

## A SOUND DESIGN FOR THE PURPOSES OF MOVEMENT OPTIMISATION IN ELITE SPORT (USING THE EXAMPLE OF ROWING)

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### ABSTRACT

Monitoring sportive movements is essential for training processes to detect variations as well as progression, stagnations or even regressions. Visualization plays the dominant role in the technique analysis, even though the eyes' ability to perceive information of time-related events are limited and less efficient in comparison to the ears. Sound represents the information more differentiated and can support motion sequences. Acoustic displays offer a promising alternative to visual displays. Therefore an appropriate sound is needed that represents the specific movement patterns of a cyclic motion. In this paper we present our current considerations towards basic requirements for a sound design that fulfils the specific purposes of movement optimisation and its acceptance in elite sport.

### 1. INTRODUCTION

Human movement have been influenced at all times by sounds and different acoustic formats, e.g. for social functions (music and dance), therapeutic monitoring (using external rhythm to enhance the timing of movement) or in sport for the rhythmic synchronisation of movement patterns [1]. The physical 'nature' of movements as well as the 'nature' of sounds has an inherent time structure: both appear and depend on time, which makes them inseparable [2]. Most of the sport movements are combined with natural caused sounds, e.g. in tennis where the 'impact-sound' of the ball reports its velocity and impact force. Sound waves were always generated during the contact phase between the sport tool of the sport equipment and the surface (e.g. ground). In other words: sound is the acoustic consequence of kinetic events. In sport, sound plays an important role [3] and especially in elite sports athletes rely on sport specific sounds, which are a result of their movements, to adjust their motion sequence. In rowing, the sound of the blade and even more the sound of the boat during the boat run play an important role for the individual elite rower: they listen to the sound of the boat to control their actions [4]. Subjective descriptions of elite rowers bring an additional aspect to biomechanical measurements, and, hence for technique training: Knowing how the athletes react implicit to the sound, as an additional feedback of their actions, opens the possibility to bring the athletes the feedback they need to adjust their movements without concentrating too much to the given information unlike the way of displaying the feedback visually. The structural equivalence between sport movements and sound appears in rhythm and tempo, which is used to clarify the time-

structure of movement patterns. Taking the advantage of the auditory perception [5] which "is particularly sensitive to temporal characteristics, or changes in sounds over time" [6], athletes' attention can be guided by the rhythm to specific movement sections. This positive attributes of the sound can be implemented into the feedback training to optimise sport movements. Existing feedback systems in rowing are used regularly [7], however, they mainly use visualization techniques. In doing so the visual focus is always directed to the display. Additional acoustic information can be received by the athletes as a side effect. Furthermore, it enhances the performance of the human perceptual system and offers new possibilities, especially for motor control and motor learning and for monitoring and reproducing movement patterns [8]. Therefore the sound design has to fulfil basic requirements. First: the sound has to represent the movement appropriately: it is important to find characteristic movement parameters as well as different movement intensities in the sound result. Furthermore, qualitative changes (such as increases or decreases of the boat motion) must be perceivable and differences have to be identifiable. Finally, the sound result has to fulfil aesthetic aspects: it should be pleasant to listen to the 'melody' of the movement. The boat motion is obviously well suited for representing the cyclic motion of rowing with its characteristic time-dynamic structure. To get access to qualitative changes of the boat motion the acceleration trace in the direction of propulsion was chosen. Acceleration by definition is the change in velocity over time [9], which combines as a complex parameter, all internal and external active forces of the system (boat and rower) and, hence, makes it adequate for our purposes. Sonified to a sound sequence it implies the rhythm of the movement and can help to improve the feeling for the rhythm and duration of the boat motion. The experience of the duration of the movement creates the desired outcome as an 'idea' of the movement pattern - assuming that the 'motion-sequence' is developing together with the hearing [10]. The sound result therefore stays in relation to kinaesthetics and movement performance [2].

Since we designed a first sound version we wanted to know how athletes and coaches did percept the sound result and whether it represents the boat motion appropriate.

