
The perception of natural and modulated movement sounds

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Abstract. The motor system is engaged when we perceive movement in the environment, even when we have no sensorimotor experience of that movement. It has been suggested that this ability relies on internal models that comprise specific exteroceptive representations, such as audition and vision. It has been shown that, for human movements, the quality of perception depends on the closeness between the perceived movement and the perceiver's own capability of reproducing it. Thus, if we are able to reproduce a movement, we also have the interoceptive motor memories that enable us to run internal models and perceive the same movements more accurately when merely observed. In a behavioral study we investigated if participants would be able to distinguish between self-produced and other-produced movement sounds from a previously recorded hurdling performance. We also analyzed if participants' discriminative ability would vary as a function of specific sound features, examining rhythmic step structure and amplitude range. The results reveal that participants were able to distinguish between their own and others' movement sounds. However, changing either rhythmic step structure or amplitude range of the sounds did not influence this self–other discrimination. We suggest that identification of one's own movement sounds is holistically achieved as an auditory gestalt.

Keywords: action perception coupling, auditory manipulation, rhythmic step structure, amplitude range

1 Introduction

We perceive movement via multiple sensors, including the ear. As an example, imagine you are sitting in a library listening to a person passing by. It is easy to notice how fast the person is walking and what type of shoes he or she is wearing. In addition to this, you will recognize differences compared with your own movement sounds. What causes this high perceptual performance, and what information from the sound does it exploit? The purpose of the present study was to investigate the perception of movement sounds and to clarify if specific sound features such as rhythmic step structure and amplitude range are particularly important to identify the agent of a movement sound.

A substantial number of behavioral and neurophysiological studies point to a bidirectional coupling between action and perception (for a review, see Schütz-Bosbach & Prinz, 2007). Here, the quality of perception depends on the precision with which a perceived action can be reproduced (Knoblich, Seigerschmidt, Flach, & Prinz, 2002). Internal models (Wolpert & Flanagan, 2001) may be driven by interoceptive as well as exteroceptive sensory consequences (Schubotz, 2007) that influence the perception. More precisely, with an increasing number of appropriate internal models—sensorimotor, but also visual or auditory—the accuracy of perception rises. Consequently, a lack of internal models (eg sense of touch) leads to decreased perceptual accuracy (Bosbach, Cole, Prinz, & Knoblich, 2005).

Perceptual performance has been investigated in various ways, often using agent discrimination (ie the discrimination between self-produced and other-produced stimuli). The underlying assumption is that participants possess motor experience (and therefore internal representations) for their own movements, which should lead to a higher perceptual quality of self-produced actions. Most of the studies examined discrimination by the presentation of visual (point-light displays) or simple auditory stimuli. For instance, participants were able to discriminate agents by exclusively using kinematic information from point-light displays of complex full-body movements, such as dancing (Sevdalis & Keller, 2010), boxing (Loula, Prasad, Harber, & Shiffrar, 2005), basketball (Hohmann, Troje, Olmos, & Munzert, 2011), or walking (Cutting & Kozlowski, 1977). However, discrimination is even possible on the basis of the kinematics of single-limb movements, as has been shown for drawing (Knoblich & Prinz, 2001) and finger tapping (Daprati, Wriessnegger, & Lacquaniti, 2007). Evidence from the auditory modality has been derived, for instance, from studies on clapping (Flach, Knoblich, & Prinz, 2004) and piano playing (Keller, Knoblich, & Repp, 2007). These studies have shown that agent discrimination is possible using solely auditory information. Another line of research has provided neurophysiological evidence of the relation between activity in the motor system and agent discrimination: A higher activation of the premotor cortex was reported for visual (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005) or auditory (Justen, Herbert, Werner, & Raab, 2014) perception of movements, which matched the observers' motor expertise.

