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Original Article

An investigation of online acoustic information for elite rowers in on-water training conditions

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ABSTRACT

Schaffert N, Mattes K, Effenberg AO. An investigation of online acoustic information for elite rowers in on-water training conditions. *J. Hum. Sport Exerc.* Vol. 6, No. 2, pp. 392-405, 2011. Presenting acoustic information has become increasingly interesting for technique training and control in various sports. In elite rowing, acoustic feedback is a new and promising application to optimize the boat's forward motion. This paper describes the potential of acoustic information which represents the movement-relevant information on the boat's forward motion for rowing and its implementation as online acoustic feedback during on-water training sessions. The first significant results were encouraging and support the intention to implement the acoustic information regularly into training processes for elite athletes. **Key words**: FEEDBACK SYSTEM, ACCELERATION, VELOCITY, ACOUSTIC, TECHNIQUE.

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INTRODUCTION

Acoustic events and human movements share an inextricable relationship that has influenced social functions in all known cultures (Bruhn, Kopiez & Lehmann, 2008). In this article acoustic events will be considered as 'sounds'. The alliance between sound and movements is constituted in their physical nature that is its inherent time structure. Both are results of a temporal (chronological) sequence of events. Consequently, all kinds of movements produce sound in various frequency ranges, which was described several times before (Mechling & Effenberg, 1998).

In regards to the sound produced as a result of human movements, the frequency range is normally below the range of audibility for human beings, located between 20Hz and 20,000Hz. Excluded from this are those sounds that are caused by the interaction of materials and that accompany the movement execution. An example in sport situations is the contact phase between sports equipment with a surface. The result is a sport specific sound. Using the example of rowing, the boat's forward motion creates a sound like splashing and flowing which plays an important role especially for elite rowers (Lippens, 2005). They rely on the boat-specific sounds to obtain feedback about the boat motion in order to assess their rowing strokes as more or less successful. This natural acoustic feedback can effectively convey online information about different attributes such as the velocity and the magnitude of the force applied to the system per rowing stroke.

Actually only the sound's basic elements like loudness, pitch, duration or tempo were perceived. It is the translation and organization of this information by the brain into higher level concepts (Levitin, 2008) which gives the rowers the necessary information. Besides the advantage of perceiving multiple attributes at one time, athletes' focus of attention can be guided acoustically to specific sections in the sound without distracting and without occupying the audio sensory channel, which can analogously be the case if feedback is displayed visually and that is regularly used in elite rowing (Mattes & Böhmert, 1995).

In contrast, acoustic feedback takes advantage of humans' auditory perception that offers a special sensitivity to temporal resolution. Available human perception capacities enable augmented information gathering and interpretation of simultaneously perceived information streams. Moreover, the sound increases the awareness of every athlete in the boat. Results from neuroscience research confirm the processing of acoustic stimuli as a solid, precise and subliminal process at different neuronal levels (Thaut, Tian & Azimi-Sadjadi, 1998). The resulting neuronal impulse affects directly the human motor system, which is extremely sensitive for acoustic information. Thus, movement 'follows' sound because of the strong connection between sensory input and motor output' also known as audio-motor entrainment. Entrainment is described as one of the core topics of sound action-links and was discussed in a considerable amount of research (among others Fischinger & Kopiez, 2008; Phillips-Silver, Aktipis & Bryant, 2010).

Summarizing, sound seems to be an ideal synchronization device with its unique influence on human beings to drive rhythmic and metrically organized motor behaviour (Patel et al., 2005). The interaction between auditory stimuli and motor reaction becomes evident when people intuitively and often spontaneously, tap or clap to the rhythmic pattern of a musical piece. This reaction only occurs in the presence of acoustic stimuli: there is no comparable effect for visual stimuli. The metrically organized structure of auditory stimuli enables listener (and performer) to anticipate the future occurrence of events and may contribute to motor prediction (Zatorre, Chen & Penhune, 2007). Briefly described, it is assumedly based on combined inverse and forward models in the brain (Wolpert & Kawato, 1998).

Thus, an acoustic feedback system can be a powerful tool for the training processes of elite athletes. Using the method of sonification (Kramer, 1994) that makes numerical data audible, it becomes possible to display kinematic parameters of the boat motion acoustically as well as online to the athletes during rowing. In doing so, the sonified boat motion aims to guide athletes' attention to those specific sections in the rowing cycle that critically cause the boat to slow down by taking advantage of the properties of the auditory perception system. It is assumed to sensitize the athletes' feeling for the rhythm of the movement by listening to the sound of the boat motion.

The implementation of synthetically generated acoustic information that was labelled as movement sonification has already demonstrated the effectiveness of sonification on motor control and learning in research (Effenberg, Melzer, Weber & Zinke, 2005; Chiari et al., 2005). In competitive sports it is a new approach. A theoretical basis for this concept is founded in the ecological approach to perception (Gibson, 1979)

This article describes the potential of acoustic information feedback for the training of elite rowers using a selection of the results of the first study.

