Sound Joined Actions in Rowing and Swimming

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Abstract

The present chapter introduces the method of sonification as a tool for studying intercorporeality and enactment. We show that auditory movement information can support motor perception as well as the control of movements, and explain these effects by mechanisms which are consistent with the enactment approach. Providing additional auditory information about a movement enables the acting individual as well as observers to perceive the movement in exactly the same way via audition. Thus, a sonification can establish a common percept for all interaction partners, which corresponds well to the concept of intercorporeality. Furthermore, we show that sonifications can be specifically designed to constitute a variety of frameworks for the analysis of interpersonal coordination and intercorporeality.

Keywords

Sonification, internal modelling, motor control, motion perception, multisensory integration

Introduction

Interpersonal coordination, intercorporeality and interkinesthesia in sports and also in everyday situations are based on a close connection between perception and anticipation of actions as well as on the motor actions of all agents involved. From a traditional point of view, perception, anticipation and action refer to distinct phenomena guided by their own rules and separate functional substrates. But current theories state that one aspect cannot be considered without the others. For example, a key hypothesis in embodiment research is that action observation triggers an internal modelling of movements which actively involves the motor system. Therefore, during interpersonal interactions, the motor system seems to fulfill two distinct functions: one related to observing and anticipating other persons' actions and another related to planning and controlling one's own motor behavior. But sometimes this distinction becomes blurred: A recent study shows that perceiving another participant moving in a rocking chair subconsciously influences one's own rocking frequency, even if both participants are instructed to ignore each other (Demos et al., 2012). Thus, the participants unintentionally integrate the observed movement frequency into their own movement production – a phenomenon supporting the concept of intercorporeality.

In this chapter, we present the method of ‘sonification’ and highlight its potentials for the study of intercorporeality as well as interkinesthesia and enactment. Based on empirical data we argue that auditory movement information can influence aspects of perception and action that seem to be relevant for the interaction of an individual with a partner or with its environment.

The chapter will be structured as follows: After describing the method and concept of sonification, we present cases of its efficacy on individual motor control and movement observation and refer to possible neurophysiological mechanisms. Then we describe results indicating the retrieval of internal movement representation by sonification. Finally, we show that sound can be applied to constitute a variety of frameworks for the study of interpersonal coordination.

The method of Movement Sonification

> Sonification is the use of nonspeech audio to convey information. More specifically, sonification is the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation (Kramer et al., 1999, p. 2).

The field of sonification subsumes a variety of disciplines and is in its core interdisciplinary. In relation to human movements, Effenberg (1999, 2005) established the term *movement sonification*, which aims at an enhancement of perception and action. The principle of movement sonification is illustrated in Figure 1. A kinematic parameter is computed based on video sequences recorded in a swimming flume and mapped onto an artificial electronic sound: When the distance between wrists and pelvis is maximal, the sound amplitude is minimized and the frequency (not shown) is lowest. When the swimmer pulls his arms towards his pelvis, the sound increases in pitch and volume, resulting in a typical sound pattern which represents the arm stroke pattern. Every change of the movement kinematics will result in an adequate change of the resulting sound pattern.

Figure 1 about here

By sonifying human movement parameters in congruence to visual or kinesthetic movement information, a sonification fulfils the requirements for the activation of multisensory integration mechanisms as described in the next section.

Mechanisms of multisensory integration

Stein and Meredith (1993) have described the mechanisms of multisensory integration down to the level of a single neuron: Multisensory neurons respond with sophisticated activation patterns related to intermodal input characteristics, making motor perception as well as motor control more multifaceted and more reliable on a sensorimotor level in case of convergent afferent input of at least two different modalities (Stein & Stanford 2008). These supporting effects seem to depend on two factors: Two or more perceptual systems instead of only one are tuned into the process of perceiving a distal event. Each of them brings in its particular characteristics and thus better specifies the distal event in terms of generating more internal information about it, as described by Stoffregen and Bardy (2001). When multimodal information is integrated in multisensory regions of the CNS, the process of fusion seems to be optimized by statistical principles as described by Ernst and Banks (2002) for the integration of visual and haptic cues.

But what are the fundamental preconditions for addressing multisensory areas and what are the basic mechanisms? Calvert et al. (1998) have described three distal preconditions for audiovisual integration: Besides spatial and temporal proximity for information rich stimuli, time-varying similarity in the patterning or 'structural equivalence' seems to play an important role.

Movement Sonification and Sports

Approaches within the discipline of Sport Science reflect the whole range from fundamental research with high internal validity to applied research with high ecological validity. Applied research plays an important role for the development of new, more effective intervention methods. Assuming that more senses are more powerful in perceiving gross motor patterns it should be supportive to create and convey more acoustic movement information. For multisensory integration benefits, additional auditory movement information has to correspond to the structure of a perceptual feature stream of another modality (visual, kinesthetic, tactile). For such an acoustic enhancement of motor perception Effenberg (1996, 2004, 2005) has established the concept of 'movement sonification', adapting the sonification approach of the early 1990s to the kinematics and dynamics of human motor behavior. Transferring findings from multisensory integration to grossmotor behavior in the fields of sports, motor rehabilitation and everyday movements, two different categories of movement parameters can be used: (1) Dynamic parameters representing the forces generated by the muscles as well as the force of gravity. (2) Kinematic parameters representing the spatiotemporal features of a pose or a movement pattern.