However, the characteristic of natural occurring human movement sound is still under-investigated. An intervention study with hammer throwers showed that performance can be increased by using auditory feedback for training (Agostini, Righi, Galmonte, & Bruno, 2004). A microphone was placed on the hammer to record the sounds caused by air resistance against the hammer during the swing phase. The sound of the individual's best throw was used for stimulation in several training sessions. Another study showed that expert golfers are able to discriminate their own golf swings from those of others by using auditory information alone (Murgia, Hohmann, Galmonte, Raab, & Agostini, 2012). Here, overall duration and relative timing seemed to be the sound features that were critical for discrimination. However, since participants were even able to distinguish between different actors with the same temporal structure of up and down swing, it appears that acceleration and velocity can be exploited, as well.

A striking finding from several of the aforementioned studies is that self-recognition is still reliable when the presented stimuli are manipulated and thereby degraded with regard to informational content. Thus, self–other discrimination might be based on a number of sound features. Experiments employing visual stimuli have indicated that only a few points in point-light displays suffice to recognize the agent (for a review, see Blake & Shiffrar, 2007). In the auditory domain, it has been shown that the temporal component (eg length of a clapping sound) is sufficient for successful discrimination (Flach et al., 2004). Self-recognition of clapping sounds was preserved when only the temporal pattern in the form of uniform tones (instead of the original clapping sound) was presented.

A sound is characterized mainly by the frequency and amplitude of the sound wave, but given the particular complexity of natural movement sounds that contain certain spectra, timbres, and balance, there might be other cues for auditory self–other discrimination. From a gestalt perspective (Di Salle et al., 2003), it is questionable if the entirety of the sound is perceived differently from the sum of its individual features. For instance, one individual complex movement sound may not necessarily consist of the exact same sound parts. In particular, human movement generates a unique individual sound (Righi, Galmonte, & Agostini, 2006), independently of the rhythmic structure and the amplitude range that is by itself a gestalt that depends on individual factors, such as the weight, size, and shape of the

feet or the movement style, among others. Therefore, all these sources of information can be perceptually grouped in different ways but some groups may be more informative than others. By manipulating rhythmical step structure and amplitude range, we tried to pinpoint the discriminative relevance of different kinds of information provided by natural sounds.

In the present study we examined natural movement sounds emitted during hurdling. A unique feature of this study is that we used stimuli that are truly audible in a real hurdling situation. In contrast to earlier studies, we recorded the sounds from an in-ear position to generate a direct, perspective-free relation between movement and auditory percept. We hypothesized that self–other discrimination is possible with solely naturally occurring auditory movement information and that this ability depends on specific features of the auditory information.

2 Method

2.1 Participants

Fourteen male undergraduate or graduate students voluntarily participated in this experiment. They were recruited from the local university and took part in this study in return for financial compensation. Their age varied from 20 to 33 years ($M = 23.07$ years, $SD = 3.08$ years). Body height ($M = 182.32$ cm, $SD = 4.88$ cm) and weight ($M = 77.04$ kg, $SD = 6.06$ kg) were collected in order to match pairs (self–other) for the stimulus presentation. All participants had gained their hurdling experience from a university course as part of the athletics education, so performance level was well balanced. Participants did not know each other and were not informed about the experimental hypotheses. All participants self-reported to have normal hearing. The investigation complied with the university's ethics guidelines.

2.2 Stimulus generation

The auditory raw data were collected on a tartan track (a typical synthetic track surface that is used in track and field competition) located in an athletics hall at the local university. The participants were asked to clear four hurdles with a predetermined number of 20 steps. The distance to the first hurdle was 13.00 m. The participants had to accomplish this part with 8 steps. The distances between hurdles two, three, and four were 8.50 m each. Participants had to pass each of these sections with 4 steps (normal hurdling rhythm). These dimensions are equivalent to official competition norms and turned out to be optimal for the students as indicated in a pilot study. The height of hurdles was 91.4 cm. We used special training hurdles (ERHARD SPORT[®]) with a folding mechanism to avoid injuries. The launch took place without a start signal (to avoid noise) from a starting block. We recorded five valid attempts (correct number of steps without touching a hurdle) of every participant. Of the five recorded sounds, we used one for a short training of six trials and the other four in the subsequent perceptual experiment.