MATERIAL AND METHODS

Subjects

The subjects participating in the study were athletes in the German junior national rowing team (N=23): male participants (n=18) with a mean age of 17.8 years (±0.7), mean body height of 193.4cm (±4.1) and mean body mass of 87.8kg (±4.2). Female participants (n=5) had a mean age of 17.6 years (±0.6), mean body height of 175.0cm (±6.0) and mean body mass of 67.2kg (±8.2). Additionally, the different boat categories ranged from small to big boats that have been studied in up to five training sessions.

Test design

The main intervention took place at the race course in Berlin-Gruenau during the preparation phase for the junior world championship in June 2009. Preliminary test runs were measured for different stroke rate steps (18-36 strokes per minute) with an overall duration of 30 rowing strokes. Average stroke rate of a regular extensive training session (which is represented by lower stroke rates) as well as the average race frequency (stroke rate 32-36) has been considered.

To identify the effect of acoustic feedback on the boat motion during the main intervention, several sections with a total of 30 rowing strokes each were measured at a comparable stroke rate (±0.5 strokes per minute). The sections (s) were considered as follows:

baseline: without acoustic feedback
section 1 (s1 (with) acoustic feedback,
section 2 (s2 (without) acoustic feedback,
section 3 (s3 (with) acoustic feedback,
section 4 (s4 (without) acoustic feedback and again
section 5 (s5 (without) acoustic feedback.

The five sections were compared to the baseline. Using the example of the junior men's double sculls (JM2x), the results were analyzed for the boat velocity as well as for the stroke rate. In order to evaluate the practical value of the acoustic feedback, its effectiveness as well as the acceptance of the sound result was requested using standardized questionnaires. In doing so, it was possible to investigate athletes' experiences with the acoustic feedback.

The data were statistically analyzed with an ANOVA with repeated measures (general linear model) in which 'sonification' was taken as intra-subject factor using the software SPSS 16.0. Using this procedure, it was possible to test interdependencies as well as impacts (effects) from single factors between the sections carried out at repeated measuring times. In order to rate the size of one factor or combination of factors, partial eta-squared (ηp2) was calculated as the parameter of effect size. Partial eta-squared describes the effect size on the dependent variables according to Cohen's (1998) classification. Level of statistical significance was set at $p<0.05$.

Measurement system

In order to create the acoustic feedback, the training and measurement system *Sofirow* (Sonification in rowing) was developed in cooperation with engineers from BeSB GmbH Berlin and the University of Hamburg. *Sofirow* measured the kinematic parameter:

- Propulsive boat acceleration (aboat) with a micro-electro-mechanical (MEMS) acceleration sensor (sampling rate adjustable up to 125Hz) and
- boat velocity (vboat) with GPS (4Hz) (measuring error 0.1m/s).

Figure 1 showed the feedback system *Sofirow* and its position located on top of the boat.

***Figure 1**. The training and measurement system Sofirow.*

Sofirow converted the boat acceleration-time trace online into acoustic information and transmitted it to the athletes in the boat during rowing as acoustic feedback via loudspeaker or earplugs, optionally.

To control the timing and duration of the acoustic feedback, the sound sequence could be selectively switched on or off by remote-control from the accompanying coaching boat. Acoustic transmission was controlled by the scientist in agreement with the coach who could receive the same acoustic feedback simultaneously with the athletes online in the motorboat. Besides, it was also possible to transmit the acoustic feedback solely to the coach. In other words, the coach could listen to the sound sequence exclusively while the athletes did not receive any feedback. That enabled the coach to monitor possible occurring changes or alterations in the boat motion after the acoustic feedback was turned off.

Sound design

In order to convert the physical parameter of the boat acceleration time trace into a meaningful and audible sound result, the sonification method of Parameter Mapping (Kramer et al., 1999; Hermann, 2008) was chosen, which is regularly used to render sonification from data. In doing so, the data of the boat acceleration trace were mapped to specific tones on the musical tone scale according to the MIDI standard (Musical Instrument Digital Interface) and related to tone pitch. In doing so, every defined decimal MIDI-number equates to a specific semitone. The data were multiplied by a factor k (spread of the acoustic sound) and displaced with an absolute term h on the MIDI-scale as the pitch of sound. The middle C on the western musical tone scale represented the point of zero boat acceleration, so that positive boat acceleration varies above this pitch and negative below. In other words: as the boat acceleration increased the tone pitch increased, and as the boat acceleration decreased the pitch decreased as well. Mathematical expressed: the sound result changed as a function of the boat acceleration trace.

The technical transformation was realized with the software Pure Data (Pd) a real-time graphical programming environment (Puckette, 2007).

RESULTS

Data

To analyze the movement-relevant information, it was important to begin with the detection of characteristic movement patterns in the rowing cycle as well as of qualitative changes in the boat motion. That is phases in which the boat’s forward motion increased or decreased.

