Original Article

Testing immediate and retention effects of acoustic feedback on the boat motion in high-performance rowing

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ABSTRACT

Schaffert, N. & Mattes, K. (2014). Testing immediate and retention effects of acoustic feedback on the boat motion in high-performance rowing. *J. Hum. Sport Exerc., 9*(2), pp.616-628. Evidence exists, that rhythmic information, provided audibly, supports the timing of movement-execution subliminally. This study aimed to test immediate effects of acoustic feedback (AF) on mean boat speed during on-water rowing training with elite athletes in two squad-levels and to observe the retention of effects. 20 athletes (14 seniors, age 22.6 ± 1.6 years, body mass 93.1 ± 9.8 kg, body height 192.5 ± 3.3 cm; 6 juniors, age 17.5 ± 0.2 years, body mass 85.0 ± 7.4 kg, body height 189.3 ± 8.8 cm) of the German National Rowing Team in 8 boats (small and big boats) participated in the study. Boat acceleration and distance travelled were measured with Sofirow. The boat's acceleration-time trace was converted online into AF and presented to the athletes via speakers. Repeated measures within-subjects factorial ANOVA showed significantly increased mean boat speed with AF compared to baseline for both squad-levels ($P < 0.01$) as well as for the retention-test compared to pre-test ($P < 0.01$). Intra-cyclical analysis revealed significant changes in the acceleration-time traces. Athletes perceived AF as supportive for training, providing functional information about the boat-run, independently from vision. The concept was integrated into the final-preparation for the World Championships. **Key words**: SONIFICATION, ROWING BIOMECHANICS, PERFORMANCE ANALYSIS, MOVEMENT EXECUTION, TRAINING.

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INTRODUCTION

In competitive sports, training and testing devices have been commonly used to optimise the training process and to analyse athletes' performance. Its usage has been widely recommended for performance improvement (Krug & Martin, 1999; Liebermann, Hughes, Bartlett, McClements & Franks, 2002). Sports-specific feedback-systems also play an essential part (Baca & Kornfeind, 2006; Smith & Loschner, 2002; Harfield, Halkon, Mitchell, Phillips & May, 2014) and augmented feedback can facilitate the process of learning or improving a motor-skill (Magill, 2010; Schmidt & Lee, 2011; Wulf, Shea & Matschiner, 1998; Khan & Franks, 2004). In rowing, synchronous visual feedback is regularly used to control training of rowing-technique (Mattes & Böhmert, 1995; Mattes, 2012). Progress in technology offers new ways for presenting feedback to athletes, including acoustic feedback (AF), which is a new and promising application. Although it is known that acoustic stimuli have a profound and direct effect on the motor-system (Thaut & Abiru, 2010), auditory feedback-information presentation is sparsely used up to the present. AF for performance improvement in high-performance sports has recently become increasingly interesting.

Research in sports science provides empirical evidence that using sonification AF has effects on perception accuracy, reproduction and regulation of movement-patterns (Effenberg, 2001; 2005). There is growing evidence for the benefits of movement sonification on motor control and learning (Effenberg & Mechling, 2005), which can be enhanced by concordant multimodal information presentation (Shams & Seitz, 2008; Effenberg, Fehse & Weber, 2011). The results illustrate the potential of enhancing perception-accuracy of human movement by sensitising the listener/athlete to its time-dynamic structure. Research in neuroscience has revealed evidence, that rhythmic information, provided audibly, supports the timing of movement-execution subliminally (Kenyon & Thaut, 2005; Bengtsson, Ullén, Ehrsson, Hashimoto, Kito & Naito, 2009; Tecchio, Salustri, Thaut, Pasqualetti & Rossini, 2000). AF has thus become increasingly interesting for technique training in high-performance sports, where time-critical structures are of crucial importance for the precision of successfully executed movements. Studies in ecological acoustics showed that humans obtain information from surrounding sounds in combination with their everyday-experience of listening to interact with the world and to interpret the environment (Gaver, 1993). From an experts' viewpoint, movement accompanying sounds were a fundamental evaluation-criterion for a movement's quality. Since such sounds were equally as significant as the sensation of executing a movement itself, auditory-based evaluation can act as an indicator for the feeling of the movement.