To avoid too easy discrimination in the perceptual experiment, we matched pairs of students based upon anthropometric data (leg length and body weight). Owing to the homogenous sample and the small standard deviation, the largest difference within one experimental pair was 2 cm (94/96 cm) leg length and 4 kg (70/74 kg) body weight. Thus, a determining influence on the auditory stimuli was ruled out. We decided to use the above-mentioned criteria not only for matching but also for manipulation, because it has been shown that height (leg length) is directly related to rhythmic structure and weight is an important factor in determining amplitude (Hunter, Marshall, & McNair, 2004). For every participant we created a set of six different stimuli: one self original (S-O) and one other original (O-O); one self with the rhythmic step structure of the matched other (S-RSS) and one other with the self rhythmic step structure (O-RSS); one self with the amplitude range of the matched other (S-AR) and one other with the self amplitude range (O-AR). For a more detailed description see table 1.

Table 1. Different types of stimuli.

Condition	Agent	Rhythmic step structure	Amplitude range
S-O	self	self	self
S-RSS	self	other	self
S-AR	self	self	other
O-O	other	other	other
O-RSS	other	self	other
O-AR	other	other	self

Notes: S-O = self original; S-RSS = self with the rhythmic step structure of the matched other; S-AR = self with the amplitude range of the matched other; O-O = other original; O-RSS = other with the self rhythmic step structure; O-AR = other with the self amplitude range.

The original sounds consisted of 12 steps (three complete hurdling cycles). The beginning of each stimulus was the first step (landing) after the first hurdle. The end was the hurdle step (jump) before the last (fourth) hurdle. The duration of the stimuli ranged from 3.43 to 5.17 s. We aimed to dampen individual sound characteristics such as breathing and rustling of clothes. To this end, participants were instructed to run open-mouthed (to avoid Valsalva maneuver and respiratory sounds) and wear tight-fitting sportswear. Figure 1 shows the specific sound features of one complete movement task (three hurdling cycles).

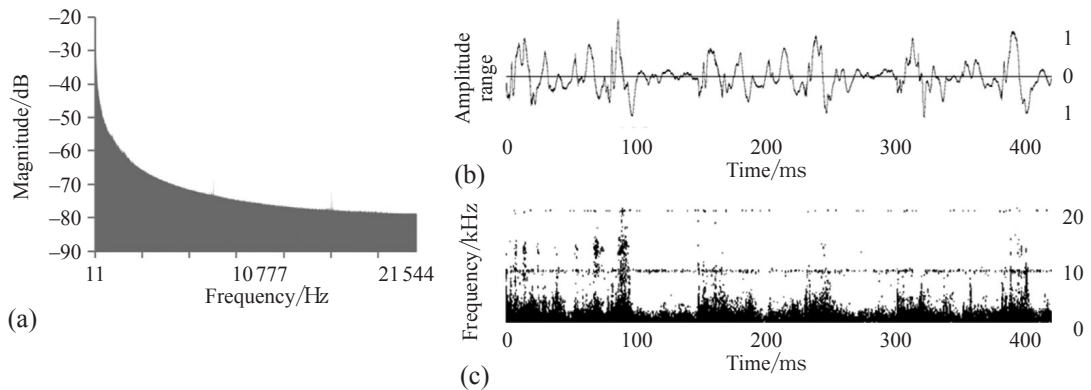


Figure 1. Footstep signature: (a) Fourier spectra of an auditory stimulus, (b) chronological sequence of an auditory stimulus, (c) spectrogram of an auditory stimulus with a sampling rate of 44.1 kHz and a fast Fourier transform size of 4096.

For the adaptation of the rhythmic step structure that is characteristic of hurdling, the start time (first ground contact) of every single step was aligned to that of the matched pair person. More precisely, each particular flight time (time between two steps) was individually adjusted (shortened or extended) in order to generate a manipulated movement sound where the start position of every single footstep was identical to that of the matched pair person. To manipulate the amplitude range, we determined the maximum absolute positive (1 Pa) and the maximum absolute negative (-1 Pa) amplitude. This amplitude range (peak-to-peak amplitude) was afterward adapted to the stimuli of the matched pair person. In more detail, we compressed or stretched the peak-to-peak amplitude of the movement sound in order to obtain the same amplitude range. In both cases we used the audio editor Audacity® 2.0.3. to manipulate the stimuli.