The question whether dynamic or kinematic movement parameters should be chosen for movement sonification should be answered under consideration of the sensory modality or modalities with which bi- or multimodal convergence should be achieved: If visual motion perception is the reference, movement sonification should be based on kinematic parameters. And if, on the other hand, perception of muscle tension and muscle force are the referenced perceptual streams, dynamic movement parameters should be selected to achieve a high level of structural equivalence. In practice, we have implemented movement sonifications based on dynamic (1) as well as kinematic (2) parameters during recent years. For both types we obtained neurophysiological evidence of multisensory integration. (1) When sonifying the ground reaction forces of counter-movement jumps, it has been shown that motor perception as well as motor control benefit significantly from movement acoustics added to video stimuli (Effenberg 2004, 2005). Furthermore, these behavioral effects coincide with an enhanced neuronal activation in multisensory regions of the perceptual system caused by convergent audiovisual movement information (Scheef et al., 2009), which might be an explanation for the behavioral effects. (2) Subjects are able to perceive differences in swimming stroke frequency more accurately when visualizations of a swimmer are complemented with a kinematic sonification. This perceptual benefit coincides with an enhanced activity of the action observation system and also of parts of the motor loop – although participants had perceived such audiovisual stimuli only for about 25 minutes before and had not moved to such kind of movement acoustics at all (Schmitz et al., 2013).

Modifying and optimizing sensorimotor control

Sensory information from different modalities is integrated via several quite different mechanisms that affect the perception and action loop in distinct ways. This section describes a phenomenon which is usually mentioned in the context of perceptual or motor performance deteriorated by bodily or environmental changes: When two modalities provide different information, the central nervous system remains capable to act by fusing slightly divergent sensory information to a single percept or by adjusting sensorimotor representations.

Recent findings provide evidence that auditory feedback can be applied as substitutive or additional feedback to modify performance during goal-directed arm movements. If participants point to a series of invisible speakers and are provided with continuous auditory feedback about the size and direction of the deviation from the straight trajectory towards these speakers (which is an alternative to the concept of movement sonification), spatial accuracy of goal-directed movements improves compared to performance without feedback. It even becomes as good as during visuomotor performance, i.e. when participants point to visual targets with visual feedback (Schmitz and Bock, 2014). An exemplary case is reflected in Figure 2.

Figure 2 about here

In that study, the direction of arm movements without additional auditory feedback was laterally shifted by about 7 degrees from auditory target direction on average. Auditory feedback significantly reduced this bias to about 4 degrees, which was not significantly different from performance with visual feedback to visual targets. Auditory feedback already improved accuracy immediately after movement onset, in a period in which the feedback of the ongoing trial could not have been effective yet because the processing of sensory information is time consuming. Thus, the feedback-guided actions of the former trials modified the movement vector of the next trial. Since the starting position for each movement was clearly defined by a wooden dowel underneath the subject's chin and therefore invariant, we argue that this effect was caused by a modified representation of the movement goal. This is plausible, considering the results of other studies on auditory movement information: Boyer et al. (2013) designed auditory avatars which separately coded directional position of targets and the hand. Although feedback about the hand had no measurable effect, target presentation time significantly influenced movement accuracy. A longer target presentation time provided more information about target location and thus very likely enhanced the subject's internal representation of the target. Further studies which investigated the role of auditory feedback on hand or arm movements only found significant results when feedback contained some information about the target or movement goal (Maulucci and Eckhouse, 2001, Robertson et al., 2009, Rosati et al., 2012).

The sensitivity of goal-related information can be explained by the internal modelling approach. According to Shadmehr et al. (2010), the perception of a given sensory state is better if the actual feedback about a sensory state is integrated with an a priori estimation about this sensory state. It can be assumed that this a priori estimation (referred to as feedforward modelling) is closely related to movement intention and is generated prior to the motor command (Desmurget et al., 2009). However, the updating and shaping of perceptuomotor control is driven by the so-called prediction-error - the error between estimated and actual sensory state (Shadmehr et al., 2010). For this the intention to move is not sufficient anymore (Ong et al, 2012); instead, subjects have to be active themselves and have to perform goal-directed movements. In more detail, Gaveau et al. (2014) have shown that the prediction error needs to be validated by the feedback error or the information about the success of a movement, respectively; i.e. the comparison of movement performance with the movement goal is necessary. This reasoning suggests for the study of Schmitz and Bock (2014) that the auditory feedback predominantly affected the feedforward modelling of the intended arm positions and calibrated the movement vectors by a fusion of the estimated final arm position with the perceived (invariant) target position.

According to further data from the same study, the adaptive rearrangement of perceptuomotor control depends much less on the sensory modality which provides feedback, than on the quality of the feedback. The authors argue that the efficacy of such calibration might be further enhanced by the development of highly accurate feedback methods. For this, the method of movement sonification offers great potential. Current research in motor rehabilitation on hemiparesis of the upper limbs in stroke patients provided first evidence about the effectiveness of real time sonification of arm movements related to sensorimotor deficits. Though the number of participants of this pilot study was small, a significant effect on relearning of everyday movement patterns of the affected upper limb occurred after five days of multimodal training (Schmitz, Kröger and Effenberg, 2014).