## 2. METHODS

### 2.1. Subjects

The subjects participated in the pilot study were four male junior athletes (international level) between 16 and 17 years (body height: 193.8cm ± 3.2; body weight: 86.3kg ± 3.9). The subjects for the follow-up study were four male and four female U23 athletes (international level) between 18 and 21 years (male (n=4; 178.8cm ± 4.6, 68.9kg ± 3.4; female (n=4; 169.5cm ± 3.4; 59.5kg ± 0.7).

### 2.2. Test design

The pilot study (n=4) took place in March 2008 during a training session in a mens four (M4-) at the rowing course in Berlin-Grünau. Six different stroke rate (sr) steps (18, 20, 22, 24, 30, 36 strokes per minute) were performed over ten strokes, separated by ten light rowing strokes between the monitored sr. The follow-up-study (n=8) took place in October 2008 at the rowing course in Hamburg-Allermöhe measuring different sr during the training. Simultaneously to the movement they got direct acoustic online feedback via earplugs and loudspeaker which were mounted inside the boat. The follow-up-study also included separate standardised questionnaires for coaches (N=42; A-C-licence) and for athletes N=8; U23). The coaches listened to the sonified boat motion, which was synchronised with the video (they were able to listen to the sound as often as they needed). The athletes were questioned directly after the training session.

### 2.3. Testing System

Kinematic parameter were measured: boat acceleration (a<sub>boat</sub>) in the direction of propulsion and horizontal boat velocity (v<sub>boat</sub>) directly with an acceleration sensor (piezo-electric sensor) and global positioning system (GPS).

### 2.4. Sonification design

The acceleration trace was measured at different sr to represent the different movement intensities acoustically. In cooperation with sound engineers from the company BeSB GmbH Berlin a device was developed to create movement defined polyphonic sound sequences. According to the definitions of Hermann's taxonomy for sonification [11], Parameter-Mapping-Sonification was used to convey the movement parameter of the boat motion in the direction of propulsion into auditory information. Therefore, every data was related to a specific tone on the musical tone scale. Changes in tone pitch resulted from changes of the boat motion. The sound data was brought to the ears of elite rowers as direct acoustic online feedback while they were rowing. For the analysis, selected rowing strokes were sonified and overlaid with the video, to make changes and variations arising in the data hearable, which are not visible by only watching the video.

## 3. RESULTS

### 3.1. Data

The cyclic rowing stroke was divided into four sub-phases, front reversal (fr), drive (d), back reversal (br) and recovery (r), which appear in every stroke cycle of the periodic boat acceleration trace. Figure 1 shows two acceleration traces for six selected rowing strokes at 36 and 24 strokes per minute in which the curve characteristics with their respective sub-phases became evident.

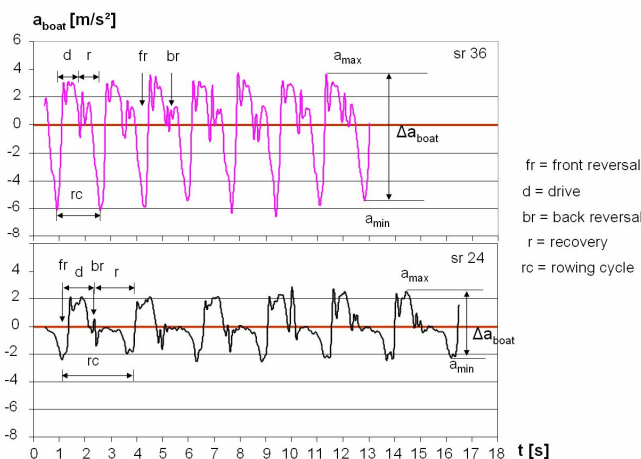


Figure 1. Acceleration trace of six selected strokes (sr 36 and sr 24 strokes per minute) measured in the pilot study.