The cyclic rowing motion is generally divided into the two main phases: the drive and the recovery phase that was described in detail several times before (Affeld et al., 1993; Hofmijster, Landman, Smith & van Soest, 2007). In order to describe the rowing stroke more precisely, it is furthermore separated into four characteristic, repetitive phases that consist besides the drive and recovery phase, in the two sub-phases: front and back reversal, also known as the catch and finish turning points. The boat acceleration trace of a rowing cycle begins at the moment of zero boat acceleration followed by a distinctive increase during the catch and drive phase where the oar-blades were below the water surface and the athletes produces an action of force on the boat. That is the result of an interaction between the athletes’ forces given on oarlock, foot-stretcher and seat and external active forces of the oar-blades. The outcome of that process accelerates the whole system (boat and athletes) in the direction of propulsion to the point of maximum boat acceleration that occurs in the middle of the drive phase.

During the finish turning points (back reversal), at the moment when the oars were lifted out of the water, the whole system produces no propulsive forces. But the boat velocity is influenced as a result of the athletes’ movement within the boat towards the stern as a result of the principle of momentum conservation. The movement impulse of the athletes has a strong influence on the boat velocity as the mass of the athletes is much greater than that of the boat (Baudouin & Hawkins, 2004; Celentano et al., 1971; Zatsiorsky & Yakunin, 1991).

Positive boat acceleration then occurs just before the recovery phase begins, at the end of the stroke (also known as the release), when the blades emerge from the water and ‘release’ the boat to run forward. After raising the oars out of the water, the athletes glide back up to the catch again to prepare the next stroke. In this process, athletes’ pushes against the foot-stretcher and with that, the foot-stretcher force acts against the direction of propulsion and decelerates the boat. Additionally, the water and air resistance causes the boat to slow down. The result becomes visible in the boat acceleration curve by a distinctive peak of negative acceleration (Figure 2). As this fact increases with increasing stroke frequencies and is characteristic for all boat categories, it is important to execute the recovery phase without reversing the boat's momentum. In other words, athletes' mass must be carefully slid toward the stern. Figure 2 shows two boat acceleration traces at different stroke rates for one single rowing stroke in each of which the characteristics of the curve became evident.

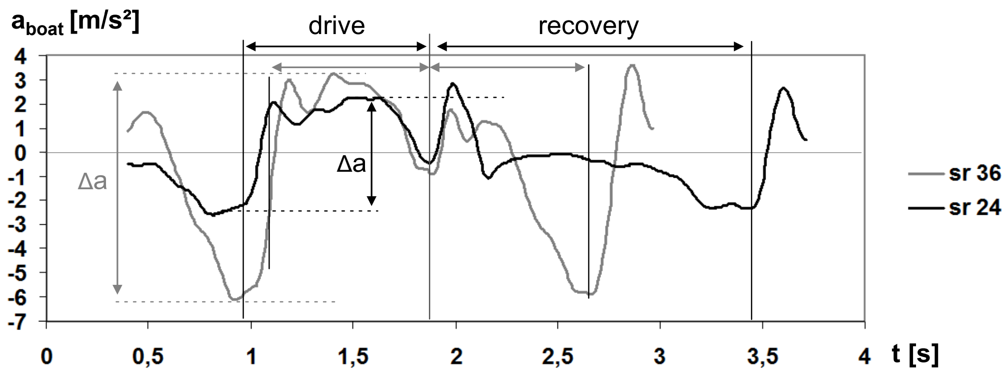

Figure 2. *Two boat acceleration traces (aboat) of one complete rowing cycle at stroke rate (sr) 24 and 36 strokes per minute divided in the drive and recovery phase.*

The comparison of the two stroke rate steps in Figure 2 shows differences in the amplitude of the boat acceleration trace and the time structure: with increasing stroke rates, the amplitude of boat acceleration increased whereas the cycle time per stroke decreased. With that, different movement intensities display the distinct difference between the stroke rate steps. Simultaneously during that process of increased stroke rates, mean boat velocity clearly increased as well. Thus, basic requirements for the acoustic transformation were fulfilled and an appropriate representation of the data measured becomes realizable in order to create a meaningful audible result and with that a useful acoustic feedback. Further requirements for the sonification process has been confirmed already by demonstrating that characteristic movement patterns are perceptible and identifiable and that there were qualitative changes in the boat motion (Schaffert, Mattes & Effenberg, 2010a).

The final results were audible in the sound result. In detail, characteristic phases of the rowing cycle were represented, and its rhythm audibly differentiated. The information contained in the measured data was transmitted acoustically, audibly perceivable for the athletes and, for our purposes even more importantly, audibly differentiated. Thus, the boat acceleration trace characterized the rhythm of the rowing cycle according to the intensity and can be thought of as the melody of the boat motion.

To identify the effect of the acoustic feedback on the boat velocity, the results of the JM2x were analyzed for the different sections. The JM2x was studied in five training sessions during which the acoustic feedback was transmitted alternately for a total of 13 test times within the described sections.

The results showed that, immediately after the acoustic feedback was switched on, there was a statistical significant increase in the mean boat velocity ($F_{2,5}=18.94$; $p=0.00$; $\eta p^2=0.61$). Thus, the acoustic feedback affected the boat motion significantly.

For more detailed information, Table 1 contrasts the power of coherence for the sections studied with the test of within-subjects contrasts.