The mentioned phenomena are in line with the enactment approach. As described by Meyer and von Wedelstaedt in chapter 1 of this book as well as by McGann (2014), perception unfolds as a continuous process during movement or interaction with the environment. Findings on altered perception after perceptuomotor adaptation can be interpreted as empirical evidence for this view (Hatada, Rossetti, & Miall, 2006, Hay & Pick, 1966, Redding & Wallace, 1988, Simani, McGuire, & P. N. Sabes, 2007, Uhlarik & Canon, 1971), because perceptuomotor adaptation unfolds during the goal-directed interaction of the individual with its environment based on the above-described mechanisms (Gaveau et al., 2014; Shadmehr et al., 2010).

Activation of the action-observation-system and the motor loop during the observation of a kinematic sonification

Data on functional magnetic resonance imaging suggest that a sonification of kinematic movement parameters can address brain areas that are associated with multisensory integration and action observation and engages a basal ganglia frontocortical network (Schmitz et al., 2013).

Figure 3 about here

We visualized kinematic data of a world champion in swimming (Figure 3) and sonified the spatial distances from wrists to pelvis and ankles to pelvis (Figure 1). The participants were lying in a magnetic resonance scanner, watched a visual swimmer model and concurrently listened to a sonification of limb movements or to an auditory control stimulus. Brain activity was analyzed by the standard univariate analyses that directly compared activations between both conditions and by functional connectivity analyses to identify network activity within each condition.

The participants were instructed to judge whether two consecutive swimmers moved their limbs at the same or at different velocities. Estimations were significantly more accurate when stimuli contained a kinematic sonification (86.6% correct answers) compared to a control condition with sounds that were not related to the movements (67.6% correct answers). Moreover, decisions were made significantly faster (1160ms versus 1322ms). Perceptual performance differences coincided with different brain activity patterns (Figure 4).

During the observation of sonified movements a more widespread network was active than during the observation of not-sonified movements. This network included areas associated with multisensory integration and parts of the mirror-neuron-system. The latter is considered to be involved in social perception and cognition (Allison et al., 2000, Saxe, 2006) and thus might support inter-individual coordination. It is active during the observation as well as during the performance of movements (Rizzolatti et al., 1996, Kohler et al., 2002) and seems to be an interface between perception and motor control. Activations of areas of the motor-loop (basal ganglia, thalamus, frontal regions) by this type of sonification support this view. Since none of the subjects had experienced sonification in relation to their own movements before, these effects cannot be explained by audio-motor expertise. Rather the type of (biological) information carried by the sound might have been the key element for the involvement of the mirror-neuron-system and motor areas during the perceptual analyses of movements.

It should be noted that observation of the visual model with an auditory control stimulus also coincided with activity in parts of the action observation system, but the activation patterns differed from those observed for sonified movements. Thus, a kinematic sonification not only enhances activation in several brain regions, but also leads to an activity shift within the brain. A kinematic sonification might support inter-individual coordination by altering the activity within brain areas that support action understanding and coordination.

Retrieval of movement representations

The neurophysiological study described in the former section predominantly detected pathways in the brain. It remains unclear whether the activation of the mirror neuron system and parts of the motor system actually meant activation of motor representations during the perceptual task. We investigated whether listening to a movement sonification addresses motor representations in a study on indoor rowing (Figure 4). One method to test this is to compare perceptual accuracy regarding a subject's own movements and those of other persons. A better performance during the perception of one's own movements is interpreted as evidence for an internal (feedforward) modelling or simulation of observed movements by the own motor system, because simulation is best when the observed movement is part of the own motor repertoire (Loula et al., 2005).

Skilled athletes rowed for about 45 minutes while they listened to a real-time sonification. A period of 45 minutes might have been sufficient to develop audio-motor co-activation (Bangert and Altenmueller, 2003). This sonification, originally developed by Effenberg et al. (2011) and successfully applied in motor skill learning with rowing novices (Effenberg et al., 2016), informed about grip extension and sliding seat position, as well as forces applied to grip and footrest. We will refer to it as 'multi-channel sonification. Nine to twelve days after this initial session, the same participants heard sonifications of their own and of other persons' movements and were asked to estimate velocity differences of two virtual boats driven by two subsequently heard athletes. Performance was markedly above chance level, but did not improve when they heard their own technique. As a second task, the participants were asked to identify their own techniques. For this purpose, they had to compare the sounds with their internally stored movement representation. The athletes were able to identify their own technique within highly standardized stimuli on the basis of only two rowing cycles. In particular, identification was significantly above chance level when they listened to their own technique (identification rate: 40%, chance level: 25%), but exactly matched chance level when they listened to techniques of other persons (identification rate: 76%, chance level: 75%). In other words, comparing the acoustic movement representation with the internally stored movement representation yielded correct decisions only if the content of heard and stored information corresponded precisely. This finding supports the hypothesis that movement representations are activated by listening to sonifications.

Using a mobile sonification system for capturing and sonifying upper limb actions (Brock et al., 2012), Vinken et al. (2013) recently provided evidence that participants are able to discriminate sonified everyday action patterns of the upper limbs (teeth brushing, rasping one’s nails etc.) even without specific perceptual expertise; i.e. Obviously even without prior sonification experience, recognition of movement patterns is successful when a sonification transmits action-pattern related information. In that study, transmodal discrimination was significant from the first trials on. Increased discrimination rates during the course of the experiment indicate perceptual learning and suggest that specific perceptual expertise is not required for pattern discrimination, but supports it.

