PERCEPTUAL EFFECTS OF AUDITORY INFORMATION ABOUT OWN AND OTHER MOVEMENTS

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ABSTRACT

In sport accurate predictions of other persons' movements are essential. Former studies have shown that predictions can be enhanced by mapping movements onto sound (sonification) and providing audiovisual feedback [1]. The present study investigated behavioral mechanisms of movement sonification and scrutinized whether effects of own movements and those of other persons can be predicted just by listening to them. Eight athletes heard sonifications of an indoor rower and quantified resulting velocities of a virtual boat. Although boat velocity was not mapped onto sound directly, it explained subjects' quantifications by regression analysis (R-squared = 0.80) significantly better than the directly sonified amplitude and force parameters. Thus perception of boat velocity might have emerged from those sonifications. Predictions of effects of unknown movements were above chance level and as good as predictions of own movements. Furthermore athletes were able to identify their own technique among others ($d' = 0.47 \pm 0.43$). The results confirm large perceptual effects of auditory feedback and - most importantly - suggest that movement sonification can address central motor representations just by listening to it. Therefore not only predictability but also synchronization with other persons' movements might be supported.

1. INTRODUCTION

Transforming human motion into sound has been the exclusive domain of musicians. But sonification of human movement data has proved to support perception and action in sport: sonifying the ground reaction force of counter movement jumps enhances the perceptual accuracy of jump height ratings, and results in enhanced movement performance, when jumps are reproduced [1]. Although there is growing evidence for the efficacy of sonification, the underlying mechanisms are largely unknown. One possible mechanism is a co-activation of auditory and motor areas in the brain: the listening to a piano melody activates motor areas in the brain, when this melody has been practiced for just 30 minutes [2]. Another mechanism might be enhanced activation of multimodal brain areas: Using the same stimuli as Effenberg [1], Scheef et al. [3] found increased neuronal activation in multimodal brain areas for audiovisual congruent compared to incongruent stimuli, suggesting an amplifier effect of sonification on motor perception. But further mechanisms are probable. A key player for the understanding of other persons' actions is the human action observation system: This systems harbors the so-called mirror neurons that are activated when a person performs an action or when this person observes another person performing the same action [4]. Knowledge of the mirror neuron system comes from studies with visual stimuli, but two recent studies suggest that natural sounds and music address the mirror neuron system as well [5,6]. Since this system is active during the observation of other persons' actions as well as when movements are preformed, it might be the neural interface between perception and action. The hypothesis is that during action observation the mirror neuron system activates the own motor system to internally simulate the movement and its outcome. In consequence predictions should be more accurate, the higher the individual motor experience in the observed task is, and experts should predict outcomes of sport-specific movements better than novices. Actually a study from Aglioti et al. [7] suggested that this is an effect of motor experience on perceptual accuracy: when basketball players, trainers and journalists have to predict the outcome of free shots at the basket, players perform best.

If motor experience shapes perceptual accuracy, effects should not be limited to sport-experts only, because everybody is expert of his own individual movements. Therefore everybody should predict actions best, when he or she observes his own actions ("own-effect"). Several studies have investigated this hypothesis using visual stimuli and found small but significant effects: when dart throws or handwriting strokes had to be predicted, predictions were most successful when the effect of the own movements - and not of movements from other persons - were observed [8,9].

Prediction and identification of actions might not depend on holistic and natural presentations of bodies. Former studies have shown that it is sufficient to display the large joints as point-lights [8,10]. But it still remains unclear which movement parameters provide relevant information. The results of Loula et al. [11], who reported different identification rates for dancing and boxing compared to walking and running, suggest that the significance of parameters varies between movement categories. Therefore a detailed investigation of this aspect is reasonable.

