Neuroscience Letters 675 (2018) 31–35

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

Research article

Modality-dependent effect of motion information in sensory-motor synchronised tapping

Kentaro Ono

Graduate School of Biomedical & Health Sciences, Hiroshima University, Japan

ARTICLE INFO

Keywords:
Sensory-motor synchronisation
Temporal asynchrony
Motion information
Auditory
Visual

ABSTRACT

Synchronised action is important for everyday life. Generally, the auditory domain is more sensitive for coding temporal information, and previous studies have shown that auditory-motor synchronisation is much more precise than visuo-motor synchronisation. Interestingly, adding motion information improves synchronisation with visual stimuli and the advantage of the auditory modality seems to diminish. However, whether adding motion information also improves auditory-motor synchronisation remains unknown. This study compared tapping accuracy with a stationary or moving stimulus in both auditory and visual modalities. Participants were instructed to tap in synchrony with the onset of a sound or flash in the stationary condition, while these stimuli were perceived as moving from side to side in the motion condition. The results demonstrated that synchronised tapping with a moving visual stimulus was significantly more accurate than tapping with a stationary visual stimulus, as previous studies have shown. However, tapping with a moving auditory stimulus was significantly poorer than tapping with a stationary auditory stimulus. Although motion information impaired audio-motor synchronisation, an advantage of auditory modality compared to visual modality still existed. These findings are likely the result of higher temporal resolution in the auditory domain, which is likely due to the physiological and structural differences in the auditory and visual pathways in the brain.

1. Introduction

Synchronisation of movements with external events is a basic and important skill for human beings and has been studied for a long time [1]. Previous studies have shown more efficient synchronisation with auditory stimuli than with visual stimuli [2–5], and reliable synchronisation is possible at faster than 200 ms inter-stimulus interval (ISI) for auditory sequences, in contrast with ISIs of approximately 500 ms for visual flash sequences [4]. Patel et al. (2005) suggested that the superiority of the auditory system for synchronised action is based on the anatomical and functional connectivity in the auditory system, which is more specialised for temporal information processing.

However, the advantage of the auditory system to synchronise action seems to be diminished by adding motion information to visual stimuli. Some studies have demonstrated that adding motion information to visual stimuli improves the stability and accuracy of synchronisation [5–8]. For example, tapping with a video of a bouncing ball yielded a variability that was not significantly larger than that with the auditory metronome [5]. There is a question as to whether adding motion information to auditory stimuli improves auditory-motor synchronisation. Because of high spatial resolution in vision [9], adding motion information may lead to more accurate visuo-motor synchronisation. However, it is unclear whether relatively low spatial resolution in audition [10,11] is beneficial.

Unfortunately, there is no study directly comparing the effect of adding motion information to visuo- and auditory-motor synchronisation. Furthermore, only a few studies have investigated the effect of motion information in auditory-motor synchronisation and the results are partly contradictory [12–14]. McAnally (2002) and Varlet et al. (2012) used frequency-modulated (FM) tones to induce the perception of vertical motion and showed no advantage when adding motion information. However, Ono et al. (2016) used the interaural level difference (ILD) to induce the perception of horizontal motion and the accuracy of synchronisation was impaired. The controversial results in these studies may be due to several differences in experimental conditions, such as finger-tapping or swinging a lever, asking to tap in a certain timing or freely. These might cause differences in the continuity of participants' movement and/or influence the control processes underlying the coordination. Thus, it is still unclear whether the motion information is beneficial to improving the accuracy and stability of visuo- and auditory-motor synchronisation. The aim of this study was to clarify whether motion information is beneficial for auditory-motor

Abbreviations: ISI, inter-stimulus interval; SD, standard deviation
E-mail address: onoken@hiroshima-u.ac.jp.

https://doi.org/10.1016/j.neulet.2018.03.055
Received 28 November 2017; Received in revised form 23 March 2018; Accepted 23 March 2018
Available online 26 March 2018
0304-3940/

synchronisation and, if so, compare the size of the effect with visuo-motor synchronisation.

2. Methods

To investigate this issue, a synchronised finger-tapping task with stationary and moving stimuli in the auditory and visual modalities was conducted. Twenty-one healthy right-handed participants (11 males and 10 females) between 19 and 23 years of age participated in the experiment. They were paid 1000 yen for taking part in the experiment. The data from two participants were excluded from data analysis because their standard deviations (SD) of temporal asynchrony were greater than 2 SD from the mean across participants. None of the participants had any motor, hearing, visual, or neurological deficits, based on self-report. This study was performed in accordance with the ethical standards of the Declaration of Helsinki and approved by the Ethics Committee of the Graduate School of Medicine and Faculty of Medicine, Kyoto University. Written informed consent was obtained from all participants prior to the experiment.

The experiment was designed with two modalities (auditory or visual) and two mobilities (stationary or motion). For the auditory-motor synchronisation task, pure tones (5 ms rise/fall ramps) with two different frequencies (440 Hz and 880 Hz) and four durations (250, 500, 750, and 1000 ms) were used as stimuli. The intensity levels of the tones linearly decreased from 65 to 0 dB over their durations and were presented binaurally as stimuli in the stationary condition (Fig. 1A). The intensity levels of the same tones linearly increased from 0 to 65 dB, and these decreasing and increasing tones were presented alternately to each ear in the motion condition (Fig. 1A). Note that opposite phases of decrease/increase were presented to the left and right ears to induce the perception of apparent horizontal motion. Thus, the auditory-motor synchronisation task had 16 conditions, including 2 frequencies (440 Hz and 880 Hz), 4 durations (250, 500, 750, and 1000 ms), and 2 mobilities (motion or stationary).