Discrimination of rowing patterns

Pattern discrimination is an important factor for the understanding and the analysis of other persons' movements. In the field of sports, observers have to discriminate between highly similar movements. We investigated whether sonification can build the basis for profound pattern discrimination when several persons perform the same movement.

Again, we used standardized rowing movements and standardized sonifications by choosing the same mapping strategy for all participants, i.e. the sonification was normalized on the individual anthropometry. Six male elite rowers (aged 26.3 ± 4.3 years) were invited to participate in two sessions. In session I they rowed for about 45 to 60 minutes on the same indoor rower used in the other studies and listened to a real-time multi-channel sonification. From those sonifications short sound samples of about six seconds were extracted and presented to all participants in session II. The participants were instructed to identify the person they heard. In order to become able to solve this task, this session started with a short auditory presentation of two rowing strokes of each rower who was then named anonymously as "Rower 1", "Rower 2", etc. This procedure was repeated once only.

The results are depicted in Figure 4. Despite the very short familiarization period, in which sounds were assigned to rowers one to six, the participants correctly identified the six rowers in about 35% of all cases. This is clearly and significantly above chance level of 16.6% (one-sampled t-test: t(5)=3.89, p=0.012). According to Cohen (1988) the effect size of d=1.59 can be classified as large. The result is unaffected by the identification of own techniques, which might have happened on the basis of a sound recognition from session I – in contrast to the recognition of movement patterns. But when the participants' own techniques were excluded from the analysis, the effect was still significant (t(5)=4.46, p=0.007, d=1.82). Thus, a possible memory effect of the (standardized) sound from session I was not confounding.

Figure 4 about here

The study confirms results from Vinken et al. (2013) on pattern discrimination of different types of arm movements. It amends these results by showing that sonification can even be used to discriminate extremely similar circular movements without extensive practice.

Taken together, amplified or artificial movement sounds can improve performance in perception and action. Observation of sonified movements activates brain areas associated with the motor loop and addresses movement representations if sonified data provide biological information. A sonification helps the observer to enhance performance, probably by strengthening the access to an internal representation. Therefore, and due to the usability for pattern discrimination, a sonification should also affect inter-personal coordination. The next part describes how sonifications can be applied to study inter-individual synchronization.

Coordinating movements with sonified movements of another person

Fifteen skilled rowers were instructed to synchronize their movements on an indoor rower (Figure 5) to sonifications of another person. Informational content of the sonification was varied: one sonification was created in consultation with expert coaches and provided information about grip force and key elements of the sliding-seat movement. In the following, we refer to this sonification as ‘expert sonification’. Another sonification was the multi-channel sonification already described in the former sections. Both sonifications not only differed with respect to the number and type of movement parameters, but they also emphasized different movement features and thus modified their salience.

Figure 5 about here

Synchronization was measured as the temporal delay between participant and sonified rower at the beginning and end of the drive phase. Measures of all strokes were aggregated to a constant error and a variable error, providing information about temporal bias and variability.

Sonifications had differential effects on rowing performance. When the athletes rowed to the expert sonification, they started their drive phase simultaneously to the sonified person and finished it later (positive error in Figure 6). When they rowed to the multi-channel sonification, they started and finished their drive phase earlier than the sonified person (negative error in Figure 6). Thus both sonifications led to different synchronization patterns as statistically confirmed by a two-way ANOVA Treatment*Time (Treatment: $F(1,14)=7.04$, $p<0.019$, $\eta^2_p=0.33$). The temporal structure of the strokes differed from that of the sonified person, because the errors at the beginning and end of the drive phase differed (Time: $F(1,14)= 10.63$, $p=0.006$, $\eta^2_p=0.43$). Most interestingly, the participants changed this temporal structure from multi-channel to expert sonification, as confirmed by a significant interaction ($F(1,14)=16.36$, $p=0.001$, $\eta^2_p=0.54$). Between-subject variability did not differ between both treatments (Levene's test: $F(1,28)=2.08$, $p=0.160$).

Figure 6 about here

The variability of the temporal deviation between the participants and sonified rower was lower during the expert sonification than during the multi-channel sonification (101 ±48 ms vs. 150 ±76 ms, $F(1,14)=4.66$, $p=0.049$, $\eta^2_p=0.25$). The variability did not differ significantly between the beginning and the end of the drive phase ($F(1,14)=2.34$, $p=0.145$, $\eta^2_p=0.15$). Thus individual synchronization was more stable during the expert sonification.

These results illustrate that different movement sonifications result in different synchronization patterns. A sonification can bias temporal control of movements and thus might be used to modify temporal synchrony of two persons moving together. Furthermore, it might be used to enhance interpersonal coordination as it reduces variability of synchronization and thus increases consistency, depending on the informational content.

It can be assumed that movement synchronization is largely governed by unconscious processes and that the participants were not aware of the subtle differences in their performance between both sonifications. However, the instruction focused on intentional synchronization, and we intended to get further information on the felt usability as well as the acceptance of the sonifications. Therefore, the experimenter asked the athletes after each treatment what it was like to row to this specific sonification and immediately documented the statements (table 1).