Using the sense of hearing to get a feeling for the movement is not a new approach. In the early stages of physical education, rhythmic stimuli were used to illustrate time-dynamic aspects of movement processes to the learner (Röthig, 1967). Naturally, movements and sports actions are always accompanied by sounds. Owing to the physical characteristics of movements and sounds on the time-base, they are inseparable from each other. The loudness of a sound event is the physical consequence of a movement's kinetic energy, representing its physical characteristics. Sonic events within the human hearing-range occur here as a result of the contact-phase (the impact-sound of a ball reflects its velocity and impact-force). In rowing, the sound of the boat's forward-motion provides the athletes with information about the boat-run. Elite athletes, especially, use this sport-specific sound as a source of natural feedback in combination with kinaesthetic responses to obtain information about the boat-run (Lippens, 2005). Owing to the specific properties of the auditory-sensory-system with its sensitivity to time-dynamic aspects and temporal characteristics of events, the information contained in the sound is used mostly unconsciously. Only when the sound is missing does its essential importance become evident. In its absence, most of the feeling for the resulting forces and their effect on the movement is lost as it is in principle not possible (or very difficult) to observe dynamic aspects of movements directly. In rare cases it is only possible to estimate the forces originating from movements qualitatively and quantitatively via the kinematical effects such as displacements and changes of location as well as deformations of materials or bodies.

New analysis and feedback systems providing acoustic information about the boat motion can support technique training. Synthetically produced acoustic information as AF is created using sonification whereby complex data structures are mapped to sound to monitor changes in data. This additionally provided AF offers abundances of possible applications for observing movements and detecting changes therein. An online AF-concept for elite athletes has been developed, and was empirically tested with junior athletes (Schaffert, Mattes & Effenberg, 2011). It was found that AF has an effect on the time-structure of the rowing-cycle, particularly on the recovery which is the most critical phase in terms of the boat-run as there is no propulsion by the blades (Kleshnev, 2010). By coordinated movements of the athletes, the boat is released to run forward after the blades have been extracted from the water and whilst the crew slides on the seats in the direction opposite to the boat's forward-motion. AF can provide detailed information about the athletes' movements and their execution during the recovery as well as for the time needed for execution of the reversal points (catch/finish turning points).

The purpose of the present study was to examine immediate effects of AF on mean boat speed during on-water training in only a few training sessions with elite athletes in two squad-levels and to observe the retention of effects during training.

METHODS

The investigation was conducted during the final preparation phase for the World Championships. The protocols were performed under a license obtained from the review committee of the German Rowing Association (DRV). Data collection was part of routine measurements within the regular sport science support.

Participants

20 athletes (14 seniors, (mean ± SD) age 22.6 ± 1.6 years, body-mass 93.1 ± 9.8 kg, body height 192.5 ± 3.3 cm; 6 juniors, age 17.5 ± 0.2 years, body mass 85.0 ± 7.4 kg, body height 189.3 ± 8.8 cm) in 8 boats participated in the study. Boat categories ranged from small to large boats (pair, double sculls, four squad sculls, eight). Before testing athletes provided consent to participate after being informed about the aims and investigational procedures of the study.

Measurement

The AF-system Sofirow (Schaffert & Mattes, 2011) was used, that measures and stores the boat's kinematic parameters: acceleration (3D-MEMS-sensor, sample-rate adjustable up to 125 Hz) and distance travelled (4-Hz-GPS). Boat speed was GPS-measured (accuracy of $0.1 m \cdot s^{-1}$) and derived from the acceleration data using the special analysis software Regatta. AF was produced by converting the acceleration-time-trace for the driving direction (x-axis) in real-time into sound using Parameter-Mapping (Grond & Berger, 2011) and was presented to the athletes via in-board mounted speakers in the rowing boat. AF-presentation was remote-controlled from the scientist in agreement with the coach who could also listen to AF in the motorboat. The acceleration-time-trace was mapped to tones on the MIDI-scale (electronic-musical-scale) in relation to tone-pitch. The sound result thus changed as a function of the boat's acceleration. Simplified, the faster the boat was accelerated, the higher was the sound in tone-pitch.

