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Research paper

Effects of velocity and motion-onset delay on detection and discrimination of sound motion

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ABSTRACT

The effect of velocity on auditory motion processing in combination with a motion-onset delay was investigated in two experiments. The detection of motion onset and discrimination of motion direction were studied, employing a psychophysical reaction time task. Listeners were presented with sounds moving along the frontal horizontal plane in a dark anechoic environment. Response times (RTs) were measured, while the velocity (20°/s, 40°/s, 80°/s) and the motion-onset delay (the time between sound onset and start of motion: 0, 200, 500, 1000 ms) were varied. Listeners responded faster with higher velocity and longer motion-onset delay. In particular, with higher velocity, the function relating RT to motion-onset delay had a steeper initial decrease than with lower velocities. The results are in line with psychophysical studies of the minimum audible movement angle and recent electrophysiological data about the role of motion velocity in auditory motion processing. The effect of motion-onset delay is discussed with regard to a dynamic temporal window, in which auditory spatial information is integrated until enough information is accumulated to trigger motion detection.

1. Introduction

The ability to perceive dynamic aspects of our environment is an essential function of our sensory system. Whereas cortical mechanisms underlying the detection and tracking of moving visual objects are relatively well analyzed, the process of auditory motion perception is not. It has been proposed that the mechanisms of motion perception are similar to those involved in the localization of static sound sources: Motion is inferred from snapshots of an object's position at its onset and offset, without direct appreciation of velocity (Grantham 1989, 1997; Middlebrooks and Green, 1991). Alternatively, single-unit recordings in animals (e.g., Spitzer and Semple, 1991; Moiseff and Haresign, 1992; Toronchuk et al., 1992) and human neuroimaging studies (e.g., Griffiths et al., 1998; Baumgart et al., 1999; Lewis et al., 2000; Bremmer et al., 2001; Warren et al., 2002; Hall et al., 2003; Krumbholz et al., 2005) revealed cortical areas specifically activated by sound motion, suggesting the existence of a motion-specific analysis system that differs from the static localization system anatomically and functionally.

In line with this notion, electrophysiological (electro- and magnetoencephalography, EEG/MEG) measures of the brain's response to moving sounds consist of a series of deflections specific to processing of motion (Altman and Vaitulevich, 1990; Mäkelä and McEvoy, 1996; Ducommun et al., 2002; Jerger and Estes, 2002; Xiang et al., 2002; Bidet-Caulet and Bertrand, 2005; Krumbholz et al., 2007). Detailed analysis of auditory evoked potentials (AEPs) to static and moving sounds suggested a modular organization of motion processing, which consists of an initial detection of motion features and a subsequent discrimination of the direction of sound motion (Ducommun et al., 2002). These processes have been discussed in the context of a temporal window of integration for auditory events that has been investigated using mismatch negativity paradigms (e.g., Yabe et al., 1998, 2001). According to this approach, acoustic stimulus features (e.g., pitch or space) are integrated within a window of approx. 200 ms width. Motion processing could be triggered after enough motion-specific information is accumulated. If motion features are detected, the direction of sound motion is discriminated in a second phase (Ducommun et al., 2002). In line with this, there is neurophysiological evidence that neural motion detectors first encode the location of a sound source and after a time period of stimulation its motion (Ahissar et al., 1992).

In a recent MEG study, Xiang et al. (2005) investigated the role of motion velocity in auditory motion processing by analysis of cortical responses to sounds that were either stationary or moving.

Abbreviations: AEP, auditory evoked potential; ANOVA, analysis of variance; EEG, electroencephalography; ITD, interaural time difference; LR, left to right; MAMA, minimum audible movement angle; MEG, magnetoencephalography; MM, motion-specific magnetic response; MMN, mismatch negativity; RL, right to left; RT, response time; SE, standard error; SPL, sound-pressure level

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Besides an early cortical response evoked by both stationary and moving sounds, a motion-specific magnetic response (MM) was found that was attributed to the cortical encoding of auditory motion information. The MM clearly depended on motion velocity and its amplitude and latency were inversely related to the velocity. It was hypothesized that the MM latency could reflect the time consumed by auditory spatial mapping in the brainstem, thus providing a neurophysiological temporal indicator of processing dynamic spatial information.

In this regard, it would be important to know whether behavioral performance in auditory motion perception depends on velocity in a similar way as the MM latency does. In visual perception, the dependence of motion detection on velocity is well documented (e.g., Ball and Sekuler, 1980; Tynan and Sekuler, 1982): a relationship between brain activity and behavioral performance in motion detection has recently been established by demonstrating that the response time (RT) is correlated with the latency of visual evoked potentials to motion onset (Kreegipuu and Allik, 2007). In auditory perception, Engelken et al. (1991) investigated the detection of a rapid change in sound position. By randomly varying the spatial distance between two stationary, successively active sound sources, virtual sound movements in the range of 5 and 40 deg were generated. As a result, RTs decreased when the distance between the sound sources was increased. This finding should not be interpreted as an effect of velocity per se, though, because different mechanisms might be involved in the processing of continuous sound motion and of rapid changes between two sound positions (Perrott and Marlborough, 1989). Thus, the relationship between velocity of sound motion and RT for motion detection is still unclear.