Table 1 about here

The statements (table 1) reflect a broad variety of impressions. Nearly all subjects commented on task-performance and on synchronization or adaptation to the sound, movement parameters or the rower as a person. That means that they felt able to set their own performance in relation to features of the instructed model. About a third of all participants commented positively, a third negatively and the remaining subjects not at all on usability of the sounds for the synchronization. Felt usability might depend on usability of the method itself but also on technical differences between the rowers and rowing model. Such differences were evident as reflected in Figure 6, in which the timing of the model at the beginning and end of the drive phase is represented by the value of zero. The mean phase-relationship of the participants differed from that of the model, because their temporal deviations at the beginning of the drive phase differ from those at the end of the drive phase. The statements of some athletes suggest that they had become aware of that (participants 8, 12, 15).

Some athletes felt unable to synchronize to all parameters at the same time and/or focused on alternating parameters. This suggests that peculiarities of the model technique should be considered in future synchronization tasks, and that synchronization might be easier if techniques of the rowing model and the participants are similar.

Eleven of the fifteen athletes focused their attention on single parameters. Statements from seven athletes can be interpreted as they also or exclusively had a holistic view on the sonification. Dominance of parameter-related focus might be explained as follows: 1. The model contained too much information, which is confirmed by the statements of two athletes (P4, P9) but also denied by those of two other athletes (P5, P8). This would suggest a reduction of informational content for future sonification models. 2. The technique of the model differed too much from the participant's technique, so that the athletes could not synchronize to all technical features but had to adapt either to the grip force or the sliding seat movement. As shown by the quantitative analysis and described above, techniques indeed differed. Both explanations are plausible.

Table 2 about here

The athletes' statements about the multi-channel sonification again addressed diverse aspects (table 2). Statements on usability were very similar to those about the expert sonification. The same number of athletes (eleven) as in the expert sonification focused on single parameters. Some statements also suggest a holistic view on the sonification. The participants felt again to have problems synchronizing to all parameters, which matches the assumption that they were not able to adapt to all technical features of the rowing model.

Despite probable differences with respect to the representation or awareness of technical features of the sonified rower, and intra-individual differences, statements about both sonification methods seem to refer to similar phenomena. From a joint reflection of the quantitative and the qualitative analysis, it might be concluded that most of the athletes focused on single parameters, because they had to do so in order to be able to synchronize to the rowing technique of the model. Therefore, in future synchronization tasks the informational content provided might be reduced, to facilitate synchronization with somebody whose technique differs strongly from the own technique. One the other hand, we assessed the synchronization only via the temporal synchronicity of two discrete reference points, the beginning and the end of the drive phase. For on-water rowing, it might also be interesting to look at the complete drive phase or even at the complete rowing cycle in its whole continuity to assess continuous synchronicity. It might be expected that continuous synchronicity results in an increased boat velocity. This aspect has to be investigated in another study.

Comments of some participants suggest that they tried to build a holistic percept of the heard rowing technique. A related phenomenon is indicated by data from Schmitz and Effenberg (2012), who showed that the percept of a distal movement *effect* (the velocity of a virtual boat calculated on the basis of mechanical power) can emerge on the basis of the multi-channel sonification.

From this study it might be concluded that the timing of one's own movements and synchronization with those of another person can directly or indirectly be modified by a sonification of movement parameters. The content of transmitted information seems to be essential for the outcome. The expert- and the multi-channel sonification provide different information about the movement of the partner, resulting in temporally shifted and different synchronization patterns. Therefore, we conclude that these sonifications constitute different frameworks for synchronization. The task itself represents a setting that structures behavior and sets boundaries – primarily in the temporal domain – for individual movement behavior. The specific type of a sonification seems to modify these boundaries due to its informational content and presentation type, so that different movement behaviors unfold.

Bringing together the theoretical perspectives of enactment and ecological psychology in a framework on enacted social ecology, McGann (2014) argues that social interactions not only depend on the individual's abilities, but also on the dynamics of interactions, which override individual tendencies. Such dynamics can be due to our "tendency to synchronize the rhythms of our actions with […] the behavior of others" and might impose tensions within the participants' action (McGann, 2014, p. 7). The interviews presented in this chapter clearly reflect that the participants felt 'tension' during the synchronization. It is possible that this was the echo of the interaction dynamics, which overrode the individual movement tendencies.

We see our results in line with the idea of an enacted social ecology – and this despite the fact that enactment seems to be largely based on unconscious processes, whereas the interview data reflect explicit verbalizations. But the expertise of the athletes (1.) as well as the nature of the task (2.) have to be considered: 1. All participants of the study were highly trained in rowing synchronization and were able to become aware of very subtle aspects of their own and observed movements. 2. The instruction focused on the temporal alignment with the recording of a rower. Therefore, the task yielded a unidirectional and predominantly intentional synchronization, which encourages the athletes to become aware of certain aspects of their own performance.

Modification of team performance

A recent study investigated whether sounds can address complex team behavior (Schmitz et al., 2012). Beat perception and temporal synchronization are partially governed by the same neural substrate (Kornysheva, 2011), so we wondered whether a rhythm can enhance coordination among soccer players. The timeline of ball- and ground-contacts of a skilled soccer player dribbling a ball was embedded into a piece of music. This music was provided via headphones to opposing soccer teams in 22 training sessions of three matches each. In a first match, both teams played without music. In a second match, members of team A heard the music in temporal synchrony whereas members of team B heard it in temporal asynchrony. In the last game it was the other way around. Team performance was evaluated by goals, number of passes, length of pass sequences and number of ball contacts of a person involved in a pass sequence.