Test Design and procedures

Athletes were introduced to the procedure with the presentation of a video-sound-sequence. After the regular warm-up-phase at the beginning of training-sessions, a baseline was conducted to assess standard of rowing technique and -performance of each crew. Following this, AF was presented in feedback-blocks, each separated in 5 sections with AF and without (nAF) presentation in alternating order (duration of 3 minutes each). Each block was conducted in tailwind-direction along the 2000-m-regatta-course to avoid variations in environmental conditions. Athletes were instructed to row at a constant stroke rate within the regular training frequency of 20 strokes per minute (max. variation 0.5 strokes per minute) to ensure that possible effects on the rowing-technique were because of the influence of AF rather than because of an increase in stroke rate, which itself can influence the acceleration-curve (Kleshnev, 2010). Athletes were asked to perform the sliding with the seat during the recovery phase as smooth as possible without variations according to the sound and they should avoid the tone-pause between the rowing strokes during the front reversal. Five feedback-blocks with the last 30 rowing cycles per section were selected and averaged for statistical analysis; separated for seniors and juniors.

To clarify aspects of long-term effects, a procedure was conducted over a 2-week-period with junior athletes. The standard of rowing-technique of each crew was assessed before (pre-test), during (post-test) and at the end (retention-test) of the intervention-time (nAF protocol in each test) with feedback-blocks in-between.

In addition, standardised questionnaires assessed the athletes' impression during rowing with AF and investigated coaches' valuation of its benefits for technique training in racing-rowing. Questions addressed comprehensibility, correspondence with the rowing-movement and AF's attention-guiding function.

Characterization of the effectiveness analysis

For detailed examination of changes in boat speed and evaluation of effects, the acceleration-time-trace was analysed intra-cyclically (curve sketching) in relation to the phase structure of the rowing cycle and of athletes' movement. In general, the rowing-stroke is separated into two characteristic main phases: drive and recovery, with further subdivision into the catch and finish turning points (front and back reversal). For its detailed analysis, 12 points in time within the acceleration-time-trace were determined that represented characteristic events (extreme-values, minima, maxima). Time-intervals between the events were defined to assess the changes that occurred within the time-structure of single movement sections. In addition, acceleration-values during the drive phase were examined.

Finally, 3 characteristic areas were identified within the propulsive-critical phases: area #1 during the recovery (including the start of the forward-sliding to the point where the slide is stopped), area #2 within the front reversal (including the forward-position and the catch), and area #3 acceleration-values during the drive. Table I provides the key to the single events.

Table I. *Key to characteristic events in the boat acceleration-time trace*

Time Point ; Acceleration-Value	Classification
t_1 [s] ; t_{12} [s]	a_{Bmin}
t_2 [s] ; t_{10} [s]	$a_B = 0\ m\cdot s^{-2}$
t_3 [s]; a_{B3} [$m\cdot s^{-2}$]	local a_{Bmax}
t_4 [s]; a_{B4} [$m\cdot s^{-2}$]	local a_{Bmin}
t_5 [s]; a_{B5} [$m\cdot s^{-2}$]	a_{Bmax} drive phase
t_9 [s]	a_{Bmax} recovery phase
t_{11} [s]	$\Delta a_B < -0.2\ m\cdot s^{-2}$

Time Interval	Classification
Δt_1 [s]	front reversal (2) ($t_2 - t_1$)
Δt_{10} [s]	second part recovery ($t_{11} - t_{10}$)
Δt_{11} [s]	front reversal (1) ($t_{12} - t_{11}$)
Δt_{rec} [s]	recovery ($t_{11} - t_9$)

Notes: t = time; aB = boat acceleration

Data analysis

Descriptive statistics including means and standard deviations were calculated for each section, separately for juniors and seniors, and each test. Repeated measures within-subjects factorial ANOVA compared boat speeds among sections with AF and nAF presentation, separately for seniors and juniors, and among pre-, post- and retentions test. Partial eta-squared (ηp^2) was calculated as effect-size to rate the impact of factors between the sections according to Cohen’s classification (0.10 = minimal effect; 0.20 = medium effect; $\geq$ 0.38 = large effect) (Cohen, 1988). Statistical significance was set at the 5%-level (IBM SPSS version 21.0).