In a pilot study we presented 30 movement sounds (10 for each factor: original, manipulated rhythmic step structure, and manipulated amplitude range) to 12 participants, who were asked to indicate on a 5-point Likert scale, ranging from 1 (original) to 5 (manipulated)

(chance level = 3.0), whether the stimuli appeared to be original or manipulated. Results showed that it was impossible to distinguish between manipulated ($M_{\text{rhythmic step structure}} = 3.1$; $M_{\text{amplitude range}} = 3.1$) and original ($M_{\text{original}} = 3.0$) sounds. Hence, manipulated sounds did not principally differ with regard to general characteristics from natural sounds, excluding an a priori bias to the subjects' judgment in the main experiment.

2.3 Material and apparatus

The movement sounds were recorded binaurally with Soundman OKM classic in-ear microphones (sensitivity: $5 \text{ mV Pa}^{-1} \pm 3 \text{ dB}$). Between the microphones and the recording equipment (Soundman digital recorder DR2; 196 kbps), an A3 adapter (input impedance = $1 \text{ k}\Omega$; output impedance = $47 \text{ k}\Omega$) was plugged in to obtain low noise floor. In addition, we used an acrylic windshield to protect the microphones against rustling noises while the athletes were hurdling. The digital audio editor Audacity[®] 2.0.3 was used to cut and manipulate the recorded sounds that were presented with Inquisit 3.0 by Millisecond Software. The participants heard the stimuli through Sennheiser PX 360 headphones (total harmonic distortion $< 0.1\%$). On the basis of a previous study, we chose a sample size of 14, the before mentioned apparatus, and a stimulus number of 144 trials, estimating an effect size of medium to strong (Kennel, Hohmann, & Raab, 2014).

2.4 Design and procedure

Six to nine months after the recording session, we invited the participants individually into our laboratory. This delay reduced the likelihood that participants would remember specific sounds that they had produced during the recording session. All of them were tested individually in a quiet testing booth where they were asked to follow the instructions on a computer and listen to the presented stimuli. The experiment consisted of a discrimination task in which participants had to decide whether the presented sounds were generated by themselves or a stranger. The participants made their identity responses on 144 trials, consisting of 24 trials of each of the 6 options (S-O, S-RSS, S-AR, O-O, O-RSS, and O-AR), repeating each of the four different recorded stimuli six times. All trials were randomized across actors and type of manipulation. The duration of the entire session was about 30 min.

Before the experimental session, there were six lead-in trials (one for each option, not the same stimuli as in the experiment) for training purposes. Neither in the training nor in the experimental session was feedback provided. The participants were asked to answer on a 6-point Likert scale from 1 (self) to 6 (other) by clicking on the corresponding field of the scale with a computer mouse. The response time for each decision was measured. Participants were not informed about the base rates of the different agencies. They were instructed to focus on accuracy rather than on fast reaction times. After the perceptual experiment, the participants completed a questionnaire. In addition to the query of general impressions of the experiment (three questions about difficulty, duration, and self-assessment on a 5-point Likert scale), we asked specifically for stimulus features on which the participants based their judgment (open question).

3 Results

The first research question was to examine if it is possible to discriminate between self and other movement sounds that occur while hurdling. On the 6-point Likert scale (1–6, self–other) the S-O stimulus was rated 2.68 (SD = 1.12), the S-RSS was rated 2.68 (SD = 1.12), and the S-AR was rated 2.55 (SD = 1.06). The O-O stimulus was rated 4.70 (SD = 0.95), the O-RSS was rated 4.69 (SD = 1.07), and the O-AR was rated 4.77 (SD = 0.89). All values from the different conditions were normally distributed. One-sample *t*-tests showed that discrimination of self-generated original and manipulated sounds was performed significantly higher than at chance level (S-O: $t_{13} = -2.74$, $p < 0.017$; S-RSS: $t_{13} = -2.71$, $p < 0.018$;