Whereas surprisingly little consideration has been given to speed of response to auditory motion, a number of studies focused on the spatial resolution of moving targets: With the minimum audible movement angle (MAMA) as standard threshold measure, the smallest angular distance was determined that a moving sound had to traverse to be just discriminable from a stationary source or from a source moving in the opposite direction. The results indicated that the MAMA depends on both stimulus duration and velocity, with the MAMA being smaller when the stimulus duration is long and the velocity relatively low (e.g., Perrott and Musicant, 1977; Perrott and Tucker, 1988; Saberi and Perrott, 1990; Saberi et al., 2003). The close relationship of these variables has been used to derive an estimate of the minimum integration time required for performance to reach an optimal level (Grantham, 1986; Chandler and Grantham, 1992). Plotting the MAMA as a function of stimulus duration suggested that the stimulus duration required for motion detection is reduced when the velocity is increased. Taken together, both physiological latency data and theoretical considerations of the MAMA suggest a close relationship of auditory motion detection and velocity.

The aim of the present study was to investigate the effect of motion velocity, employing a psychophysical reaction time task. In addition, the effect of a delay between the onset of auditory stimulation and the start of motion was tested. Assuming a modular organization, in which motion processing does not start before integration of auditory information across a certain period (Ducommun et al., 2002), motion detection should be faster, when auditory information is available for integration before the motion starts. More specifically, providing motion-independent, stationary information prior to the motion onset should enhance the processing of subsequent motion. Thus, a motion-onset delay should significantly decrease RTs. By using delays of various lengths, it should be possible to assess the width of the assumed temporal processing window: The decrease in RT (relative to a motion starting immediately at sound onset) should be most prominent with a relatively short motion-onset delay, whereas RTs should not decrease further when the delay exceeds the width of the temporal window, i.e., when the motion starts after the initial phase of integration is finished. Also, the effect of motion-onset delay should depend on the target velocity: Assuming that the time required for motion processing is shorter with a higher velocity, the decrease in RT should occur with short onset delays; conversely, a long onset delay should be necessary when the velocity is low. To test these predictions, RTs to motion onset were measured, while motion-onset delays and velocities were varied.

Finally, to examine the degree to which the integration time depends on specific task requirements, in the present study listeners performed either a motion-detection task, in which simple RT was measured, or a motion-discrimination task, in which choice RT was measured. With regard to the concept of modular organization, simple RTs should relate to the initial phase of detection, whereas choice RTs should relate to the subsequent phase of discrimination. If more integration time is required for motion discrimination, choice RTs should decrease at relatively long motion-onset delays, whereas simple RTs should decrease at shorter motion-onset delays; if the integration time does not depend on task requirements, the effects of velocity and motion-onset delay should be the same in motion detection and discrimination.

2. Experiment 1

2.1. Method

2.1.1. Subjects

Sixteen naïve listeners (9 female; mean age 24.4 yr; age range 19–40) participated in experiment 1. They were without any known hearing deficits. For each listener all data were collected in a 45 min session, including rest breaks. Prior to the inclusion in the study, all listeners gave their informed consent. The experiments were non-invasive and were performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

2.1.2. Apparatus and stimuli

The listener sat on a chair in an absolutely dark, echo-reduced chamber (4.4 m wide × 5.4 m long × 2.1 m high), which was insulated by 40 cm (height) × 40 cm (depth) × 15 cm (width at base) fiberglass wedges on each of the six sides. A suspended mat of steel wires served as floor. The ambient background noise level was below 20 dB(A) SPL. The position of each listener's head was held constant by a custom-made chin and forehead rest. In front of the listener at a constant distance of 1.5 m from the centre of the head, 91 broad-band loudspeakers (Visaton SC 5.9, 5 × 9 cm) were mounted in the subject's horizontal plane. The azimuth of the loudspeakers ranged from −90° (left) to +90° (right) in steps of 2° with the centre loudspeaker at 0°. All loudspeakers were selected on the basis of similar efficiency and frequency response curves.

The target sound was generated digitally and converted to analogue form by a PC-controlled, 16-bit soundcard (Creative Sound Blaster 16) at a sampling rate of 48 kHz. The sound pressure level was 66 dB(A), as measured at the listener's head position by using a Brüel & Kjær Sound Level Meter (Type 2226). The target sound consisted of continuous white noise (band-pass-filtered; lower and upper cut-off frequencies 1 and 3 kHz, respectively). Apparent auditory motion was generated by successively activating one loudspeaker after the other along the horizontal loudspeaker arrangement. During the active period of the loudspeaker, continuous noise was emitted. No acoustic transients were audible as the signal was shaped by envelopes (rise/decay times 15 ms) and switched between the loudspeakers with a slight overlap. This overlap between the envelopes of two consecutive stimuli was 3 ms; that is, 3 ms before the end of the decay time of the noise presented via one loudspeaker, the subsequent, adjacent stimulus