RESULTS

Table II shows the means for boat speed and stroke rate for the sections AF and nAF, for seniors and juniors as well for the tests. The immediate and retention effects of AF on mean boat speed for the two squad-levels are presented in Table III. Significant main effects for AF were found for both juniors and seniors, during the sections with AF compared to baseline ($P < 0.01$). Mean boat speed was also significantly increased in both consecutive sections without AF for the seniors, and in the last section without AF for the juniors ($P < 0.05$) compared to baseline. But the sections without were slower than with AF. No statistical differences were found for stroke rate and acceleration-values.

Table 2. *Mean ± SD for boat speed and stroke rate; N=14 (seniors), N=6 (juniors)*

Squad level	Section/ Test	Boat Speed [$m \cdot s^{-1}$]	Stroke Rate [1/min]
Seniors	**Baseline**	4.15±0.03	20.2±0.2
	AF 1	4.26±0.02	20.1±0.2
	nAF 2	4.22±0.03	20.2±0.1
	AF 3	4.28±0.02	20.1±0.1
	nAF 4	4.20±0.02	20.1±0.2
Juniors	**Baseline**	3.70±0.01	19.9±0.2
	AF 1	3.79±0.01	19.8±0.1
	nAF 2	3.75±0.02	20.0±0.2
	AF 3	3.83±0.02	19.9±0.1
	nAF 4	3.78±0.02	19.9±0.2
Juniors	**Pre**	3.84±0.02	20.1±0.2
	Post	4.00±0.01	20.2±0.1
	Retention	4.05±0.01	20.1±0.1

Notes: AF = with Acoustic Feedback, nAF = without Acoustic Feedback

Table 3. *Immediate and retention effects of AF training on mean boat speed for two squad levels*

Squad level	Section/ Test	Δv_B	± 95% CI	*P*	eta^2	Δv_B %
Seniors	**AF 1**	0.11 ± 0.02	0.05 - 0.15	0.001	0.66	2.6
	nAF 2	0.07 ± 0.02	-0.33 - 0.16	0.051	0.16	1.7
	AF 3	0.14 ± 0.01	0.03 - 0.22	0.001	0.42	3.2
	nAF 4	0.05 ± 0.01	-0.01 - 0.16	0.050	0.30	1.3
Juniors	**AF 1**	0.08 ± 0.02	0.03 - 0.14	0.001	0.92	2.2
	nAF 2	0.05 ± 0.01	-0.23 - 0.13	0.052	0.68	1.3
	AF 3	0.13 ± 0.02	0.04 - 0.17	0.001	0.93	3.3
	nAF 4	0.07 ± 0.01	0.04 - 0.15	0.042	0.80	2.0
Juniors	**Post**	0.09 ± 0.02	0.04 – 0.20	0.001	0.97	2.3
	Retention	0.12 ± 0.01	0.03 – 0.25	0.001	0.98	2.9

Notes: AF = with Acoustic Feedback, nAF = without Acoustic Feedback; ∆vB = mean difference in boat speed between sections versus baseline (m·s-1); ± 95% CI = 95% confidence intervals of differences; P = significance at the 5%-level, sections versus baseline; eta2 = effect size (0.10=small, 0.20=medium, >0.38=large effect); Mean change in boat speed (%), sections: AF/nAF versus baseline; tests: post- and retention- versus pre-test

The results of the retention analysis revealed a significant main effect for mean boat speed ($P < 0.01$). Between-subject effects detected higher mean boat speed for the post and retention-test compared with the pre-test ($P < 0.01$). Effect-size of retention on mean boat speed revealed a high impact ($\eta p^2 = 0.98$). No statistical differences were found for stroke rate and acceleration-values.

