The Shifting Effect of Subjective Simultaneity of Auditory and Tactile Stimuli in Voluntary Movement

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Abstract: The point of subjective simultaneity (PSS) is important for human to integrate or discriminate cross-modal information coming from one event or not respectively. The present study aims to research the effect of voluntary movement on PSS using temporal order judgment task with auditory-tactile stimuli. We found that compared to no-movement, voluntary movement shifted the PSS to the time point in which auditory stimulus should be presented earlier than tactile stimulus.

Keywords: Subjective simultaneity, Auditory stimulus, Tactile stimulus, Voluntary movement, Temporal order judgment

1 Introduction

With little knowledge about the speeds of sound and light in the air, it is hard to believe that thunder is the sound caused by lightning for the ancient men because of the totally different arriving times of thunder and lightning to the ears and eyes. And also it would be natural that the point of subjective simultaneity (PSS) is one criterion for human to integrate cross-modal information as they came from one event. The PSSs are often determined as the intervals between two stimuli at which people mostly perceive the stimuli as occurring simultaneously. The PSSs between different modal stimuli are usually not zero. In addition, previous researches had showed that the PSSs were affected by many factors, for example, the adaptation [1]; the prior entry [2]; and also movement. In recent years, it was found that the voluntary movements decrease the PSS. For instance, the voluntary movement reduces the PSSs and between visual and haptic stimuli [3] and between auditory and tactile stimuli [4]. However, there is also different result appeared, in which active movement did not influence the PSS [5].

These mixed results from the previous studies could be caused by diverse the stimulus onset asynchronies (SOAs) used in the studies and a little defective method In order to reduce the impact of methodological difference on these results and reveal the effect of movements, especially voluntary movement, on subjective simultaneity, we improved the procedure of temporal order judgment (TOJ) task on the subjective simultaneity of auditory and tactile stimuli in movements.

2 Methods

2.1 Participants, stimuli and apparatus

Five right-handed graduate students (2 female and 3 males; mean age: 25 years) from Tokyo Institute of Technology participated in this experiment and were paid for their participations. Auditory stimulus was a sinusoidal wave sound (2000 Hz, 50 dB, 10 ms) in both ears by earphones and tactile stimulus was impulse force (5N, 10 ms, rectangular pulse) provided by the PHANToM@ Desktop haptic device (SensAble Technologies, USA) operated by computer programs installed on a PC workstation (HP xw4600/CT, Hewlett-Packard, USA).

2.2 Procedure

This auditory-tactile stimuli TOJ task, in which a pair of stimuli was presented to participants with the various SOAs, e.g. ±240, ±120, ±60, ±30, and 0 ms (where the negative values indicated that the tactile stimulus preceded the

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auditory stimulus), were performed under voluntary, involuntary, and no-movement conditions. The intervals between the start of the movement and the presentation of stimuli were changed slightly between trials.

In the voluntary condition, the participants started to move their right index fingers voluntarily at their own timings for each run of trials and were asked to answer "which first" between auditory and tactile stimuli. In involuntary condition the participant's finger movements were controlled by the PHANToM device. In the no-movement condition, the participants remained stationary throughout the experiment.

3 Results & Discussion

For each SOA, the ratio of the answers as the earlier presentation of the auditory stimulus was calculated. Then with a generalized linear model, logistic regressions were conducted on the ratio data of each experiment. Psychometric curves were fitted to the distribution of the mean TOJ data for voluntary, involuntary and no-movement conditions (Fig.1) and Positive SOA values meant that auditory stimulus was presented before tactile one, and vice versa. The PSS were calibrated for each participant with the regression analysis (Eq. (1)). The following equation was used in the logistic regression analysis:

$$y = \frac{1}{1+e^{\frac{(\alpha - x)}{\beta}}} \qquad (1)$$

In Eq. (1), α represents the estimated PSS, *x* means SOA.

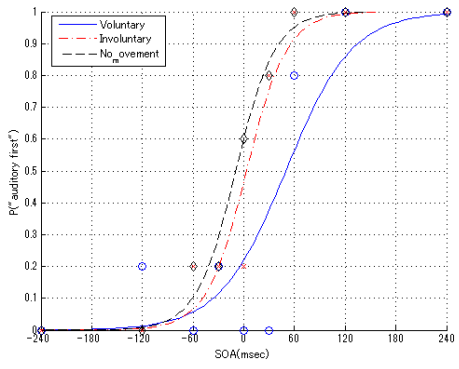

Fig. 1 Average psychometric function in the voluntary, involuntary, and no-movement conditions of one participant.

From the mean values of PSS, we could saw that in voluntary movement the PSS was positive, the PSS in no-movement was negative, and the PSS of involuntary movement was nearly the same with 0. These meant that the subjective simultaneity was obviously affected by voluntary movement but not involuntary movement and shifted to the time point in which auditory stimulus should be presented earlier than tactile stimulus, compared to no-movement.

Our results revealed that the voluntary movements affect the subjective simultaneity. The results of our study were the nearly same with Nishi *et al*. [4] and different from the study of Frieseen *et al*. [5]. The effect of voluntary movements on PSS might be caused by an efference copy appearing only included in voluntary movement condition, which is a copy of the motor command and is available before the voluntary movement occurs, and also could be used to predict the timing of an active movement.

In conclusion, voluntary movement influenced the subjective simultaneity of auditory-tactile stimuli in TOJ task, which means that simultaneity is perceived if auditory stimulus came earlier than tactile stimulus.

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