Table 1. *Test of within-subjects contrasts for the effect of acoustic feedback on the boat velocity in the different sections studied versus the baseline (F-value (F), level of significance (p) and partial eta-square (η2p); degree of freedom=1; N=6.*

Sections		F	p	η_p^2
	s1 (with)	30.42	0.00	0.72
	s2 (without)	1.28	0.28	0.10
baseline	s3 (with)	32.96	0.00	0.73
	s4 (without)	1.91	0.19	0.14
	s5 (without)	1.83	0.20	0.13

In order to specify the differences between the sections with and without acoustic feedback studied, post-hoc tests were calculated using the Bonferroni procedure for the pairwise comparisons. In doing so, the sections with and without acoustic feedback were compared to the baseline condition. The results showed significant increase in the boat velocity for the sections with acoustic feedback (section 1 and section 3) compared to the baseline. In contrast to the sections with acoustic feedback, the sections without acoustic feedback (section 2, 4 and 5) showed no significant differences.

To visualize the differences between the mean values of the sections studied in relation to the baseline, Figure 3 specifies the mean differences in increase of the boat velocity graphically.

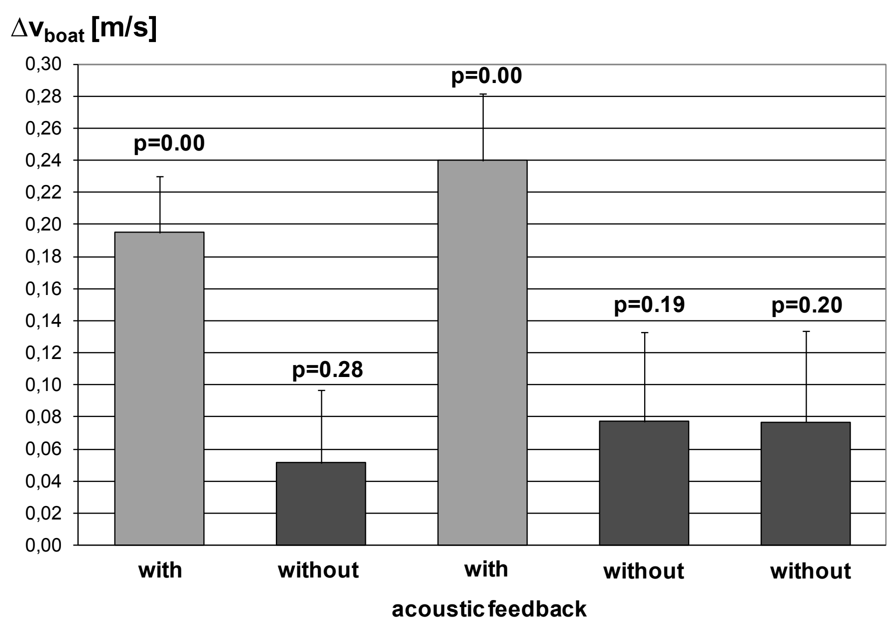

Figure 3. *Mean differences and standard errors of the boat velocity (Δvboat) for the five sections studied compared to the baseline. Each section consists of 30 rowing strokes repeated in a total of 13 tests.*

In Figure 3 it becomes obvious that the sections with acoustic feedback show a distinct increase in the boat velocity. More in detail, the greatest mean boat velocity was measured in section 3 with acoustic feedback (4.2m/s), that is an increase in the average boat velocity in this instance by about 2.4±0.04m/s. The lowest mean boat velocity was measured in section 5 without acoustic feedback (3.9m/s). The distance travelled, a factor dependent on the boat velocity, also increased as well during the sections with acoustic feedback and is included in Table 2 for completeness of the results.

Table 2. *Mean values and standard deviation (sd) for the boat velocity (vboat), stroke rate (sr) and the distance travelled (sboat) for the baseline and the five sections studied: with acoustic feedback (highlighted) and without.*

sections	v_{boat} [m/s]		s_r [1/min]		s_{boat} [m]	
	mean	sd	Mean	sd	mean	sd
baseline	3.9	0.2	20.8	0.3	11.48	0.58
s1 (with)	4.2	0.1	20.5	0.3	12.28	0.38
s2 (without)	4.0	0.2	20.7	0.4	11.66	0.49
s3 (with)	4.2	0.2	20.7	0.2	12.28	0.41
s4 (without)	4.1	0.2	20.8	0.4	11.69	0.52
s5 (without)	3.9	0.2	20.8	0.3	11.23	0.68

To summarize, the results reported here for the individual case of the junior men's double scull as an example for all boat categories studied. It further remains to say that there was no difference found between the different boat categories with regard to the effect of the acoustic feedback.

Questionnaire

The results of the athletes' questionnaires showed overall positive answers in view of the acoustic feedback experienced and its supporting function during on water training. They could recognize the reproduction of the boat motion and focusing of attention on several movement sections inside the rowing stroke was facilitated. For instance, it was possible to concentrate on the second part of the recovery phase and the finish turning points.

The athletes perceived the sound sequence in detail as comparable to the characteristic phases in the boat acceleration trace that were revealed as changes in tone pitch during the rowing strokes but also between the rowing stroke series (Schaffert, Mattes, Barrass & Effenberg, 2011). Individual answers of the athletes confirmed the overall statement: "The sound pointed to things of which we have not been aware before and we became more conscious of the movement."