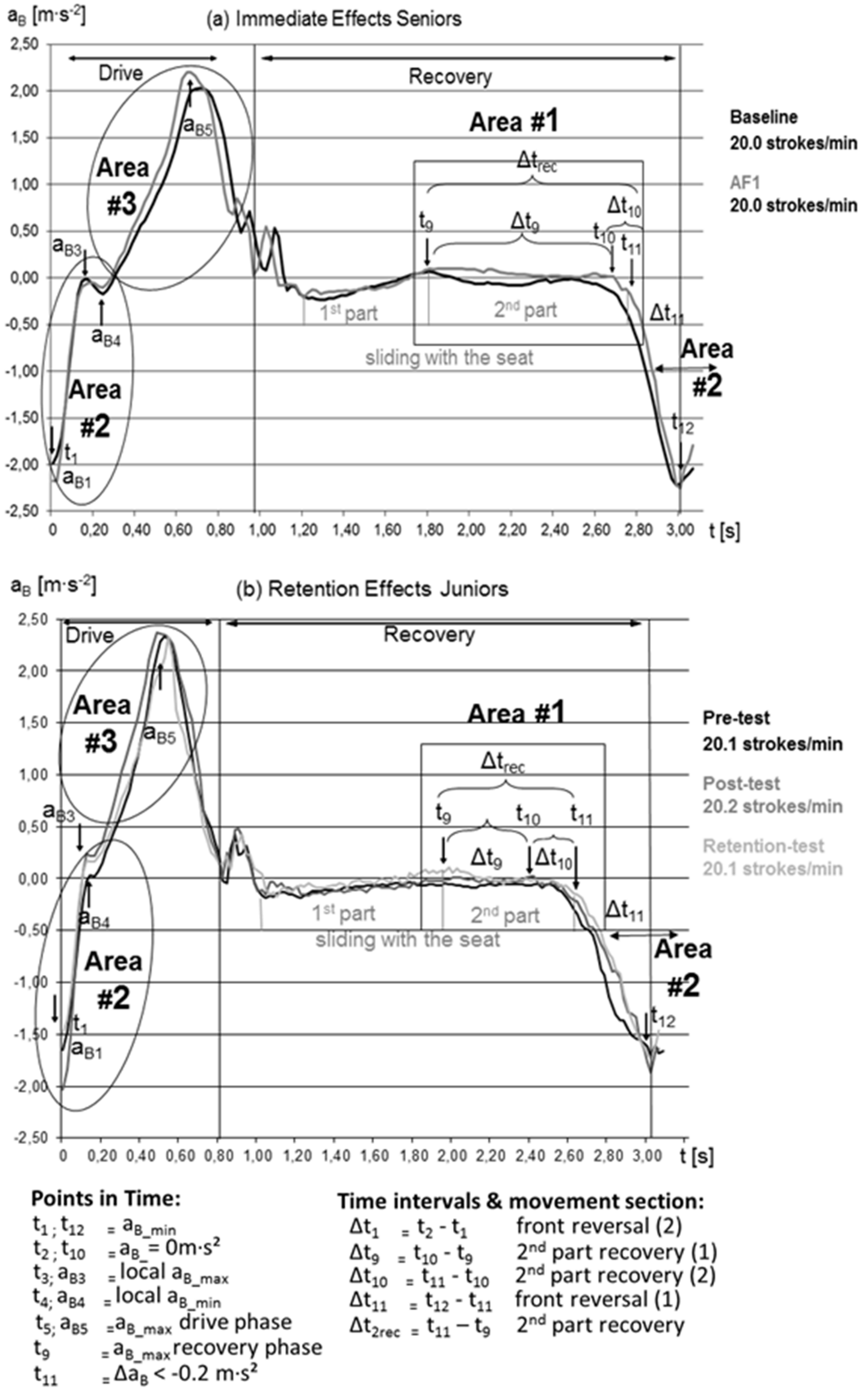
Intra-cyclical analysis revealed improvements within the time-structure of boat-acceleration-curves for seniors and juniors as well as for those in the post and retention-test. Table IV shows the means for the three areas. Changes in area #1 showed an extended time-period of positive acceleration (time-interval Δtec) and a shortened deceleration phase of the boat (Δt10). In area #2, both time-intervals Δt11 and Δt1 showed a reduced time of marked negative acceleration. No significant differences were found for the acceleration-values (area #3) although mean acceleration-curves of the AF-section indicated higher acceleration-values during the drive phase.