The cited studies argue for a close relation between action and visual perception, notably an internal simulation of movements by the own motor system, when actions are observed. One study reports a similar effect from the field of

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music: Keller et al. [12] found that pianists synchronize their movements better with recordings of their own than with recordings of other persons, indicating that the "own-effect" might not be limited to the visual domain. The demonstration of an "own-effect" for sonification would broaden the knowledge about behavioral aspects and their neural mechanisms addressed by sonification and about motor representations: providing evidence for an internal action simulation on the basis of sonification would suggest that motor representations are multisensory. Therefore one goal of the present study was to investigate, whether sonified movements are anticipated best when they are own movements, and if own movements can be identified by their sonification.

In addition to the theoretical knowledge sport practical implications can be expected: Movement coordination and synchronization depend on action prediction. This is a common principle for intraindividual synchronizations as the coupling of hands [13], as well as the interindividual synchronization of two or more persons [14]. Therefore any team sport and many forms of social interactions should benefit from optimized predictability of own and other movements.

Predictability does not depend on motor experience alone: a crucial factor is the accurate perception of significant movement parameters. Since there is an overflow of information into our sensory systems we have to focus our attention onto single parameters and in this way filter information streams. Years of sport-specific training are necessary to develop perceptual expertise and to direct the attention to important and neglect unimportant movement parameters. Therefore sport-experts show improved perceptual performance compared to novices and predict movements better [15]. In addition to the expertise effect predictability of movements can be enhanced by other mechanisms: Team players often exaggerate their own movements to make them perceivable and predictable to their team mates [16]. Movement sonification can address these issues twofold: 1. Attention can be focused more easily when relevant parameters are accentuated by sonification. But this requires the knowledge of the relevance of parameters. 2. The continuous mapping of movement parameters onto sound enhances the perceptual accuracy in observers, since it provides complementary information to the visual and kinesthetic modality, yielding superadditive integration effects [3], as well as additional or accentuated information about movement features. Therefore a second goal of the present study was to analyze which parameters among others are chosen by athletes to predict action effects and to identify the own movement.

2. METHODS

Eight rowing athletes (21.8 ± 9.2 years) participated in the study. They all had been nominated by the state coach due of their high technical qualification. In a first session they performed 50 minutes on an indoor rower (Concept2, Inc., VT, USA). After 5 minutes of rowing at a self-chosen velocity they were instructed to follow eight different velocities in three blocks of 15 minutes, interleaved by rest breaks of about 10 minutes. Two types of real-time feedback were provided to the athletes: A) Virtual boat velocity was calculated online and displayed by the indoor rower itself, permitting target-performance comparisons. All athletes were familiar with this kind of feedback from their own training. B) Most importantly athletes heard a sonification of their rowing performance via earphones (AKG K330). An exemplary stimulus is attached as supplementary file. The sonification system was described in detail previously [17] and only the main elements will be reported here: The indoor rower was featured with two incremental encoders and two force-sensors attached to the handle, seat and foot rest, measuring grip force and amplitude, seat amplitude and foot rest force (sampling rate 100 Hz, FES Berlin ®). Movement parameters were mapped onto sound using standardized MIDI control messages [18]. Parameter variations were linearly (kinematics) or non-linearly (dynamics) proportionally to modulations of pitch and loudness. Mapping characteristics were standardized inter-individually.

Sonification of four parameters is characterized by a high information density. In addition to the magnitude of the two kinematic and two dynamic parameters, it informs about temporal aspects of the movement: It could be possible to perceive movement frequency by identifying the frequency of similar sound patterns (for example detection of the absolute minimum of the grip amplitude, Figure 1). Combining those information then might built further percepts of mechanical power or individual technical patterns.