The data analysis confirmed improved passing performance in the synchronous compared to the asynchronous condition. Overall-performance was significantly better in teams whose members heard music with the same beat (synchronously, $z = 0.12 \pm 0.46$) than in teams whose members heard different beats (asynchronously, $z = -0.16 \pm 0.43$).

These results suggest that soccer team performance can be influenced by synchronicity of externally provided sounds. Noteworthy, performance changes were evident at ecologically valid performance measures, which are related to inter-individual actions.

Summary and conclusion

In this chapter, we presented the method of movement sonification and its potential for the study of intercorporeality. First and foremost, the potential can unfold in two ways: 1. A sonification might create intercorporeality, since it can create common perception; 2. Thanks to the wide variety of possible designs, a sonification can emphasize specific aspects of movement, action or behavior and thus help to study the underlying mechanisms of intercorporeality through variation.

By transforming human movement data into sound, the sonified individual itself and all of its interaction partners can perceive the movement acoustically in exactly the same way. This creates a shared auditory perception which facilitates embodying another person's movements and ensures that effects of the movements from oneself and from known or unknown persons can be estimated comparably well. The ability to demarcate oneself from others persists, because it is still possible to discriminate highly similar movements (even without specific practice) and to identify one's own movements among those of others (Schmitz and Effenberg, 2012).

When a sonification provides movement information equivalent or complementary to information from the kinesthetic modality, it offers actors and observers or interacting persons the possibility to share auditory information about kinesthetic perceptions and therefore might become an auditory equivalent to interkinesthetic perception. The reported brain activation during the observation of sonified movement amplitudes in swimming support the view of a shared (auditory) movement perception, because observers activate brain areas that are associated with biological motion perception at the interface to the mechanisms of own motor control (Schmitz et al., 2013).

Auditory movement information can address mechanisms of multisensory integration and support the understanding, reproduction and coordination of movements and actions. The information of different sensory modalities is merged into a multisensory percept. A sonification can amend this percept, as it represents a new (artificial) sensory modality, which provides additional movement information in a new way.

The enactment approach states that perception unfolds during interaction with the environment or with a partner (compare chapter 1). This chapter presents data on the efficacy of two different sonifications on unidirectional, intentional movement synchronization. Depending on its specific design, a sonification provides selected information about a partner’s movement. Accordingly, different sonifications constitute distinct frameworks for synchronization, which set different boundaries for inter-individual coordination. Therefore, a systematic variation of a sonification can be applied to investigate the conditions in which inter-individual interactions can unfold.

Auditory movement information can also increase (Effenberg, 2005) or modify (Schmitz and Bock, 2014) perceptuomotor control. We have argued that modifying perceptuomotor control requires an active subject and can induce purely perceptual effects. This is in line with the central postulation of the enactment approach that perception unfolds during interaction with the environment. Whether similar effects can be achieved during interactions with a partner is an exciting question that has – to the best of our knowledge – not been investigated yet, but should be studied in future.

When sound joins actions, performance can be increased, a partner's action can be better understood and interactions can become more successful. In a similar taxonomy as described by D'Ausilio et al. (2014) for the field of music, the method of sonification can be applied in the field of Sport Science to better understand the mechanisms for interpersonal coordination, intercorporeality and interkinesthesia.

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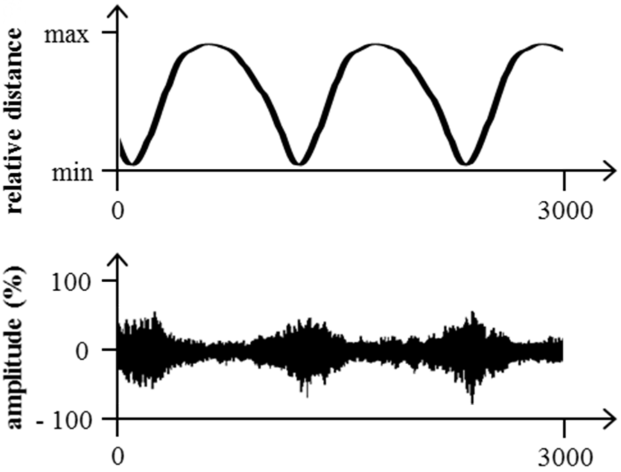

Fig. 1. Principle of movement sonification. Selected movement parameters are mapped onto sound. In this example the relative distance of wrists and pelvis (top row) during breaststroke movements is mapped onto amplitude (second row, sound pressure diagramm) and frequency (not shown). Modified from Schmitz *et al. BMC Neuroscience* 2013 14:32 doi:10.1186/1471-2202-14-32