Table 4. *Mean ± SD values for three characteristic areas for the sections and tests for seniors and juniors; N=14 (seniors), N=6 (juniors)*

Squad level	Section/ Test	Area # 1		Area # 2		Area # 3		
		Δt_{rec} [s]	Δt_{10} [s]	Δt_{11} [s]	Δt_1 [s]	a_{B3} [$m \cdot s^{-2}$]	a_{B4} [$m \cdot s^{-2}$]	a_{BmaxD} [$m \cdot s^{-2}$]
Seniors	**Baseline**	0.65±0.02	0.40±0.02	0.49±0.04	0.23±0.02	0.13±0.10	-0.07±0.02	2.06±0.11
	AF 1	0.72±0.03	0.19±0.01	0.35±0.02	0.17±0.01	0.12±0.07	-0.03±0.01	2.10±0.8
	nAF 2	0.67±0.02	0.35±0.03	0.45±0.02	0.22±0.01	0.14±0.09	-0.05±0.03	2.08±0.10
	AF 3	0.75±0.04	0.17±0.02	0.31±0.01	0.15±0.02	0.11±0.03	-0.08±0.02	2.11±0.7
	nAF 4	0.70±0.02	0.32±0.01	0.41±0.02	0.20±0.02	0.12±0.05	-0.04±0.04	2.12±0.12
Juniors	**Baseline**	0.44±0.02	0.38±0.02	0.35±0.01	0.23±0.03	0.13±0.03	-0.03±0.03	2.01±0.8
	AF 1	0.37±0.01	0.27±0.01	0.15±0.01	0.16±0.01	0.13±0.01	-0.03±0.01	2.11±0.9
	nAF 2	0.40±0.02	0.37±0.02	0.32±0.02	0.21±0.02	0.14±0.02	-0.04±0.02	2.08±0.10
	AF 3	0.35±0.01	0.21±0.01	0.13±0.01	0.13±0.01	0.17±0.01	-0.07±0.01	2.07±0.7
	nAF 4	0.39±0.02	0.33±0.02	0.30±0.02	0.20±0.01	0.12±0.01	-0.02±0.01	2.12±0.09
Juniors	**Pre**	0.36±0.02	0.46±0.03	0.36±0.02	0.25±0.01	0.14±0.11	0.03±0.11	1.83±0.14
	Post	0.64±0.01	0.19±0.01	0.15±0.01	0.10±0.01	0.24±0.01	0.02±0.01	1.90±0.15
	Retention	0.68±0.02	0.17±0.02	0.15±0.02	0.08±0.02	0.26±0.11	0.03±0.10	1.92±0.17

Notes: AF1 = first section with Acoustic Feedback, measured during the last training session; Δtrec = recovery phase (t11-t9); Δt10 = second part recovery phase (t11-t10); Δt11 = first part front reversal (t12-t11); Δt1 = second part front reversal (t2-t1); aB3 = local acceleration maximum; aB4 = local acceleration minimum; aB5 = acceleration maximum during the drive phase.

The changes in the mean acceleration-curves for the first section with AF compared to baseline are shown in Figure 1a using the example of the Men's Quadruple Scull (M4x). Figure 1b illustrates the changes for the post- and retention compared with the pre-test using the mean acceleration-curves of the Junior Men's Pair (JM2-).



Points in Time:

$t_1 ; t_{12}$ = a_{B_min}
$t_2 ; t_{10}$ = $a_{B\_} = 0 m \cdot s^2$
$t_3 ; a_{B3}$ = local a_{B_max}
$t_4 ; a_{B4}$ = local a_{B_min}
$t_5 ; a_{B5}$ = a_{B_max} drive phase
t_9 = a_{B_max} recovery phase
t_{11} = $\Delta a_B < -0.2 m \cdot s^2$

Time intervals & movement section:

Δt_1	= $t_2 - t_1$	front reversal (2)
Δt_9	= $t_{10} - t_9$	2nd part recovery (1)
Δt_{10}	= $t_{11} - t_{10}$	2nd part recovery (2)
Δt_{11}	= $t_{12} - t_{11}$	front reversal (1)
Δt_{2rec}	= $t_{11} - t_9$	2nd part recovery

Figure 1. *Mean boat acceleration-time traces (30 rowing cycles). (a) baseline versus first section with acoustic feedback (AF1), measured with seniors; (b) post- and retention-test versus pre-test, measured with juniors*

Athletes' subjective descriptions revealed the supportive function of AF as "it is helpful, and enables an improved check on the individual rowing-technique". Further, it indicated "focussed improvements of the weak points in the movement" by "pointing to things of which we have not been aware before". This yielded an increased "consciousness of the movement". More precisely, characteristic phases within the curve became recognizable and easier to detect due to changes in the sound sequence as "it is audibly very clear that the tone became lower during the slide-movement". That focussed athletes' attention on the critical aspects of the curves, especially a smoother execution of the rowing-movement as "it is possible to control mistakes directly" by "keeping the tone as constant as possible during recovery". The coaches' statement reported that AF improved the smoothness of the movement-execution during the recovery and was rated to be beneficial for on-water training.