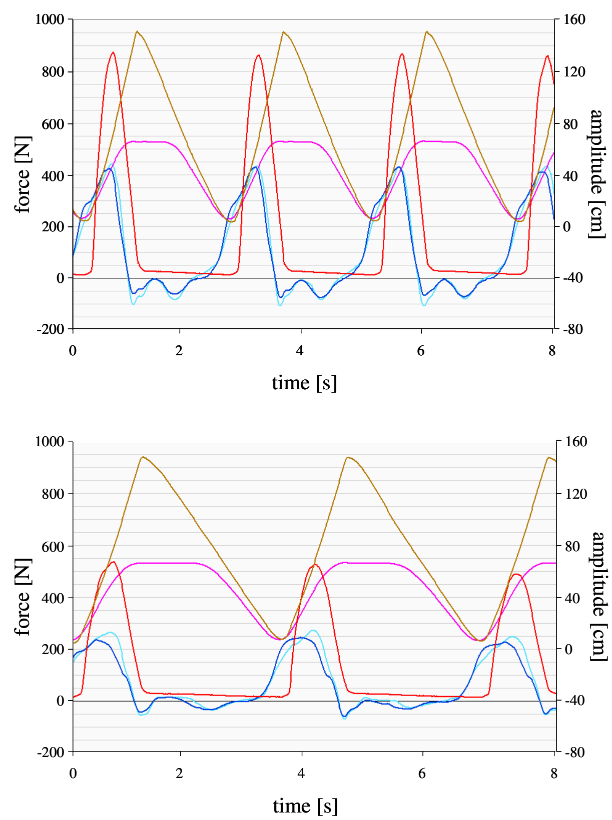

Figure 1: Grip amplitude (light red), seat amplitude (pink), grip force (dark red) and foot rest forces of the left (light blue) and right foot (dark blue) during slow (top) and fast (bottom) rowing cycles.

Perceptual effects of the sonification were investigated nine to twelve days after the rowing session. Each athlete heard sonifications of his *own*, of a person *known* from training or *unknown*. This design was created in accordance to Loula et al. [11], who reported higher identification rates for own movements than for movements of known and unknown persons, confirming the above mentioned “own-effect”. Furthermore identifications were better when movements of *known* persons were observed than those of *unknown* persons, which can be interpreted as significant influence of perceptual expertize on movement perception.

One trial consisted of two consecutive stimuli. Length of stimuli varied randomly and contained about two rowing cycles. Stimuli of one trial were from the same person (*own, known, unknown_same*) or from two different persons (*unknown_different*). 30 trials of each treatment were presented to the athletes yielding 120 trials in one session, arranged pseudo-randomly. Before the session started, subjects received in three trials knowledge of results. This procedure was repeated every 30 trials.

Athletes were instructed to (1.) quantify differences of virtual boat velocities within one trial (task 1: 120 estimations), differing within a range of ±1.4 m/s and (2.) to detect own techniques from the sonifications (task 2: 240 decisions). Virtual boat velocity *v* [m/s] was calculated on the basis of the mechanical power *P* [W] at the grip as

$$v = 500m * \left(\frac{dF * 10^{6}}{P} \right)^{-\frac{4}{11}} \qquad (1).$$

(dF - the drag factor of the wind wheel, which depends on the position of wind panel - was inter-individually standardized at 125 Nms^2). This velocity matches the virtual boat velocity calculated by the indoor rower itself.

3. RESULTS

All subjects performed well at all velocity stages in session I. Movements of different velocities of a single subject are illustrated in Figure 1. Parameters varied marginally between subsequent cycles, indicating that indoor rowing performance was highly stereotyped (Figure 1). Therefore sonification of those parameters resulted in highly stereotyped sounds that were provided to the subjects in real-time.