Therefore the required characteristic movement parameters were given. The data showed in detail that the highest acceleration change was measured during the front reversal as deceleration of the boat, while main propulsive positive acceleration occurred during the drive phase. The back reversal was characterized by negative and positive acceleration peaks (deceleration and acceleration of the boat), which appeared temporarily. During the recovery phase, the boat was accelerated again in the direction of propulsion due to the motion of the crew, who moved the boat below themselves by pulling on the footstretcher especially at higher stroke frequencies. As a result of the water resistance the complete system (boat and crew) was decelerated in the recovery phase. Characteristic movement patterns as well as different movement intensities occurred with an increase in stroke rate (sr 18-36) and boat velocity (3.9 m/s – 5.4 m/s) (table 1).

sr-step	sr [strokes/minute]		v <sub>boat</sub> [m/s]	
	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

Table 1. Pre-selected stroke rate steps versus stroke rate (sr) and boat velocity (v<sub>boat</sub>) during the pilot study.

The acceleration trace was differentiated by the rhythm of the boat motion and its four characteristic sub-phases and dependent on the movement intensities (fig. 1). In other words:

with increasing stroke rate the cycle time per stroke decreased. The ratio of the rhythm, as coefficient of the drive time divided by the recovery time, changed significantly. The sound result represented consequently the characteristic rhythm of several stroke rate steps.

### 3.2. Coaches' questionnaire

All coaches answered the questionnaire regarding the acceptance of the concept and the acoustic feedback (100%)\*: they rated the sonified boat motion in the direction of propulsion and identified the characteristic phases of the rowing cycle (100%) (fig. 2).

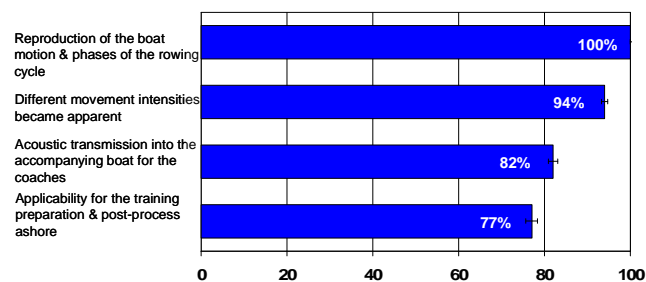


Figure 2. Percentage of answers (coaches' questionnaire) taken in the follow-up-study.

The different movement intensities (represented by the stroke rate steps) became apparent for 94% of the coaches. The assistance for the coaches by transmitting the acoustic information into the accompanying boat was appreciated (82%). Using the sound result to support the preparation and post-processing training phases as a conceivable implementation, 77% of the coaches would take the benefit out of it.

### 3.3. Athletes' questionnaire

All athletes answered the questionnaire regarding the acceptance of the concept and the acoustic feedback (100%): they recognized the reproduction of the boat motion to 100%. Every respondent athlete (100%) could focus the attention to several movement sections as a result of the guiding function of the sound. 87.5% of the athletes detect the characteristic sub-phases of the boat motion reproduced in the sound result. 75% of the athletes believe in the successful application of the acoustic information during on-water training sessions. 50% of the athletes said that the sound result did not distract the attention from the actual perception (50%) (fig. 3).

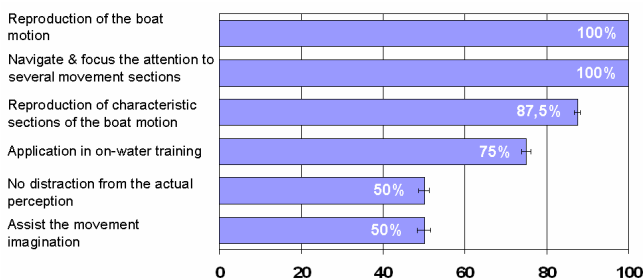


Figure 3. Percentage of answers (athletes' questionnaire) taken in the follow-up-study.

Furthermore, 50% of the athletes could assist and support their own movement imagination in the way, the sound was providing the time structure. The outcome of this is that the athletes get a feeling for the duration of the rowing cycle.

Individual responses of the athletes for selected questions are listed below.

