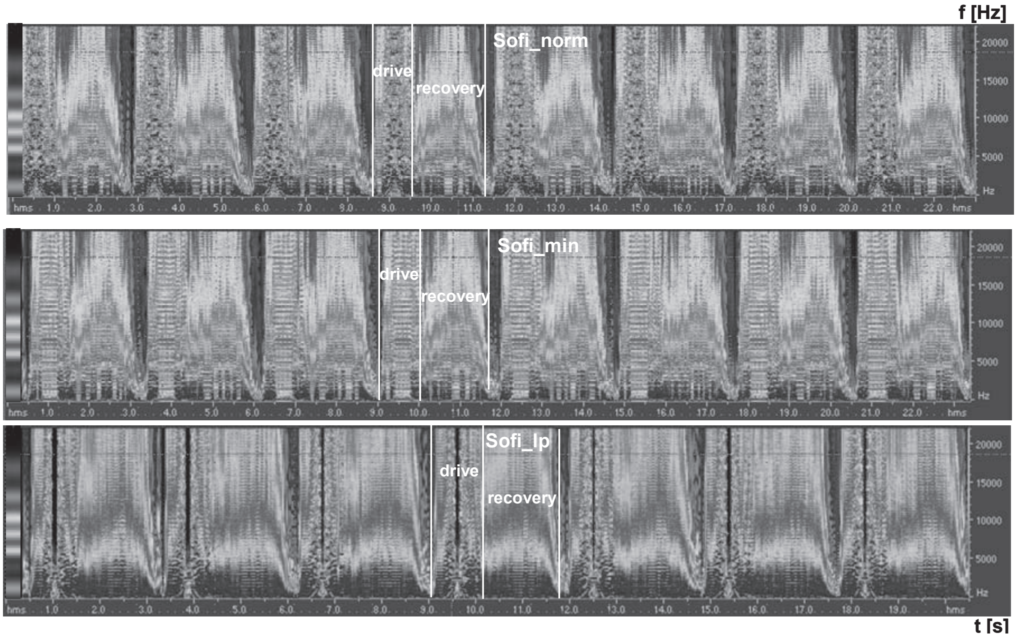

Figure 2. Spectrograms for the three sound versions *Sofi_post_norm*, *sofi_post_min* and *sofi_post-lp* in comparison for eight rowing stroke cycles in each case.

represent the characteristics of the acceleration trace of the rowing stroke cycle and provides fundamental information to the athletes about their movement execution?

According to initial considerations about the kinematic parameter of the boat acceleration-time trace when creating the original sound sequence as acoustic feedback, the whole process was sonified including multiple minima and maxima within the acceleration curve. This procedure was retained unchanged for the design of the modified sound sequences. But it was tricky to represent audibly the whole process of the rowing movement including several sequences of movements within the range of an optimal perceivable pitch that is distinguishable from the surrounding sounds such as those originating from water, wind, the rowing shell itself as well as from other boats (motorboat), etc. Owing to the fact that the boat reaches acceleration values of around ± 0 m/s^2 during the recovery phase, it is important to choose a tone pitch that is still noticeable. But as a consequence, tone pitch increases with higher stroke frequencies with correspondingly higher acceleration values.

Indeed, the sound critical section could have been eliminated, with the incorporation of a threshold as done with *sofi_post_min* and presenting no sound or just white noise instead of a threshold sound. But, keeping in mind our initial considerations to provide information about the rhythm of the movement of the boat, this procedure would have been contrary to the nature of the rowing stroke cycle as it is a cyclic motion and thus has recurring movement sections that represent the rhythm of the whole movement. This includes, according to its definition, an ordered structure of regularly recurring sequence of events in time. In the context of human movements, these time-dependent events are crucial for the timing of successfully executed movements. And precise timing on the other hand, depends on rhythm [8]. A partial presentation of several sections such as single extreme values would, in comparison, have been less beneficial for perceiving the rhythm of the movement corresponding to its typical structure as a whole, especially as it was intended to provide information about the rhythm in order to increase the crew's synchronization which is one of the most challenging factors influencing rowing performance (besides force and endurance). Owing to the continuous acoustic mapping of the acceleration curve, crucial aspects of technique training were addressed by representing several movement patterns and the movement as a whole.

The results of the questionnaire underline the individual nature of aesthetic aspects within the context of sound designs for practical applications as besides pitch, timbre also is a significant aspect that is defined by the relationship between frequency and amplitude of the partial oscillation as well as by the relationship between the single frequencies and the frequency of the fundamental [9].

Most of the athletes (75%) had not experienced sonification during rowing and thus, they had no idea how the sound sequence affects the movement execution. But it is worth mentioning, that up to the present, most of the athletes reacted similarly when presented with the sonification prior to the training session on-shore. Afterwards, they rated the sound as informative for the rowing movement, although, different opinions in terms of aesthetic aspects of the sound always exist. But this is the case with all kinds of information presentation (visually and/or acoustically) in the context of training and/or in a general context which was confirmed with the individual answers as well as in a former investigation by Henkelmann [10].

However, the above tested versions were just a first attempt to provide another sound sequence to the existing one. It is desirable for the future to create further versions that include functionality and pleasurable aspects and are noticeable within the rowing process with all its accompanying sounds.

5. ACKNOWLEDGMENT

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6. REFERENCES

[1] N. Schaffert, K. Mattes & A.O. Effenberg. „An investigation of online acoustic information for elite rowers in on-water training conditions.” *J. Hum. Sport Exerc*. 6 (2):392-405, 2011.

[2] http://www.sofirow.de/english.html

[3] N. Caplan & T. Gardner. “Modeling the Influence of Crew Movement on Boat Velocity Fluctuations during the Rowing Stroke.” *Int. J. of Sports Science and Engineering*, Vol. 1, No. 3:165-176, 2007.

[4] N. Schaffert. *Sonifikation des Bootsbeschleunigungs-Zeit-Verlaufs als akustisches Feedback im Rennrudern*. Logos Verlag Berlin, 2011.

[5] T. Hermann, “Taxonomy and Definitions for Sonification and Auditory Display.” *Proc. 14th Int. Conference on Auditory Display (ICAD)*, June 24-27, Paris, France, 2008.

[6] N. Schaffert, K. Mattes & A.O. Effenberg. „A Sound Design for Acoustic Feedback in Elite Sports.” In S. Ystad et al. (Eds.) *Auditory Display*. CMMR/ICAD 2009, Lecture Notes in Computer Science (LNCS) Vol. 5954, Springer-Verlag Berlin Heidelberg 2010.,pp.143-165.

[7] M. Puckette. *The theory and Technique of Electronic Music.* World Scientific Publishing Co. Pte. Ltd., 2007.

[8] G.P. Kenyon & M.H. Thaut. “Rhythm-driven optimization of motor control. In M.H. Thaut. *Rhythm, Music and the Brain: Scientific Foundations and Clinical Applications.* New York: Routledge Chapman & Hall. 2005.

[9] F.S. Cooper. “Spectrum Analysis.” *J. Acoust. Soc. Am*. Vol. 22, Issue 6: 761-762, 1950.

[10] C. Henkelmann. *Improving the Aesthetic Quality of Realtime Motion Data Sonification.* Computer Graphics Technical Report CG-2007-4, University of Bonn, 2007.