3.1. Velocity estimations

The perceptual effect of this sonification was investigated in task 1, when subjects quantified velocity differences of two rowers. Velocities of the virtual boats differed from -30% to +40% and subjects´ estimations filled the complete spectrum (Figure 2). To evaluate if subjects had followed the experimenter’s instructions and based their estimations on evaluations of the virtual boat velocity, it was analyzed whether subjects’ estimations could be best explained by the complex parameter virtual boat velocity – not directly perceivable - or other parameters as grip force maximum, foot rest force maximum, grip amplitude and seat amplitude, which could directly be perceived via pitch and loudness differences. Linear regression analysis yielded best predictability of subjects’ estimations by virtual boat velocity, explaining 80% of variance ($F(1,955)=3926.55$, $p<0.001$). Significantly less variability ($t(954)=13.38$, $p<0.001$) was explained by the force maxima (grip force: R-squared=0.67, $F(1,955)=1982.66$, $p<0.001$; foot rest force: R-squared=0.66, $F(1,955)=1821.15$, $p<0.001$) and marginal or no correlations were evident for grip amplitude (R-squared=0.01, $F(1,955)=13.93$, $p<0.001$), and seat amplitude (R-squared<0.01, $F(1,955)=1.72$, $p>0.05$). Therefore perceptual results are best described by virtual boat velocity. Most importantly, explanation of 80% of variance means that only 20% of variability are due to individual differences and preferences, biases and random errors (Figure 2).

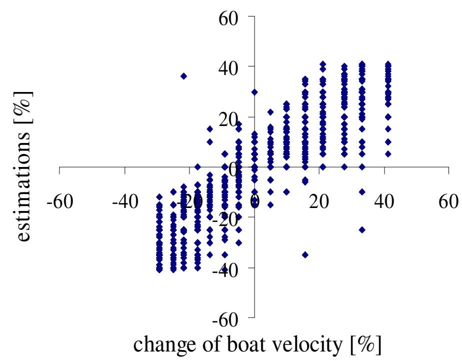

Figure 2: Correlation of estimated and calculated virtual boat velocity of an indoor rower.

To analyze perceptual accuracy to own or others´ sonifications the absolute error between estimated and given change of boat velocity was calculated for the different treatments. Figure 3 illustrates across-subjects´ means and standard deviations: Absolute errors were significantly below chance level ($t(7)=-24.09$, $p<0.001$), which was defined as absolute error of constant estimations of 0% velocity difference. Results differed between treatments as confirmed by one-way analysis of variance ($F(3,21)=4.10$, $p<0.05$).

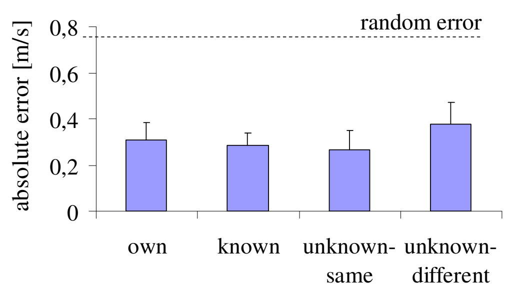

Figure 3: Absolute error [m/s] between estimated and absolute difference of virtual boat velocity when listening to sonifications of the *own* technique, technique of *known* or *unknown* persons.

Decomposing this effect by Scheffe’s post hoc test yielded no differences between *own*, *known* and *unknown_same* (all $p>0.05$). But estimations were better

($p<0.05$) when subjects subsequently heard sonifications of the same rower (*unknown_same*) than of two different rowers (*unknown_different*). The results indicate a high perceptual performance, but performance was not better when a subject heard his own sonification.

3.2. Identification

Task 2 was to explicitly judge whether the provided sonifications were from the own or from other persons´ techniques. Subjects correctly identified their own rowing in 40 ± 16% of all cases, which is significantly above chance level of 25% ($t(7)=2.500$, $p<0.05$). They correctly rejected their own technique to 76 ± 12%, which is close to chance level of 75% ($t(7)=0.289$, $p>0.05$). It should be considered that identification rate could be positively biased by the tendency to identify a technique as "own" or negatively biased by the tendency to identify a technique as "not own". Subjects of the present study responded in 28 ± 11% of all trials that they had heard their own technique, a value that nearly matches the correct rate of 25% ($t(7)=0.715$, $p>0.05$). Nevertheless, response biases might have influenced the results and should be eliminated from analysis. A common procedure is to calculate the discrimination index *d'* as unbiased identification variable, that considers individual relations of *hit* rates (correctly identifying the own technique) and *false alarm* rates (wrongly identifying a technique as "own") [19]. Subjects of the present study yielded a *d'* of 0.47 ± 0.43, which is significantly larger than zero ($t(7)=3.10$, $p<0.05$), confirming a significant detection of own among other techniques.