Question: How was the feeling with the additional sound while you were rowing?

*"The feeling was good. I was encouraged to accelerate backwards and when implemented I've received a positive feedback."*

*"Good, so far as you have got direct feedback. (...) The sound was similar to the sound of an impeller wheel (compare to the sound of an old rowing ergometer), which fits well to the drive phase."*

Question: Are the different movement intensities mapped clearly (by the several stroke rate steps)?

*"During the drive phase there was a high pitched sound whereas during the recovery phase the sound was low pitched and, just before the blades touched the water it sounded very low pitched."*

*"You recognized the sound getting higher and shorter at higher frequencies."*

*"You recognized the shorter recovery phase at higher stroke frequencies in the sound."*

Question: Is it possible to hear variations of successful and less successful strokes (e.g. if a stroke didn't feel successful, but another one did)? We mean variations between single strokes of the same stroke rate step.

*"Especially a break at the front reversal (catch) was very good perceptible."*

*"I could hear the moment of the front reversal (catch) very precisely. The sound of the drive phase was different from the sound of the recovery phase."*

Question: If yes, what especially can you hear?

*"I perceived very well the moment of the highest sound during the drive phase. So you can try to keep the sound high pitched as long as possible and let it get lower pitched after the stroke was finished."*

*"I heard changes: the better the acceleration the higher was the sound."*

Question: Is it possible to navigate and focus the attention to several movement sections because of the sound for the purposes of adjusting and regulating movements?

*"You can concentrate on the sound especially for the moment before the oar blades enter the water: trying not to decrease the sound too much to get the best boat acceleration."*

*"Especially at the finish position it was possible to 'play with the sound': you can try to keep the decrease of the sound as small as possible."*

*"You try to accelerate backwards to minimize the sound decrease before the catch."*

*"You can try to extend the rise of the sound at the end and keep it high pitched before the oar blades entered the water."*

Question: In which modality is the sound applicable for on-water training?

“Not during the whole session, sort of phased getting the chance to implement the ‘heard strokes’, then, turning the sound on again to compare the strokes. It can be helpful to listen to the recorded sound after the training session to compare the different strokes.”

#### 4. DISCUSSION AND CONCLUSIONS

Conceptual considerations concerning a sound design for the optimization of sport movements with first practical experiences in elite rowing were presented in this paper. The boat motion was verified and described acoustically (sonified) to make the measured differences of intensity between several stroke rate steps hearable. Sonification offers an abundance of applications in elite sport, however there is still not enough practical experience. It is important to implement the sound information meaningful into the training process to get the desired benefit. Therefore conceptual knowledge of the design is necessary as well as how athletes perceive the sound data. The ‘melody’ changed as a function of the acceleration trace which means, athletes perceived an increasing tone pitch the more the boat was accelerated. Tone pitch by definition “is the perceptual correlate of periodicity in sounds” [12] whose waveforms repeat in time comparable to the rowing cycle. The appearance of the sound is equivalent to the way the auditory information is encoded in the human brain. With it, the sound data remains in close connection to the boat motion. Listen to the movement as an acoustic totality, the sound data become intuitive comprehensible and applicable for the athletes.

The results presented in this study show, that coaches and athletes basically agree in their responses regarding the acceptance and effectiveness of the concept and the sound result in particular. Athletes perceived the sound result differently, which becomes evident in their responses and confirms the concept of the subjective theories [4]. According to this, every athlete has his own way to optimise his or her movement. Learning approaches differ from subject to subject and, consequently, every athlete realises rowing technique differently, which means they need different ways of instruction. One may prefer the visual input, while another prefers the acoustic stimuli. Therefore it becomes evident that “subjectivity in human perception and interpretation is shared with other perceptualisation techniques that bridge the gap between data and the human sensory system” [11]. The sound result as acoustic information, presented here, offers a promising application for technique training and provides an alternative to the existing feedback systems [7]. An additional presented sound can not affect every athlete in the same way, apart from aesthetic questions. However, it can help getting an enhanced feeling for the rhythm and duration of the movement. Furthermore, most important for the purposes of the study, is the time for the feedback: it should not be used in every training session rather temporarily, to sensitise the athletes’ focus of attention towards specific sections during the rowing movement, or, more in general, to the rhythm of the movement, e.g., in cases, athletes change the boat class (from a pair to a four). The sound data may help the athletes to find the characteristic rhythm faster. Despite this, the sound data should be presented additionally to the ‘natural sounds’, such as the splash sound the blade makes when it enters the water. The additional acoustic information produced from the movement,