DISCUSSION

The present study was designed to examine immediate effects of AF on mean boat speed with elite athletes in two squad-levels and to observe the retention of effects in on-water training. On the basis of a previously developed overall concept of AF for rowing (Schaffert, Mattes & Effenberg, 2011), it was aimed at covering a gap in communication between athletes and coaches during the training process by providing feedback acoustically, as sound conveys time-critical information that is important for the precision in movement-execution (Kenyon & Thaut, 2005). Further, AF is implicitly intelligible to every athlete without further explanation, which verbal instructions, in contrast, often require.

Statistical results showed significant improvements in mean boat speed for both squad-levels in sections with AF-presentation. Intra-cyclic analysis confirmed that AF beneficially affected the time structure of acceleration traces for propulsive-critical areas #1 and #2: the overall duration of the second recovery part and the duration of propulsion was greater whereas the time needed for preparing the next rowing stroke (front reversal), and so the duration of deceleration was less. Effects occurred because of improvements in the time-structure during the recovery rather than as a consequence of greater effort during the drive phase. To provide information about a potentially higher physical effort of the athletes, the acceleration-values were analysed for the drive phase of the rowing cycle. The magnitudes of differences between the sections were small and inconsequential for mean boat speed (Kleshnev, 2010). The immediacy of the effects might be astonishing as the rowing-action is a relatively automated movement which is executed cyclically and it thus is hard to effect changes therein. But results from feedback training with elite rowers show that it is possible to modify specific technique characteristics directly by means of feedback provided during rowing and to refine movement execution (Mattes, 2012). This fine-tuning is achievable with elite rowers particularly, even after a few rowing-strokes, as they are better able to modify their movements owing to their more highly developed, experienced-based sensitivity in executing the rowing-motion, compared to novices. Findings in neuroscience indicate that auditory rhythmic cues add stability in motor control immediately (within short period of stimuli presentation) rather than through a gradual learning process (Thaut, 2005). Facilitation and immediacy of effects presumably occurred due to the close neural connection between auditory and motor areas and happened at subliminal levels of sensory perception (Repp, 2006).

The intervention was conducted during the final preparation phase for competition which is typically marked by fluctuations in the athletes' performance. In fact, overall athletic performance typically improves during this period (Mattes, 2012). The feedback training was designed to refine rowing technique and enhance the encoding of mental imagery to develop an internal template for correct movement (Mattes & Böhmert, 1995), to support the focus during this time of competitive preparation on rectifying specific deficiencies.

During this phase of training it is of particular importance that athletes internalise a correct movement execution and develop stable templates for reproduction. The retention analysis showed significant differences between the post- and retention test versus the pre-test. This lead to the conclusion that the benefits taken from AF on modifying the movement-execution was retained during the 2-week-period of intervention. The effects presumably occurred because of the athletes' improved focussed concentration on a common characteristic area within the rowing-motion that was guided via time-synchronous AF. It is the time-base of acoustic information that provides regular reference points and also can guide the focus of attention reliably to specific sections. Furthermore, it supports synchrony and effectiveness of interaction which becomes observable when humans easily move in time and effortlessly adjust their movements to rhythmical acoustic elements such as beat and tempo. This was consistent with the athletes' inner-sensation of and their feeling for the boat-run and supported the execution in a uniform way that yielded to an enhanced crew-rhythm and possibly to an improved synchronisation of the crew's movements.