S-AR: $t_{13} = -3.39, p < 0.005$). Also, other-generated original and manipulated sounds were discriminated at significantly higher than chance level (O-O: $t_{13} = 4.71, p < 0.001$; O-RSS: $t_{13} = 4.17, p < 0.001$; O-AR: $t_{13} = 5.36, p < 0.001$). A repeated-measures analysis of variance (ANOVA) on the two-level factor agent (self, other) and the three-level factor manipulation (original, manipulated rhythmic step structure, and manipulated amplitude range original) revealed a significant difference in the identification performance depending on the agent ($F_{1,13} = 17.97, p = 0.001, \eta^2 = 0.580$) but not on the manipulations of the stimuli ($F_{2,26} = 0.23, p = 0.798, \eta^2 = 0.017$). The interaction of agent and manipulation showed no significance ($F_{2,26} = 1.61, p = 0.219, \eta^2 = 0.110$). Figure 2 shows the results from the discrimination task on a Likert scale including chance level (3.5) for a clearer description.

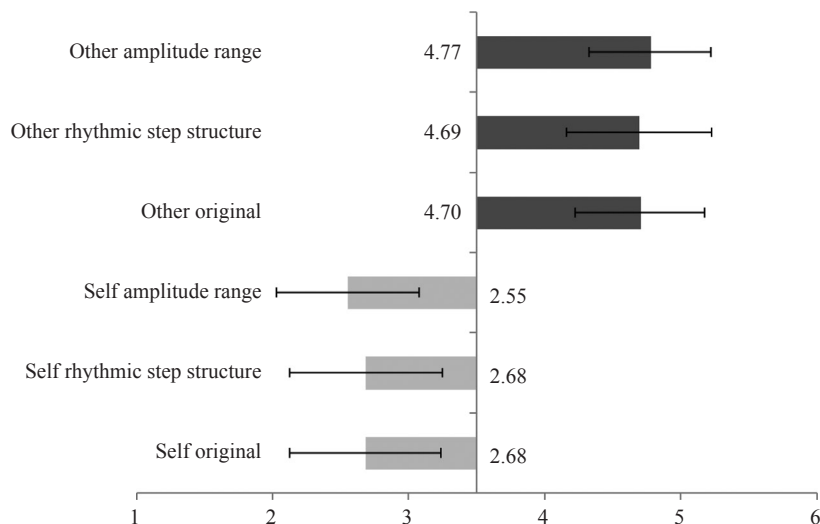


Figure 2. Results of the discrimination task on a 6-point Likert scale from 1 (self) to 6 (other). The vertical axis represents chance level (3.5). Error bars indicate standard deviation.

The second research goal was to investigate if specific characteristics of the movement sounds have an influence on perceptual quality. Therefore, we calculated the d' sensitivity index (Macmillan & Creelman, 2005). The estimation form of this d' calculation is a statistical method used in signal detection theory that subtracts the Z -scores of hit rates and false alarms. In this way we could take a potential response bias, which occurred in other studies (Knoblich & Repp, 2009), into account. A higher d' value indicates a more accurate perceptual performance. For the six possible answers, we generated two alternative categories of responses. Responses 1, 2, and 3 were grouped as self. Responses 4, 5, and 6 were grouped as other. The calculation yielded $d' = 1.72$ (SD = 1.53) in the original situation, $d' = 1.76$ (SD = 1.57) in the manipulated rhythmic step structure condition, and $d' = 1.82$ (SD = 1.43) in the manipulated amplitude range condition.

The t -tests revealed a significant difference from d' chance level ($d' = 0$) in the original condition ($t_{13} = 4.20, p < 0.001$), the modulated rhythmic step structure condition ($t_{13} = 4.16, p < 0.001$), and the manipulated amplitude range condition ($t_{13} = 4.77, p < 0.001$), reflecting the predicted bias. Paired t -tests showed no difference between the original and modulated conditions (O-RSS: $t_{13} = 0.36, p < 0.727, d = 0.02, r = 0.01$; O-AR: $t_{13} = 1.19, p < 0.257, d = 0.07, r = 0.04$) and also no difference between the modulated conditions (RSS-AR: $t_{13} = 0.59, p < 0.593, d = 0.05, r = 0.03$). Figure 3 highlights the d' scores in the different conditions.