The sound result correlated with athletes' individual kinesthesia and intensified their imagination of the movement, for example, "… the sound emoted the movement". The answers of the athletes indicated that the sound did not interfere with their usual perception (Schaffert, Mattes & Effenberg, 2010b). Preferred transmission was via loudspeaker in order to perceive the natural rowing sounds in addition, compared with isolated transmission via headphones. They emphasized that it was important for them to perceive the natural environmental sounds during rowing despite the undoubted support of the acoustic feedback. Other evidence was found for the dominance of functionality of the sound sequence over aesthetic aspects.

Altogether, *Sofirow's* use in on water training achieved high acceptance among athletes (and coaches) and most athletes would appreciate a regularly use of *Sofirow* as a promising training-aid.

DISCUSSION

This article described the potential of acoustic feedback information which represented the movement-relevant information of the boat motion in rowing and its implementation online for the training of elite rowers in on-water training conditions. Therefore, the training and measurement system *Sofirow* was developed and underwent preliminary testing in which the boat motion was analyzed and described acoustically (sonified) for the purpose of making audible the measured differences in movement intensity. The online generated sound characterized (differentiated) the rhythm of the rowing cycle, related to tone pitch. Accordingly, every change in the boat motion was acoustically represented in the boat's propulsive acceleration trace that also indicated those changes that were not visible by solely watching the boat travelling.

The appropriateness of the direct data mapping made apparent changes or reversals in the boat's momentum that interrupted the boat motion. This fact was also demonstrated as well offline in videos which were synchronized with the sonified data sequence of the boats' acceleration trace for a junior men's four (JM4-) (see "Rowing example").

In neural science, tone pitch is defined as "the perceptual correlate of periodicity in sounds" (McDermott & Oxenham, 2008). Thus, tone pitch by its nature occurs in waveforms which repeat periodically. Put in simple words, this process is comparable to the characteristics occurring in the rowing cycle. Athletes perceived the rowing cycle as a short sound sequence that repeated with its characteristic phases, such as the refrain in a piece of music, in every single rowing stroke. This periodic recurrence of characteristic sections (as a sub-part of the total of the rowing cycles) awakened a sensitivity for details in the sequence which did not need any explanation. Awareness of the structure emerged solely from the knowledge of the movement and audio-visual interaction. The changes in tone pitch represented and characterized variations inside the rowing cycle that also repeated variably with every rowing stroke. By listening to the sound of the boat motion, the sound data became intuitively comprehensible and applicable for the athletes. It helped them to improve their feeling for the time duration of the movement for the single rowing stroke as well as for the series of rowing cycles.

Results from earlier empirical studies in motor learning have already proved effective for enhancing both the process of learning new movement techniques using audio-visual information and the performance of the human perceptual system (Effenberg, 2005). There is neurophysiological evidence on the existence of subcortical or cortical areas as well as indications for an "action-listening"-mechanism in humans (Lahav, Saltzmann & Schlaug, 2007). Initial results from this study confirmed that multi-sensory information facilitates movement execution as well as its regulation and reproduction.

Such an action-listening takes place during human interaction with the world in their regular daily activities associated with sounds. Most probably, the sound is recognized, the brain is simulating the action (Aziz-Zadeh et al., 2009). When people observe another person performing an action, cross-modal neural activity in the brain is evoked that produces activity similar to that which would have been produced if the person himself had moved (Mukamel, Ekstrom, Kaplan, Iacoboni & Fried, 2010).

This system of mirror-neurons becomes active when people execute movements themselves, watch others or listen to something (Kohler et al., 2002). As a result of this, perception (sound) and action (movement) become coded in the same modality (Keysers & Gazzola, 2010).

In other words: sounds were associated with specific movements and their execution. The specific sound of different stroke rate steps thus becomes associated with the respective movement intensities and can be thought of as an acoustic footprint of the particular movement pattern. That indicates that the auditory modality can access the motor system as shown previously before in neuroscientific research (Zatorre, Chen & Penhune, 2007). Transferred to the results of the present study, the rhythm and duration of the movement experienced created a feeling for the sound of the desired outcome that remains in relation to kinaesthesia and movement performance.

Further evidence for this indicates to a responding mechanism in the brain that creates a neural basis for the coherence of sounds according to Levitin's (2008) description. An oversimplified view would be that in the auditory cortex in the brain, a specific neuron exists that is responsible for every component in the sound and whose firing rate corresponds to the frequency rate of the sound (Langner, 2007). Thus, the vibrating rate of the sound and the firing rate of the neurons become synchronized with each another.

With reference to the rowing stroke and its audible representation as acoustic feedback, the components of the movement became synchronized for both the interpersonal rhythm (that is the measured rhythm of the boat) as well as the intrapersonal rhythm (that is the rhythm which is subjectively perceived by the athletes). In combination it yields to a common crew rhythm with its characteristically compulsive and intoxicative effects. An athlete's individual rhythm becomes automatically subordinated to the rhythm of the crew (Meinel & Schnabel, 2007).