introduces a new approach to the technique analysis and optimisation in elite rowing. Therefore it is possible to describe the ideal boat run by the rhythm of the boat acceleration and implicates the option for a rhythm education in racing boats. It opens new opportunities for technique training and racing tactics. In further studies the sonified ‘optimal movement’ will be used in feedback training as a guideline (‘reference sound’), bringing the athletes closer to their main goal: to cover the race distance in the shortest time possible which is mainly influenced by decreasing the periods of negative boat acceleration.

#### 5. ACKNOWLEDGEMENTS

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#### 6. REFERENCES

- [1] H. Bruhn, R. Kopiez, A.C. Lehmann (Hrsg.), „Musikpsychologie. Das neue Handbuch“. Reinbek bei Hamburg, 2008.
- [2] A.O. Effenberg, „Sonification – ein akustisches Informationskonzept zur menschlichen Bewegung“, Verlag Schorndorf: Hofmann, Germany, 1996.
- [3] E. Loosch, Allgemeine Bewegungslehre, Wiebelsheim, 1999.
- [4] V. Lippens, “Inside the rower’s mind”, in V. Nolte (Ed.) *Rowing faster*. Human Kinetics, Inc., 2005, pp.185-194.
- [5] O. Hoener, T. Hermann, C. Grunow, “Sonification of Group Behavior for Analysis and Training of Sports Tactics”, in *Proc. Int. Workshop of Interactive Sonification (ISon)*, Bielefeld, Germany, 2004.
- [6] G. Kramer, B. Walker, T. Bonebright, P. Cook, J. Flowers, N. Miner & J. Neuhoff, “Sonification Report: Status of the Field and Research Agenda”, *NSF Sonification White Paper – Master 12/13/98*, 1999, p.5. <http://sonify.psych.gatech.edu/publications/pdfs/1999-NSF-Report.pdf>
- [7] K. Mattes, W. Böhmert, „Biomechanisch gestütztes Feedbacktraining im Rennboot mit dem ‚Processor Coach System-3‘ (PCS-3)“. In J. Krug, H.-J.Minow, (Ed.), *Sportliche Leistung und Techniktraining*. Schriften der deutschen Vereinigung für Sportwissenschaft 70, St. Augustin: Academia, 1995, pp.283-286.
- [8] A.O. Effenberg, “Multimodal Convergent Information Enhances Perception Accuracy of Human Movement Patterns”, in *Proc. 6<sup>th</sup> Ann. Congress of the ECSS*, Sport und Buch, Strauss, 2001, p.122.
- [9] H. Crew, “The Principles of Mechanics”, BiblioBazaar, LLC., 2008, p.43.
- [10] C. Böger, “Der Bewegungsrhythmus – grundlegendes Prinzip beim Lernen und Lehren von Bewegungen?“ In K. Moegling (Ed.), „*Integrative Bewegungslehre TeilIII. Wahrnehmung, Ausdruck und Bewegungsqualität*“. Bewegungslehre und Bewegungsforschung, 14, Kassel, Germany, 2001, p.161.
- [11] T. Hermann, “Taxonomy and Definitions for Sonification and Auditory Display”, in *Proc. 14<sup>th</sup> Int. Conference on Auditory Display (ICAD)*, Paris, France, June 24-27, 2008.
- [12] J.McDermott, A.J. Oxenham, Music perception, pitch, and the auditory system, *Current Opinion in Neurobiology*, 18, 2008, pp.1-12.

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