The measured response time (in seconds) did not differentiate in the original (self = 4.90; other = 4.82), or in the rhythmic step structure (self = 4.84; other = 4.87), or in the amplitude range condition (self = 5.03; other = 5.01).

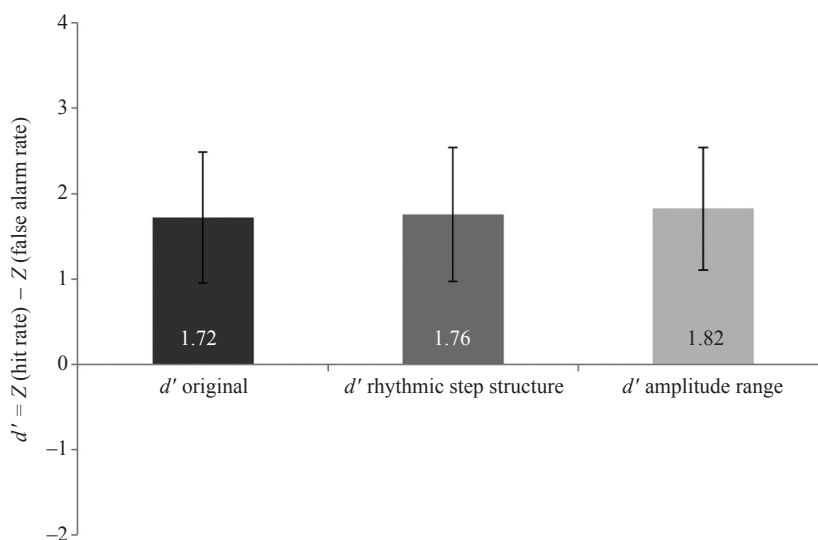


Figure 3. Average d' scores for the original, rhythmic step structure, and amplitude range conditions. Chance level is $d' = 0$. Error bars indicate standard deviation.

4 Discussion

The aim of the present study was to investigate if self–other discrimination is possible via naturally occurring movement sounds and if the quality of this perceptual performance is bound to particular sound characteristics, such as rhythmic step structure or amplitude range. Results show that the success rate for our discrimination task was significantly above chance level and even stable against a manipulation of rhythmic step structure or overall amplitude range. Thus, the perception of natural movement sounds is either independent of specific sound features, or the manipulation of the sound features were not distinctive enough or the auditory perception happens holistically based on limited information.

Previous research showed that it is possible to discriminate between one’s own and others’ movement information (eg Cutting & Kozlowski, 1977; Flach et al., 2004; Repp & Knoblich, 2004). This was mostly demonstrated by using visual stimuli. This research bias is at odds with the fact that the auditory sense is highly adapted to the perception of rhythmic structure, amplitude, and duration, which are all also core parameters of human movement. To develop complex auditory stimuli, we investigated hurdling sounds, which are characterized by multifaceted properties but also by a standardized structure (predetermined number of steps and distances). The results of the auditory discrimination task conceptually replicate the findings from the visual domain (Hohmann et al., 2011; Loula et al., 2005), suggesting that auditory self–other discrimination is possible for complex movement. Presumably, the different number of interoceptive representations for own and other movements has an impact on auditory movement discrimination.