Because of the data-to-sound-mapping, the functional attribution of tone-pitch as a function of changes in acceleration, made the sound particularly informative; detailed information about periods of acceleration and deceleration were conveyed as a result of the parameters and the instantaneous states of kinematic influences (boat, athletes' movements and water resistance). Thus, the characteristic profile of the rowing cycle was represented in the periodic patterns of tone-pitch and intensity which are caused by the boat acceleration. As such, the resulting sound facilitated a clear perception of the specific areas within the acceleration-curve and facilitated their modification. It was possible, for example, to extend the duration of the sliding-movement within the recovery by a more careful executed movement in combination with delayed deceleration of the sliding. As a result, the front-reversal was shortened. Athletes stated that they were aware of this modification in executing the movement by trying to sustain the high pitch-tone, and to keep the time before the tone began to lower, for as long as possible during the recovery (area #1). This is reflected in the measured data, in which the corresponding time-interval Δtrec was longer and thus the recovery was enhanced. In terms of area #2, the athletes tried to keep the time in which the tone felt below the human hearing range, during the finish turning points with maximum negative acceleration, as short as possible. This resulted in a reduction in the corresponding time-intervals during which the boat was decelerated (Δt11 and Δt1).

For understanding the process between sound-perception and movement-modification, the theoretical basis of an action-related behavioural dynamic approach (Warren, 2006) was taken in combination with an ecologically-based approach to perception. As such, perception is considered as a process in which the time-structure of external events is synchronized with the time-structure of internally-perceived events (Jones, 1986). This is in-line with psychological theories in attention research and psychophysical perception that describe the process of attention-focussing as dynamical according to which the perceiving individual has the ability either to listen to the complete sound sequence or to bring specific sections within the acoustic event into the focus of attention (Cherry, 1952; Bregman, 1990). This flexibility in concentration is consciously driven and is an essential quality of the human perception system.

Using AF to support the refinement of movement execution in high-performance rowing takes advantage of the time-base of rhythmic information that affects the motor-system and enforces motor-reactions (Thaut & Abiru, 2010). Via the rhythm and its inherently stimulating nature, the sonified boat-motion can improve the feeling for the movement and its duration. This produced more synchronised executed movements and contributed to the reduction of intra-cyclically occurring variations in boat speed. Moreover, it supports the athletes' feeling for the rhythm of the specific boat (i.e. of different stroke rates and different boat categories) by creating associations between AF and the movement execution. This is in line with research in motor control and learning according to which the learner develops internal models between the stimuli presented and the movement outcome (Schmidt & Lee, 2011).

Athletes reported an overall positive reaction and high acceptance of AF. The athletes described the supporting function of AF for technique training in high-performance rowing because of its attention-guidance on specific sections within the rowing-movement. Particularly on those sections that affect the boat-motion critically such as the concentration on the second-part of the recovery and the finish-turning points. "… the sound pointed to things of which we have not been aware before and we became more conscious of the movement." … "The sound demonstrated audibly very clearly the deceleration of the boat during the slide-movement." … "It is possible to control mistakes directly, such as in cases in which placing the blades was too slow." They further stated that the sound result was in correlation with their kinaesthesia and corresponded to the movement-execution … "the sound evoked and amplified the movement".

Although differences were found among the athletes' individual statements in dealing with the sound, most of them appreciated it as a supportive training-aid. However, the underlying mechanisms of AF's positive influence on motor-performance presumably vary depending on the individual as the perception of feedback-information differs in principle between individuals. Especially when feedback is presented in a new way (audibly) and, even more, when it is generated synthetically as it could be confusing or potentially perceived as disturbing. Actually, most of the athletes stated that AF did not interfere with their normal perception during rowing which is in line with results from previous investigations (Schaffert, Mattes & Effenberg, 2011).

However, further investigations should combine biomechanical data and physiological data to assess also the role of feedback-induced changes in the biological effort by the athletes during the drive-phase.

CONCLUSIONS

The AF-concept described contributes to previous research in rowing-biomechanics (Affeld, Schichtl & Ziemann, 1993; Böhmert & Mattes, 2003; McBride, 2005; Nolte, 2011) and complements the existing visual analysis of the rowing-technique used for biomechanical diagnostic analysis (Mattes, 2012) suitably expanded for the audible domain. Sofirow is the first device that synthetically creates AF of the boat-motion and offers audible assistance for movement-execution. The concept was successfully implemented into the preparation for the World Championships within the DRV.

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