Movement Sonification: Motion perception, behavioral effects and functional data

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ABSTRACT

The sonification of human movement data is a new approach to support motor perception, motor control and learning in sports and rehabilitation. Perceptual and motor control mechanisms both benefit of additional acoustic information, both are performing more accurate compared to unimodal conditions. But how does movement sonification work when supporting perception and action - especially when processing together with visual information? What kind of perceptual mechanisms are addressed by movement vision and which are activated by additional movement acoustics? While visual motion perception is attended with reference to the approach of 'biological motion perception' in this paper, audio-visual phenomena are treated on the basis of 'multisensory integration'-research. Multisensory integration-research on speech perception as well as on basic perceptual phenomena had identified audiovisual integration sites in the CNS. The activation of multisensory integration-areas correlates with enhanced perceptual as well as behavioral performance. Here we proof this correlation for the sonification of human movement pattern with a first fMRI-study. Data support behavioral effects of movement sonification on perception and action in a first step.

1. INTRODUCTION

Sonification is used in many different applications and also the number of regarded data-streams and data-sound mappings vary in a wide range (Katz et al., Bovermann et al. in this proceedings). To optimize the efficency of sonified auditory information it is important to know how the perceptual system processes available information of other modality, e.g. visual information. How are visual and auditory information getting integrated and how are perceptual activation patterns correlated with behavioral perfomance? In the area of movement perception the visual approach of 'biological motion perception' was initiated by Johansson and Cutting and Kozlowski in the seventies of the last century. There is a huge amount of actual empirical studies on biological motion perception, indicating a still growing relevance of this approach. The approach focuses on visual mechanisms specified for the observation of human movement patterns. Therefore it is valuable for the research on motor perception, motor control and motor learning. Initially biological motion research had been dedicated to cognitive psychology but later on the neurofunctional background has been integrated more and more: Behavioral data had been set in relation to neural activation, measured with brain image techniques. Even if techniques like functional magnetic resonance imaging (fMRI) are quite new, they deliver accompanying evidence for the validity of cognitive models.

After focussing on biological motion perception we will consider the aspect of how visual and auditory perception are interacting. On basic perceptual phenomena like stimulus detection and stimulus identification as well as from the area of speech perception there comes evidence of enhanced performance based on convergent audiovisual information. Adjacent neurophysiological measures reveal that activation of multisensory integration sites correlate with enhanced behavioral data. For sonification research it is important to know about the mechanisms of multisensory integration, especially for applications, where visual information is also available. Since we have observed a higher precision on perception, assessment and reproduction of sport movements based on audiovisual stimuli (video and movement sonification) we are now interested to find out if audiovisual integration sites are activated by additional movement sonification.

2. BIOLOGICAL MOTION PERCEPTION

The term of 'biological motion' stands for mainly grossmotor human motion pattern like locomotion pattern (walking, running, biking etc.) as well as non cyclic motion like Karate or dancing [1], but also for motion of distinct parts of the body. Research on biological motion is based on a characteristical kind of stimulus, call the 'point-light-display': Only the kinematics of main joints of the moving human are marked with little lights or LEDs, and thus subjects can only observe a bundle of light-traces representing the trajectories of the joints on the screen (video or computed animation) as can be seen in Figure 1.

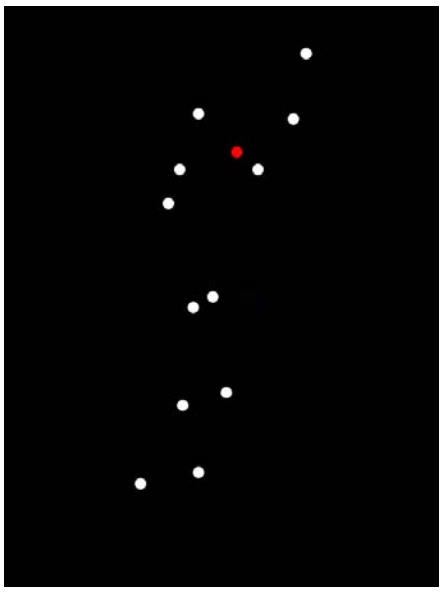


Figure 1: Picture from a 'point-light display' of a jumping person. 12 LEDs fixed on the main joints, a 13th. LED fixed on the head (for better orientation highlighted in red).