The d' calculation shows a signal detection rate that is significantly above chance level, highlighting the ability of self–other discrimination. The d' values, as a measure of the quality of perception, are comparable with other studies from the visual (Sevdalis & Keller, 2011) and the auditory (Keller et al., 2007; Knoblich & Repp, 2009; Repp & Keller, 2010; Repp & Knoblich, 2004) domain. Strikingly, this perceptual quality was, unlike in previous studies (eg Murgia et al., 2012), independent of a manipulation of the rhythmic structure or the amplitude range of the movement sounds. Even these strong manipulations (which should be expanded in future research) did not lead to a decrease in perceptual quality. These findings may be attributable to the ecological complexity of the presented stimuli or the above-mentioned alternative explanations. Moreover, our study investigated for the first time

naturally occurring movement sounds which were de facto perceived by the participant in the way we presented them afterwards in the offline perceptual experiment. Therewith, the link between internal representations and presented stimuli was particularly direct and tight. A postexperimental questionnaire pointed out that the majority participants (85.7%) also used the ‘individual heaviness or weight of the steps’ (open question: “What you have paid special attention to?”) besides the amplitude range and the temporal structure of the sounds. Note also that individual morphological aspects, such as the torso dimensions (Algazi, Avendano, & Duda, 2001), affect sound frequencies around 3.5 kHz—which corresponds to the typical sound signature of a human footstep (Ekimov & Sabatier, 2006).

Analyzing the results from a gestalt psychological perspective, it seems that in the present study the ecological sound of footsteps represented a perceptual grouping that allowed participants to recognize their own movements, while other features such as rhythmic step structure and overall amplitude were less relevant in this case. Following the notion of the brain as a holistic system perceiving auditory information in its entirety (Klapp & Jagacinski, 2011), missing or changed parts in the auditory information may not influence the quality of auditory perception.

Assuming the bidirectional connection between perception and action (Schütz-Bosbach & Prinz, 2007), and acknowledging that movement is characterized through sound very well, further investigation into the influence of movement sounds on movement quality would be worthwhile. Upcoming studies should therefore examine if the current findings in movement perception also apply to the control of movements. Recent findings suggest that auditory offline training leads to improved performance (Agostini et al., 2004). Thus, one could provide optimized, reduced, or changed feedback online and analyze the performance during a movement task.

In conclusion, it has been found that experience in the form of interoceptive representations affects the accuracy of discrimination between one’s own and another’s movement sounds. The particularly novel finding of the present study is that naturally occurring movement sounds contain information that enabled participants to discriminate between their own and others’ movements, independently of important sound features of movement such as rhythmic structure or amplitude range. We suggest that the individuality of de facto audible movement sounds is information-rich enough to activate one’s own sensorimotor memories, enabling the recognition of one’s own movements.

References

- Agostini, T., Righi, G., Galmonte, A., & Bruno, P. (2004). The relevance of auditory information in optimizing hammer throwers performance. In B. Pascolo (Ed.), *Biomechanics and sports* (pp. 67–74). Vienna: Springer.
- Algazi, R., Avendano, C., & Duda, R. O. (2001). Elevation localization and head-related transfer function analysis at low frequencies. *The Journal of the Acoustical Society of America*, **109**, 1110–1122.
- Blake, R., & Shiffrar, M. (2007). Perception of human motion. *Annual Review of Psychology*, **58**, 47–73.
- Bosbach, S., Cole, J., Prinz, W., & Knoblich, G. (2005). Inferring another’s expectation from action: The role of peripheral sensation. *Nature Neuroscience*, **8**, 1295–1297.
- Calvo-Merino, B., Glaser, D. E., Grèzes, J., Passingham, R. E., & Haggard, P. (2005). Action observation and acquired motor skills: An fMRI study with expert dancers. *Cerebral Cortex*, **15**, 1243–1249.
- Cutting, J. E., & Kozlowski, L. T. (1977). Recognizing friends by their walk: Gait perception without familiarity cues. *Bulletin of the Psychonomic Society*, **9**, 353–356.
- Daprati, E., Wriessnegger, S., & Lacquaniti, F. (2007). Kinematic cues and recognition of self-generated actions. *Experimental Brain Research*, **177**, 31–44.