To scrutinize if identifications can be ascribed to one or more movement parameters exploratory discriminant analysis were calculated. In addition to the four sonified parameters, two technique-related parameters were included as predictors. An initial impulse can be optimized when the grip force reaches its maximum early in time. Therefore t_*grip* was calculated as time of maximal grip force in relation to the duration of the rowing cycle. Impulse transmission from foot rest to grip force necessitates temporal coupling of both forces, which can be expressed by the quotient of the points in time of both force maxima (t_*grip/footrest*). The optimal coupling of both force maxima depends on the anthropometry of the athlete and therefore differs inter-individually; thus each athlete might have his own optimal value and t_*grip/footrest* might support discrimination of rowing techniques. The stepwise procedure resulted in a model with five parameters ($F(5,474)=9.53$, $p<0.001$) explaining 9% of the variance of *hits* (true/false): both technical parameters (t_*grip* $p<0.001$, t_*grip/footrest* $p<0.05$) both amplitudes (grip $p<0.001$, seat $p<0.01$) and grip force maximum ($p<0.001$), but not foot rest force (both $p>0.05$). A stepwise approach with the dependent variable "rejections (true/false)" resulted in a much lower correlation of R-squared<0.006 ($F(1,1432)=9.50$, $p<0.001$), with significant contributions only of t_*grip/footrest*.

4. DISCUSSION

The purpose of the present study was to investigate perceptual effects of a complex movement sonification. Subjects heard movement sonifications of two consecutive rowers and had to estimate velocity-differences of their virtual boats. On a basic level this sonification provides information about two kinematic (grip and seat amplitude) and two dynamic parameters (grip and foot rest force) – parameters directly measured and mapped onto sound. Considering the continuous course of the parameters this sonification even provides information about temporal, biomechanical or technical parameters: Repeating pitch sequences provide information about rowing frequency; the time course of grip force informs about mechanical power; the time of a certain event in relation to other events reflects an individual technical pattern. Correlations between single parameters and the results of the perceptual task would suggest that higher percepts emerge from this sonification of the execution of own or foreign movements.

An interesting finding is that perceptual results were related to complex movement parameters. Variance of perceptual estimations was explained up to 80% by the parameter virtual boat velocity. Cohen [20] labeled correlations as large, as far as they explained more than 25% of variance. The much larger value of the present results therefore strongly suggests that this sonification has a large perceptual effect. Virtual boat velocity had not been mapped onto sound directly and therefore had to be derived on the basis of other parameters. Equation (1) points out that those parameters are related to displacements, time and forces, and correlation analysis show that the sonified parameters do not explain perceptual effects alone. Therefore it can be suggested that percepts emerged from combinations of those factors.

Coefficients of determination were in sum much larger than one and thus argue for a redundancy of information carried by the four sonified parameters. Further experiments might be necessary to reduce this redundancy or to identify the significant information content. But in contrast to this cognitive interest, the applicability of the sonification in training might profit from this redundancy: it gives the opportunity to chose among several parameters and to get sufficient results independent of the choice. The choice itself might depend on several factors as for example individual preferences, expertise, cognitive strategies or attentional focus. Therefore this redundancy could be of interest for experts, but first and foremost for non-experts as they have not learned to detect the most relevant movement parameters and to focus their attention on them.