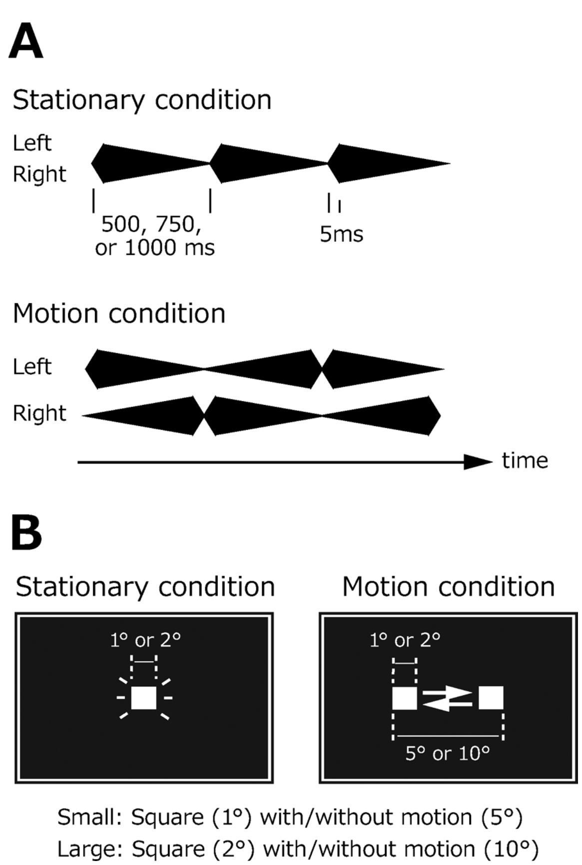

Fig. 1. Stimuli used in the experiment. A. Pure tones presented in the auditory-motor synchronisation task. B. White squares presented in the visuo-motor synchronisation task.

For the visuo-motor synchronisation task, a white square on a black background was used as the stimulus (Fig. 1B). Two sizes of squares (1° × 1° and 2° × 2°) were used to control the effect of size. In the stationary condition, the white square was presented 50 ms with four different stimulus-onset-asynchrony (SOA) of 250, 500, 750, and 1000 ms. In the motion condition, a sequence of pictures in which the location of the white square moved slightly from side to side. The pictures were presented sequentially to create the perception of motion and the maximum width of motion was 5° for the small square (1° × 1°) and 10° for the large square (2° × 2°). Thus, the visuo-motor synchronised tapping task had 16 conditions, including 2 sizes (1° × 1° or 2° × 2°), 4 intervals (250, 500, 750, 1000 ms), and 2 mobilities (motion or stationary). All stimuli were presented using a personal computer (CF-NX1, Panasonic, Japan) with headphones (MDR-Z1000, SONY, Japan), placed approximately 60 cm in front of the participants. The refresh rate of the PC monitor was 60 Hz, meaning that the timing of the presentation of visual stimuli caused a delay of approximately 16.7 ms in some cases.

After training sessions to familiarise the participants with the synchronised tapping task, the participants performed two separate sessions (auditory and visual) with 16 conditions. The total length of experiment was between 10 and 12 min, including the rest between conditions. Each condition was conducted in a separate block and the order of conditions and sessions was counterbalanced across participants. In the stationary condition, they were instructed to use their right index finger to tap at the onset of each stimuli (tone or square). In the motion condition, they were instructed to tap when the moving stimuli reached the extreme left and right positions. The stimuli were presented 50 times in each condition and the first 10 taps were discarded as practice from the data analysis. Tapping was detected by sound using a custom-made tapping device connected to the PC. The temporal resolution of this device was approximately 1 ms. The experiment was programmed using Presentation (ver. 19.0, Neurobehavioral Systems, Berkeley, CA, USA). At the end of the experiment, the participants were asked whether they recognised the motion of the tones in the motion condition, and all participants reported recognising smooth horizontal motion in both the auditory and visual sessions.

3. Results

The time difference between tapping and the onset of the corresponding stimulus was estimated as temporal asynchrony. Eleven participants exhibited negative values for asynchrony (tapping earlier than the stimuli) in all conditions, but the others showed positive values (tapping later than the stimuli) in some conditions. Thus, the absolute value of temporal asynchrony was used for data analysis in order not to underestimate the size of asynchrony (The signed temporal asynchrony was plotted in Supplementary Fig. 1). In the visuo-motor synchronised tapping task, the 250 ms duration was almost impossible for the participants to follow the stimuli. Because more than half of the tapping was missed, this condition in the visual modality was excluded from the data analysis. Therefore, the data from 250 ms SOA in the auditory-motor synchronisation task were also excluded from the analysis to compare auditory and visual modalities.

First, the absolute value of temporal asynchrony in the auditory and visual modalities was separately analysed. In the auditory modality (Fig. 2A), a three-way ANOVA with factors of frequency (440 Hz and 880 Hz), mobility (stationary and motion), and SOA (250, 500, 750, and 1000 ms) showed a main effect of mobility ($F_{1,18} = 21.59$, $p < 0.001$) and an interaction between frequency and mobility ($F_{1,18} = 5.99$, $p = 0.025$). A simple main effect analysis revealed that the temporal asynchrony in the motion condition was larger than the