The general structure of an auditory stimulus is organized metrically and has a regularly recurring (rhythmical) cue which enables the listener to create expectations for the likelihood of future events. With that, the listener is able to anticipate the next temporal event accurately and makes it possible for the listening performer (as for instance a musician playing his instrument) to synchronize his movements with the sound in an easy way. Although synthetically generated acoustic feedback is not really comparable to a classical piece of music, it consists of the same acoustical structure and thus, the athlete can be seen as a listening performer who is able to synchronize the movement execution to the movements of each of the others (the rhythm of the crew) in several movement sections (for example like the moment when the oar blades enter the water all at the same time) as well as to synchronize the movements to the sound individually. As stated before, perception and actions can be tightly coupled, suggesting that there is an inherent link between auditory and motor systems in the context of rhythm (Chen, Penhune & Zatorre, 2008).

From a psychological-physiological point of view, rhythm is transferred as a result of the phenomenon of the 'ideomotor effect', also known as the carpenter effect. Due to the observation (and less strongly to the imagination) of a specific movement by another person, motor reactions occur involuntarily and often unconsciously that are in principle not distinguishable from the executed real movement (Carpenter, 1852; Meinel & Schnabel, 2007).

In summary, the sound result presented here, supported the feeling for synchronization and improved coordination among the athletes. The acoustic feedback represented the boat motion audibly in a perceptually and cognitively meaningful way that was realized on the basis of the boat's acceleration trace. With the positive attributes of the sound it is possible to implement the acoustic feedback in the training processes of elite athletes in order to optimize their movements during on-water training sessions. But it would be also possible to implement the sound sequence in off-water training during ergometer sessions. Others are likely to follow, as for example, mental training processes in order to sensitize athletes' perception to the sound sequence of a particular boat category or crew. This could be especially helpful for athletes who join an existing crew on a big boat later than other members in order to get an idea of how the crew rhythm sounds like to facilitate acquiring a feeling for the crew and boat.

Athletes basically agreed regarding the acceptance and effectiveness of the acoustic feedback in answering the questionnaire and confirmed the initial assumptions, whereas it would be true to say that individual perception differed between them. That is because every athlete has his own way of experiencing the feeling of rowing and thus, realizes rowing technique differently. Presenting acoustic feedback can in principle not affect every athlete in the same way. This is even more the case if the audible information consists of a synthetic generated sequence that has the potential to be perceived as displeasing or even annoying by the individual if it doesn't suit personal aesthetic considerations. However, it was not intended in the present study to entertain the athletes with the sound sequence used during their on water training. It was rather developed to help the athletes enhance their feeling for the rhythm and duration of the movement in a new way that bridges the gap between the coach and athletes in their psychological interaction. As acoustic feedback is consistent with the physical movement as its cause, it thus is conveyed by the same modality of senses. This means that acoustic feedback is intelligible to all in contrast to verbal instructions and includes also the possibility of forming an idea of the movement based on earlier experiences. Thus, expectations developed from those ideas can be satisfied by the received sensory information while executing the movement.

CONCLUSIONS

The sound result presented here contributes to existing feedback systems with an expansion into the audible range for the presentation of information. The first results showed that the acoustic feedback helped the athletes to adjust their rowing strokes with an increase in the mean boat velocity. As a side effect, the distance travelled per stroke was extended.

The sound result also was understandable for every athlete without any extra explanation. Considering the abundance of applications that is offered in general by dint of the sonification method according to Kramer et al. (1999), acoustic feedback systems seem to be promising for the training of elite rowers, offering too new possibilities especially for motor control and learning. Moreover, the reproduction of several movement patterns is facilitated and its monitoring is eased.

However, there is still a lack of practical experience. To get the desired benefit, it is important to use the acoustic feedback effectively and regularly in the different training processes. Additionally, there are still questions that remain open in regards to the practical implementation in the daily training routine of elite athletes. With regards to content, it is still necessary to investigate whether the measured effects appeared actually as a matter of the acoustic feedback or possibly as a result of the new kind of feedback information presentation. If effects actually measured are due to the acoustic feedback, the next questions that arise will be about the retention of information, that is the number of training sessions with acoustic feedback that are necessary to keep the positive effect during the movement execution. Further interesting questions will concern the frequency with the acoustic feedback should be presented within the training session in order to accomplish an optimal (maximal) effect.

To clarify these questions, further studies will examine the effectiveness and validity of the acoustic feedback in on-water training sessions of elite athletes this year.

Finally it should be said that the potential of acoustic information for training processes of elite athletes is neither restricted to elite athletes nor to the sport of rowing. It furthermore has the potential for recreational sports (Barrass, Schaffert & Barrass, 2010) as well as especially for rehabilitative processes as has already been investigated (Vogt, Pirro, Kobenz, Höldrich & Eckel, 2010).