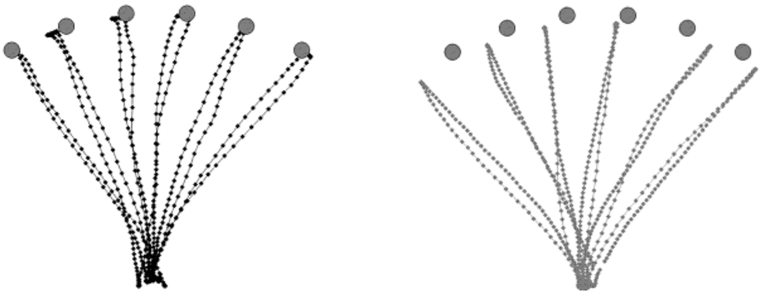

Fig. 2. Trajectories of subjects pointing to auditory targets with (left) and without (right) auditory feedback. Exemplary finding for enhanced precision through additional auditory feedback. Modified from Schmitz and Bock (2014) doi:10.1371/journal.pone.0107834.g001

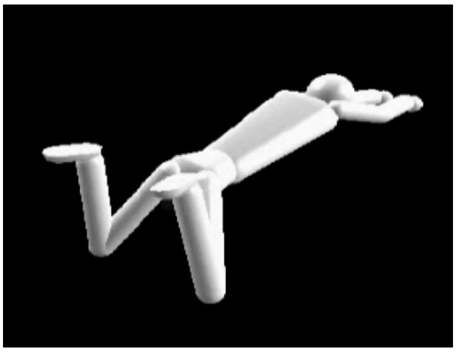

Fig. 3. Visual volume model of kinematic data from a swimmer recorded in a swimming flume. Schmitz *et al. BMC Neuroscience* 2013 14:32 doi:10.1186/1471-2202-14-32

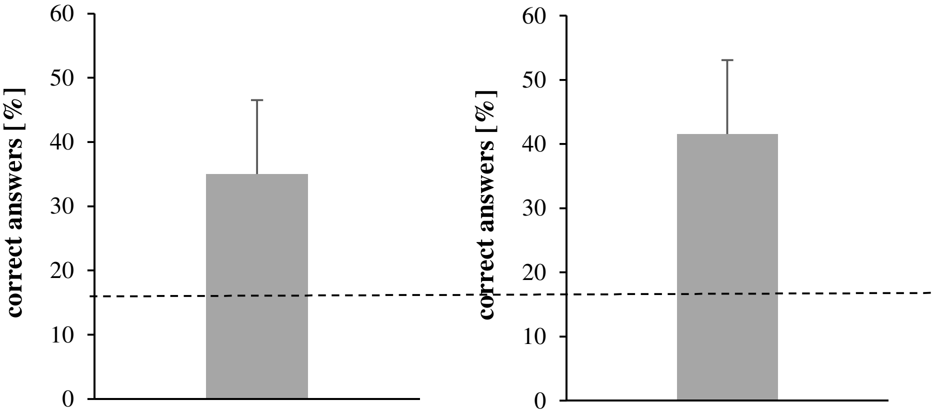

Fig. 4. Pattern discrimination of sonified rowing movements. Means and standard deviations of participants who tried to identify six rowers on the basis of sonifications of two rowing strokes. The left graph shows the rate of correct answers that included the participants' own techniques, the right graph illustrates the result after the own technique was excluded from the analysis. The dashed line indicates chance level.

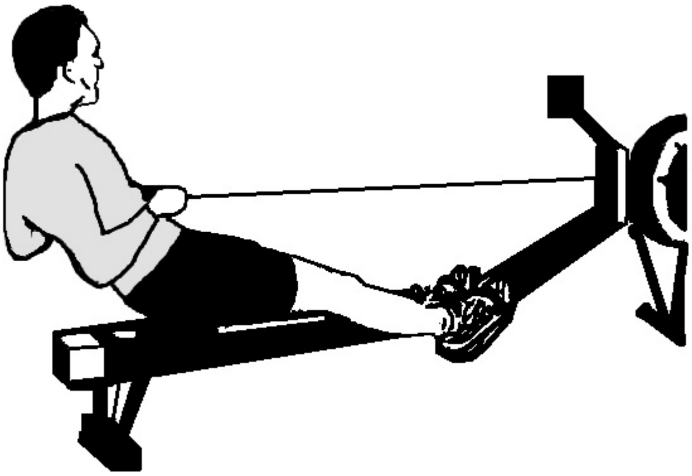

Fig. 5. Indoor rowing. Grip extension, sliding seat position, grip and footrest force were measured and used to modify frequency and amplitude of midi instruments.

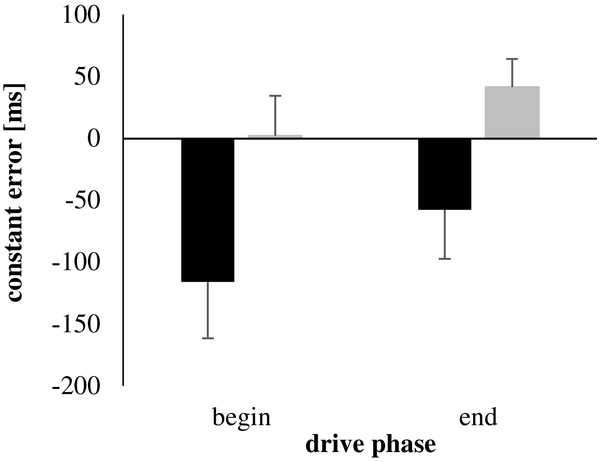

Fig. 6. Synchronization with a sonified rower. Constant error (means and standard errors) of rowing performance during synchronization to the multi-channel sonification (black) and the expert sonification (grey). When the participants started or finished their drive phase earlier than the sonified rower, negative - and in the other case positive - errors were measured.