The detection of the own movement yielded a *d'* of 0.47. Knoblich et al. [9] found in visual prediction tasks *d'*s of 0.34, 0.47 and 0.56, which is comparable to our detection task (task 2). But in contrast to our study those authors found in two experiments that subjects were just able to predict the outcome of self-induced movements, but not those from other persons. A possible explanation for the discrepancy: the prediction rate correlated negatively with the similarity of stimuli that had to be differentiated. When own movements and those of other persons were assimilated via instruction to perform in a defined way, predictions of other persons' movements became possible: Analysis of responses yielded a *d'* of 0.50, which was quite similar to the prediction rate of own movements. This finding sheds light on results of task 1: Movements on an indoor rower are constrained and limited to a few degrees of freedom. The standardization of rowing velocities adjusted and assimilated individual rowing techniques even more. Therefore, in line with

Knoblichs' interpretation, predictions of other movements should have been as good as predictions of own movements. This has exactly been found! Furthermore, when two different rowing techniques were presented within one trial (*unkown_different*), accuracy of predictions was significantly lower than when two similar techniques were presented (*unknown_same*).

Thus it can be concluded that own techniques and those of other persons can be well predicted by listening to movement sonification. This finding is supported by a final identification task, in which all rowers were asked to identify themselves and their named rowing partner after presenting two rowing cycles of five different persons: four athletes succeeded in identification of their *own* and three in the identification of the partner (*known*).

The results are compatible with the view that the own motor system is activated during the predictions of movement effects. The present study demonstrates large perceptual effects of movement sonification and most importantly, own techniques can be identified among others as good as in the visual modality. This suggests in line with former interpretations [8,9,11] that sonification can address motor representations. Latter conclusion is supported by a recent neurophysiological experiment: Schmitz et al. [21] could show that congruent movement sonification addresses the human object observation and mirror neuron system as well as key players of the motor loop. In that study congruent movement sonification was based on two kinematic parameters indicating that they carry sufficient information about the movement to address the mirror neuron and the motor system. Discrimination analysis of the present study supports this view. Two of five significant parameters provided information about spatial distances as in the above cited study. It is tempting to speculate that the technical parameters and information about grip force address motor representation too. But it could be criticized that hits were only predicted with a low to medium effect [19], even if the to-be-predicted own-effect is low. Nevertheless regression models could only predict decisions during presentation of own movements and not movements from other persons, indicating a linkage of those parameters to representations of own movements. Therefore a further study on these aspects including neurophysiological methods should be conducted.

4.1. Practical implications

The present study provided evidence for large perceptual effects of rowing sonifications and their potential to activate the own motor system just by listening to them. These and former findings [17,22] have practical implications. Vesper et al. [16] have shown that joint action – the coordination and synchronization of two or more people – succeeds if an athlete builds representations of his or her *own task* and the *movement goal*. Former studies have demonstrated that sonification can address both aspects: Novices learn more quickly and better to row when the rowing model and their own movements are sonified [17]. Thus they can build better representations of their *own task* than subjects that have to rely on visual perception or "natural" auditory information of the indoor rower. Another study chose a different approach as not movement techniques but movement effects were sonified: In a field-study Schaffert et al. [22] investigated whether the sonification of boat acceleration enhances boat velocity. Providing real-time feedback of boat velocity might help the athletes to build a common representation of the *goal* of their joint actions. By attending the common effect they might coordinate their movements in time yielding a common impulse. This hypotheses are supported by the finding of increased velocities [22].

The present results refer to a third mechanism for joint action addressed by sonification: building a representation of the *task of another person* [16]. Perceiving when and – most importantly - how other athletes move make their movement effects predictable as shown in task 1 of the present study. In consequence the synchronization of own and other movements could be even more effective. However, this is a hypothesis that will be investigated in further studies.

5. CONCLUSION

The results of the present study show that continuous sonification of two kinematic and two dynamic parameters provides enough information to predict the effects of complex movements and to identify the own technique among others. Further studies should investigate whether this kind of sonification can optimize synchronization of athletes.

6. ACKNOWLEDGMENT

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