- Di Salle, F., Esposito, F., Scarabino, T., Formisano, E., Marciano, E., Saulino, C., ... & Seifritz, E. (2003). fMRI of the auditory system: Understanding the neural basis of auditory gestalt. *Magnetic Resonance Imaging*, **21**, 1213–1224.
- Ekimov, A., & Sabatier, J. M. (2006). Vibration and sound signatures of human footsteps in buildings. *The Journal of the Acoustical Society of America*, **120**, 762–768.
- Flach, R., Knoblich, G., & Prinz, W. (2004). Recognizing one's own clapping: The role of temporal cues. *Psychological Research*, **69**, 147–156.
- Hohmann, T., Troje, N. F., Olmos, A., & Munzert, J. (2011). The influence of motor expertise and motor experience on action and actor recognition. *Journal of Cognitive Psychology*, **23**, 403–415.
- Hunter, J. P., Marshall, R. N., & McNair, P. J. (2004). Interaction of step length and step rate during sprint running. *Medicine and Science in Sports and Exercise*, **36**, 261–271.
- Jeannerod, M. (2001). Neural simulation of action: A unifying mechanism for motor cognition. *NeuroImage*, **14**, 103–109.
- Justen, C., Herbert, C., Werner, K., & Raab, M. (2014). Self vs. other: Neural correlates underlying agent identification based on unimodal auditory information as revealed by electrotopography (sLORETA). *Neuroscience*, **259**, 25–34.
- Keller, P. E., Knoblich, G., & Repp, B. H. (2007). Pianists duet better when they play with themselves: On the possible role of action simulation in synchronization. *Consciousness and Cognition*, **16**, 102–111.
- Kennel, C., Hohmann, T., & Raab, M. (2014). Action perception via auditory information: Agent identification and discrimination with complex movement sounds. *Journal of Cognitive Psychology*, **26**, 157–165.
- Klapp, S. T., & Jagacinski, R. J. (2011). Gestalt principles in the control of motor action. *Psychological Bulletin*, **137**, 443–462.
- Knoblich, G., & Prinz, W. (2001). Recognition of self-generated actions from kinematic displays of drawing. *Journal of Experimental Psychology: Human Perception and Performance*, **27**, 456–465.
- Knoblich, G., & Repp, B. H. (2009). Inferring agency from sound. *Cognition*, **111**, 248–262.
- Knoblich, G., Seigerschmidt, E., Flach, R., & Prinz, W. (2002). Authorship effects in the prediction of handwriting strokes: Evidence for action simulation during action perception. *Quarterly Journal of Experimental Psychology*, **55**, 1027–1046.
- Loula, F., Prasad, S., Harber, K., & Shiffrar, M. (2005). Recognizing people from their movement. *Journal of Experimental Psychology: Human Perception and Performance*, **31**, 210–220.
- Macmillan, N. A., & Creelman, C. D. (2005). *Detection theory: A user's guide* (2nd ed.). Mahwah, NJ: Erlbaum.
- Murgia, M., Hohmann, T., Galmonte, A., Raab, M., & Agostini, T. (2012). Recognising one's own motor actions through sound: The role of temporal factors. *Perception*, **41**, 976–987.
- Repp, B. H., & Keller, P. E. (2010). Self versus other in piano performance: Detectability of timing perturbation depends on personal playing style. *Experimental Brain Research*, **202**, 101–110.
- Repp, B. H., & Knoblich, G. (2004). Perceiving action identity: How pianists recognize their own performances. *Psychological Science*, **15**, 604–609.
- Righi, G., Galmonte, A., & Agostini, T. (2006). Rhythm, a Gestalt of human movement? *Gestalt Theory*, **28**, 283–291.
- Schubotz, R. I. (2007). Prediction of external events with our motor system: Towards a new framework. *Trends in Cognitive Sciences*, **11**, 211–218.
- Schütz-Bosbach, S., & Prinz, W. (2007). Perceptual resonance: Action-induced modulation of perception. *Trends in Cognitive Sciences*, **11**, 349–355.
- Sevdalis, V., & Keller, P. E. (2010). Cues for recognition in point-light displays of action performed in synchrony with music. *Consciousness and Cognition*, **19**, 617–626.
- Sevdalis, V., & Keller, P. E. (2011). Perceiving performer identity and intended expression intensity in point-light displays of dance. *Psychological Research*, **75**, 423–434.
- Wolpert, D. M., & Flanagan, J. R. (2001). Motor prediction. *Current Biology*, **11**, 729–732.