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REFERENCES

1. AFFELD K, SCHICHL K, ZIEMANN A. Assessment of rowing efficiency. *Int J Sports Med*. 1993; 14(1):39-41. doi:10.1055/s-2007-1021223 [Back to text]
2. AZIZ-ZADEH L, IACOBONI M, ZAIDEL E, WILSON S, MAZZIOTTA J. Left hemisphere motor facilitation in response to manual action sounds. *Eur J Neurosci*. 2009; 19:2609-2612. doi:10.1111/j.0953-816X.2004.03348.x [Back to text]
3. BARRASS S, SCHAFFERT N, BARRASS T. Probing Preferences between Six Designs of Interactive Sonifications for Recreational Sports, Health and Fitness. In R Bresin, T Hermann, A Hunt (eds.). *Proceedings of the 3rd Interactive Sonification Workshop (ISon).* Stockholm: KTH; 2010. [Back to text]
4. BAUDOUIN A, HAWKINS D. Investigation of biomechanical factors affecting rowing performance. *J Biomech*. 2004; 37(7):969-76. [Full Text] [Back to text]
5. BRUHN H, KOPIEZ R, LEHMANN AC. *Musikpsychologie. Das neue Handbuch*. Reinbek: Rowohlt; 2008. [Back to text]
6. CARPENTER WB. On the influence of suggestion in modifying and directing muscular movement, independently of volition. *Proceedings of the Royal Institution*. 1852; 147-154. [Back to text]
7. CELENTANO F, CORTILI G, ET AL. The biomechanics of rowing. II. Efficiency of technical progression. *Boll Soc Ital Biol Sper*. 1971; 47(7):185-7. [Back to text]
8. CHEN JL, PENHUNE VB, ZATORRE RJ. Listening to musical rhythms recruits motor regions of the brain. *Cereb Cortex*. 2008; 18:2844-2854. doi:10.1093/cercor/bhn042 [Back to text]
9. CHIARI L, DOZZA M, CAPPELLO A, HORAK FB, MACELLARI V, GIANSANTI D. Audio-Biofeedback for Balance improvements: An Accelerometry-Based System. *IEEE Eng Med Biol Mag*. 2005; 52(12):2108-2111. doi:10.1109/TBME.2005.857673 [Back to text]
10. COHEN J. *Statistical power analysis for the behavioral sciences*. Hillsdale: Lawrence Erlbaum; 1998. [Abstract] [Back to text]
11. EFFENBERG AO, MELZER J, WEBER A, ZINKE A. MotionLab Sonify: A Framework for the Sonification of Human Motion Data. In: *Proceedings of the 9th International Conference on Information Visualization (IV '05)*. London: IEEE; 2005. [Full Text] [Back to text]
12. EFFENBERG AO. Movement Sonification: Effects on Perception and Action. IEEE Multimedia. 2005; 12(2):53-59. doi:10.1109/MMUL.2005.31 [Back to text]

13. FISCHINGER T, KOPIEZ R. Wirkungsphänomene des Rhythmus. In: H Bruhn, R Kopiez, AC Lehmann (ed.). *Musikpsychologie. Das neue Handbuch*. Reinbek: Rowohlt; 2008. [Back to text]
14. GIBSON JJ. *The ecological approach to visual perception*. New York: Houghton Mifflin; 1979. [Abstract] [Back to text]
15. HERMANN T. Taxonomy and Definitions for Sonification and Auditory Display. In: *Proc. 14th Int. Conference on Auditory Display (ICAD)*. Paris; 2008. [Full Text] [Back to text]
16. HOFMIJSTER MJ, LANDMAN EH, ET AL. Effect of stroke rate on the distribution of net mechanical power in rowing. *J Sports Sci*. 2007; 25(4):403-11. doi:10.1080/02640410600718046 [Back to text]
17. KEYSERS C, GAZZOLA V. Mirror Neurons recorded in Humans. *Curr Biol*. 2010; 20(8):R353-R354. doi:10.1016/j.cub.2010.03.013 [Back to text]
18. KOHLER E, KEYSERS C, UMILTA MA, FOGASSI L, GALLESE V, RIZZOLATTI G. Hearing sounds, understanding actions: action representation in mirror neurons. *Science.* 2002; 297:846-848. [Full Text] [Back to text]
19. KRAMER G, WALKER B, BONEBRIGHT T, COOK P, FLOWERS J, MINER N, NEUHOFF J. *Sonification Report: Status of the Field and Research Agenda.* NSF Sonification White Paper–Master 12/13/98. [Full Text] [Back to text]
20. KRAMER G. *Auditory Display: Sonification, Audification, and Auditory Interfaces. Santa Fe Institute Studies in the Sciences of Complexity. Proceedings Volume XVIII*. Reading: Addison-Wesley; 1994. [Abstract] [Back to text]
21. LAHAV A, SALTZMAN E, SCHLAUG G. Action representation of sound. *J Neurosci*. 2007; 27(2):308-314. doi:10.1523/JNEUROSCI.4822-06.2007 [Back to text]
22. LANGNER G. Die zeitliche Verarbeitung periodischer Signale im Hörsystem: Neuronale Repräsentation von Tonhöhe, Klang und Harmonizität. *Zeitschrift für Audiologie Acoustics*. 2007; 46(1):8-21. [Abstract] [Back to text]
23. LEVITIN D. *This is your brain on music. Understanding a human obsession*. London: Atlantic Books; 2008. [Abstract] [Back to text]
24. LIPPENS V. Inside the rower's mind. In: V Nolte (Ed.). *Rowing faster*. Human Kinetics, Inc.; 2005. Pp. 185-194. [Back to text]
25. MATTES K, BÖHMERT W. (1995). Biomechanisch gestütztes Feedbacktraining im Rennboot mit dem „Processor Coach System-3“ (PCS-3). In: J Krug, H-J Minow (Eds.). *Sportliche Leistung und Techniktraining. Schriften der deutschen Vereinigung für Sporwissenschaft*. St. Augustin: Academia; 1995. [Back to text]
26. MCDERMOTT JH, OXENHAM AJ. Music perception, pitch, and the auditory system. *Curr Opin Neurobiol*. 2008; 18:1-12. [Full Text] [Back to text]
27. MECHLING H, EFFENBERG AO. Perspektiven der Audiomotorik. In: *Praxisorientierte Bewegungslehre als angewandte Sportmotorik*. Sankt Augustin: Leipziger Sportwissenschaftliche Beiträge; 1998. [Full Text] [Back to text]
28. MEINEL K, SCHNABEL G. *Bewegungslehre – Sportmotorik. Abriss einer Theorie der sportlichen Motorik unter pädagogischem Aspekt*. Aachen: Meyer & Meyer Verlag; 2007. [Abstract] [Back to text]
29. MUKAMEL R, EKSTROM AD, KAPLAN J, IACOBONI M, FRIED I. Single-neuron responses in humans during execution and observation of actions. *Curr Biol*. 2010; 20:750-756. doi:10.1016/j.cub.2010.02.045 [Back to text]
30. PATEL AD, IVERSEN JR, CHEN Y, REPP BH. The influence of metricality and modality on synchronization with a beat. *Exp Brain Res*. 2005; 63:226-238. doi:10.1007/s00221-004-2159-8 [Back to text]