Table 1. Athletes' statements on the expert sonification.

P1	I probably performed better.
P2	I guess that I did not synchronize well. I did not catch the stop of the sliding seat and stopped too early during the recovery phase.
P3	I felt that I lost it sometimes, but besides this, it was okay.
P4	Unfamiliar, because you had to pay attention to many things. I tried to adapt to the technique.
P5	The best model for synchronization. It has the essential information: 1. Acceleration in the drive phase, 2. you know how the sliding seat moves, and 3. the continuous sound during the recovery phase supports joint sliding. Not too much information, a selection is not necessary. An artificial sound for the sliding seat during the recovery phase is probably easier to imitate than an increasing and a decreasing sound.
P6	The grip force was disconcerting. I synchronized the end of the grip extension with the stop of the sliding seat. The idealized sliding seat movement during the recovery phase was good.
P7	The drive phase of the rowing model was short; probably he was smaller than me. I am not sure whether I adapted to the stop of the sliding seat movement. The grip force at the beginning of the drive phase fitted well. I guess that during the recovery phase, I first failed to synchronize, but at the end, I did it well.
P8	It was nice. There was not too much information, and the information did not overlap. The recovery phase was good. With respect to the stop of sliding seat: I understood it consciously, but could not use it.
P9	Nice idea, but all in all too much information. This made the beginning difficult. I did the catch at the front position well and synchronized well in the middle. You always have to draw attention to two aspects. If you focus on the rhythm, you forget to control the force - force control is important. Something is missing.
P10	I had the feeling that the model sometimes did not row full length but terminated the movement at the half of the drive phase (i.e. he did not use the whole space as sometimes made during warm-up). It is fun! The sound at the stop of the sliding seat is not beneficial, a sound at the end of grip movement would be better. The sound during the recovery phase is very good and can be used for adaptation to the velocity. It is important to arrive at the same time at the front and back positions.
P11	It was difficult. I focused on the deep sound, the sliding seat. The grip force was confusing, I could not adapt to it.
P12	The grip force during the drive phase was confusing; I could not use it. I had the feeling that I had not finished my drive phase yet, when the sound was gone. That is why I only concentrated on the sound of the seat. That worked well. I used both sounds, also the stop signal for the sliding seat, because we currently practice torso movements during the training, and pay attention to such a parameter.
P13	That was extremely bad, the most difficult sonification. The grip force ended too early, actually you are supposed to press. The model stops too early. Furthermore, it was difficult to get used to the two beeps. Normally, the drive phase should be made with tension and the recovery phase relaxed. The sonification emphasizes the recovery phase, so that it is the other way around.
P14	Difficult. I either (and more) focused on the stop of the sliding seat and the forward movement or on the other sound (the grip). I started later with the pull-out than indicated by the sound. In-between I focused on the grip, but then it did not fit to the beep tones.
P15	I predominantly focused on the grip, but also on the sliding seat parameters. I checked, whether we arrive together at the rear position.

P1-P15: Participants 1 to 15.

Table 2. Athletes' statements on the multi-channel sonification.

P1	Probably I have rowed anti-phase.
P2	It was like music.
P3	It is unfamiliar when you do not see anything. My performance was partially bad.
P4	Very pleasant, after I had found out, what the sounds meant. In particular the foot rest force: at first it became louder, and when it ended, I knew that I had to stop.
P5	At first, I focused on one parameter and synchronized to it, then I tried to use the other parameters, experimented and - unfortunately - lost synchronization. It was difficult.
P6	Easier than I thought it would be. During [the initial] listening I had worried about the number of sound channels. I just was lost once after a velocity change. I started to concentrate on the recovery phase - that was quite easy. Then I heard the beginning and the end of the drive phase.
P7	More difficult than the other model. I concentrated on the drive phase. Synchronization was partly good, partly bad. I guess I did not coordinate well with the seat.
P8	My aim was the synchronization in the front and the rear position. I adapted to the pressure course. But I had problems to coordinate with the recovery phase, because the model paused at the front position, but immediately moved the seat again after it had arrived in the rear position.
P9	Lots of information - too much at the fast velocities. At the lower velocities, it was vividly and easy to imagine. I predominantly focused on the pull out and less on the footrest force. At the end I worked with all phases.
P10	Quite well to follow. It was good to hear the position of the seat. But the amount of information would disturb me in a real boat. In an eight, it is sufficient to arrive together at the same time in the front and the rear position.
P11	At the beginning, the synchronization was not easy, because it was too much information. Then I decided to focus on a single information, which first was grip force during the drive phase (power) and then grip extension during the recovery phase (elegant).
P12	First, I was completely wrong, but made it after a velocity change. Now I think I know how it is.
P13	The sound during the familiarization phase was strange. But during rowing it was not bad, it fit to what I wanted to do. Good rhythm. I guess, I misinterpreted the sliding seat position at the front position as footrest force.
P14	Exhausting. You had to focus on a single sound: I chose a deep humming at the beginning of the drive phase and then a "weaau" [grip force]. I was happy that there was no display.
P15	Increasing frequencies signified the drive phase. At the end I changed my mind and focused on a different sound. I thought that decreasing sounds defined the recovery phase, but that did not fit to the other parameters. I guess that we had the same tempo, but rowed differently.

P1-P15: Participants 1 to 15.