Already with the first studies on biological motion a very rapid identification of the demonstrated motion pattern within 200 msec - 400 msec had become evident [2;3]. Furthermore the studies demonstrated a potential of subtle discrimination for similar pattern (discriminating walking friends from unknown people [4] as well as a for different intensities of a certain motion pattern (different throwing ranges of a sandsack, [5]). Especially the very rapid recognition of motion patterns based on a few light traces led to the assumption by Johansson that higher cognition may not be necessary for the identification of human motion pattern and that the low-level mechanisms are primarily bottom-up responsible for motion identification.

About two decades later there was supplementary functional evidence achieved with brain imaging techniques. Within the cortex of the macaque on the level of single neurons some areas had been identified which are responsible for the visual detection and identification of other monkies. Beside others one region of the temporal sulcus was of special interest, because some neurons of the anterior superior temporal polysensory area (STPa) activate only on motions of other monkies or parts of them - but not so on static monkies or other moving objects [6]. Furthermore activation of these neurons were differentiated related on the kind of motion (translation vs. rotation) as well as on the direction of motion and the perspective of the observer. Also on humans the existance of biological motion specified regions in the CNS had been shown: Bonda *et al.*[7] had been showing with PET- and fMRI-techniques enhanced neural activation within the right hemisphere "of the rostrocaudal portion of the superior temporal sulcus as well as in the adjacent middle temporal cortex." The findings of Bonda et al. had been supported by measures of others [1]. The authors reported correlated activity along the ventral bank of posterior superior temporal sulcus (STSp), just behind the dorsal blend. Again enhanced activity was "more highly correlated and larger in extend in the right hemisphere..." (Grossmann et al. 2000, 713).

Even if neurophysiological research can be only touched briefly in this paper, the reported results (besides others, [8]) may indicate the existance of neural mechanisms which are specialized for the analysis of characteristic native kinematic pattern. If movement sonification shall be used additionally to visual information on healthy subjects in sports the question rises if auditory information is competing with visual information or if both kinds of information are getting integrated withing the perceptual system. To deal with this aspect of the perceptual system mechanisms of multisensory integration related to a speech comprehension will be introduced in the next section.

3. MULTISENSORY INTEGRATION

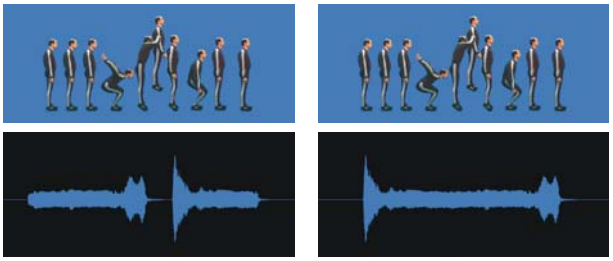
Multisensory integration enhances the ability to detect and to locate distal stimuli like events or objects [9]. Furthermore the identification of distal events and objects is more precise and reliable [10] and attended broadly [11]. Due to the nature of speech perception this area is well suitable for research on phenomena of multisensory integration, especially of audiovisual integration. Traditionally speech perception had been studied as a strictly auditory phenomenon. In the nineties of the last century it had been particularly Massaro [12] and Calvert *et al.* [13] showing the benefits of additional visual information on speech comprehension: Comprehension of spoken words is enhanced, if the talking face could be seen additionally. For our work the following step of Calverts research is of important relevance: Calvert *et al.* [13] used fMRI to look for the functional correlates of enhanced audiovisual determined behavior. Beside other regions they found a correlation for an enhanced activation "... in the ventral bank of the superior temporal sulcus" (Calvert *et al.*, 2000, 651). In this study convergent stimuli had been used (lip movement dubbed audible story in experiment 1) as well as incongruent (different story being mouthed in experiment 2). Results demonstrate, that enhanced activation in the superior temporal sulcus and in further areas activated by audiovisual convergent stimuli correlates with a higher performance, a better comprehension resp.. Calvert *et al.* (2000, 649) were summing up: " The data provide fMRI evidence of crossmodal binding by convergence in the human heteromodal cortex. They further suggest that response enhancement and depression may be a *general property of multisensory integration* operating at different levels of the neuroaxis and *irrespective of the purpose for which sensory inputs are combined*." (accentuations by Effenberg).