31. PHILLIPS-SILVER J, AKTIPIS A, BRYANT GA. The ecology of entrainment: Foundations of coordinated rhythmic movement. *Music Percept*. 2010; 28(1):3-14. [Abstract] [Back to text]
32. PUCKETTE M. *The theory and Technique of Electronic Music*. World Scientific Publishing Co. Pte. Ltd; 2007. [Full Text] [Back to text]
33. SCHAFFERT N, MATTES K, BARRASS S, EFFENBERG AO. Exploring function and aesthetics in sonifications for elite sports. In: R Dale, D Burnham, CJ Stevens (Eds.). *Human Communication Science: A Compendium*. Sidney: ARC Research Network in Human Communication Science; 2011. [Full Text] [Back to text]
34. SCHAFFERT N, MATTES K, EFFENBERG AO. A Sound Design for Acoustic Feedback in Elite Sports. In: S Ystad, et al. (Eds.). *Auditory Display. 6th International Symposium, CMMR/ICAD 2009*. Berlin: Springer-Verlag; 2010a. [Abstract] [Back to text]
35. SCHAFFERT N, MATTES K, EFFENBERG AO. Listen to the boat motion: acoustic information for elite rowers. In: R Bresin, T Hermann, A Hunt (Eds.). *Proceedings of the 3rd Interactive Sonification Workshop (ISon).* Stockholm: KTH; 2010b. [Full Text] [Back to text]
36. THAUT MH, TIAN B, AZIMI-SADJADI MR. Rhythmic finger tapping to cosine-wave modulated metronome sequences: Evidence of subliminal entrainment. *Hum Movement Science*. 1998; 17(6):839-863. doi:10.1016/S0167-9457(98)00031-1 [Back to text]
37. VOGT K, PIRRO D, KOBENZ I, HÖLDRICH R, ECKEL G. Physiosonic – Evaluated Movement Sonification as Auditory Feedback in Physiotherapy. In: S Ystad, et al. (Eds.). *Auditory Display. 6th International Symposium, CMMR/ICAD 2009*. Berlin: Springer-Verlag; 2010. [Full Text] [Back to text]
38. WOLPERT DM, KAWATO M. Multiple paired forward and inverse models for motor control. *Neural Netw*. 1998; 11:1317-1329. doi:10.1016/S0893-6080(98)00066-5 [Back to text]
39. ZATORRE RJ, CHEN JL, PENHUNE VB. When the brain plays music. Auditory-motor interactions in music perception and production. *Nature Reviews Neuroscience*. 2007; 8:547-558. doi:10.1038/nrn2152 [Back to text]
40. ZATSIORSKY VM, YAKUNIN N. Mechanics and biomechanics of rowing: A review. *Int J Sport Biomech.* 1991; 7:229-281. [Abstract] [Back to text]

Other References:

BeSB GmbH Berlin: http://www.besb.de/; retrieved May 1st, 2011.
Musical Instrument Digital Interface (MIDI): http://www.midi.org/; retrieved April 29th, 2011.
Rowing example "Sin-ification": http://www.youtube.com/watch?v=PDBdYG57mc4. Retrieved December 2, 2010.