For further application of movement sonification in sports as well as in motor rehabilitation it would be essential to prove if convergent audiovisual movement information - a combination of a video of the movement (counter-movement jump) with the sonification of the movement (for stimulus description see [14]) - will also enhance activity of multisensory integration sites within the CNS. For this purpose a first fMRI-study about audiovisual integration on movement sonification had been realized by the Institute for Sportscience and Sport and the Experimental Radiology at the University of Bonn. In our setting subjects should assess counter-movement jumps of different hights under visual, auditory, audiovisual convergent and divergent stimulus conditions. A base line condition had also been added. The brain activation was measured with functional magnetic resonance imaging (fMRI).

4. BEHAVIORAL EFFECTS AND FUNCTIONAL BACKGROUND

When perceiving, assessing and reproducing sport movements like counter-movement jumps additional sonification of the movement pattern ('movement sonification') provokes enhanced performance: Precision of perception is enhanced as well as precision of motor control, as had been shown by Effenberg (2005). But how is higher precision achieved by the perceptual system? In our study subjects should assess counter-movement jumps of different hights under visual, auditory, audiovisual convergent and divergent stimulus conditions. Brain activity was measured with functional magnetic resonance imaging (fMRI) using a SPARSE-Design on a 'Philips Achieva 3.0 T' Scanner [15]. The stimuli are shown in figure 2.

1) unimodal visual 2) unimodal auditory



3) bimodal convergent 4) bimodal divergent

Figure 2: fMRI stimuli had been nearly identical to those used in behavioral studies [14]. Visual: Video of CMJs of different hights; auditory: Movement sonification, based on ground reaction force; bimodal convergent: sychronized Video and movement sonification; bimodal divergent: Video and inverted movement sonification.

5. RESULTS AND DISCUSSION

Results and discussion: Data reveal a specific bilateral activity of area V5/MT and significantly enhanced activity in the convergent condition compared to the divergent condition as to both unimodal conditions alone (visual, auditory). It is the first study showing that V5/MT activity is obviously affected by simultaneous convergent auditory input as generated by movement sonification. Besides that an inhibition of right STS by audiovisual stimulus divergence compared to convergent stimuli had been observed also, but no supraadditive characteristics had become obviously (for detailed results see [16]). Our data are indicating a specific activation of V5/MT and thus data are supporting behavioral findings on perception and action. Additional movement sonification – convergent to available visual information – can enhance precision of perceptual as well as control processes as shown by [14;17]. Though V5/MT is an area integrated within the dorsal visual stream [18], it would be plausible that observed behavioral effects could have been achieved even with less requirement of consciousness.

6. CONCLUSION

We had reported first fMRI data related to a movement sonification indicating, that multisensory integration sites within the CNS can be addressed additionally via convergent auditory information. But this is only a first hint about how sonification *can* work together with visual information, additional research is needed urgently. When dealing with the visual modality of the perceptual system it has become evident, that it is important to know about the emergence of information within each single perceptual modality as well as in intermodal mechanisms additionally. Based on our findings it has become clear that there can be no *single* concept of an optimal efficient sonification defined for all applications. Besides the individual level of expertise it is rather necessary to analyse the whole perceptual scenery, regarding each single modality as well as intersensory functions. If there exists parallel visual information, one way to achieve high efficiency is to generate *convergent* auditory information. Convergent means temporal coincidence and spatial convergence of both stimuli as well as similar stimulus duration and intensity resulting in a structural equivalence [19].

7. REFERENCES

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