Proceedings of the 2015 ICME
International Conference on Complex Medical Engineering
June 18 - 21, Okayama and Kyoto, Japan

The Study about the Effect of Voluntary Movement on Subjective Simultaneity of Auditory-tactile Stimuli in TOJ task

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Abstract **- The point of subjective simultaneity (PSS) is important for human to integrate multi-modal information, which would be the base for successful interaction with the environment including other people. The present study focused on how does voluntary movement affect the PSS of auditory and tactile stimuli by using temporal order judgment (TOJ) task. We found that compared to no-movement, voluntary movement shifted the PSS to auditory-lead stimulus between auditory and tactile stimuli, which meant that simultaneity wss perceived if auditory stimulus came earlier than tactile stimulus.**

Index Terms - Subjective simultaneity. Voluntary movement. Auditory-tactile stimulus. Temporal order judgment.

I. Introduction

People are interacting with the environment including other people, with judging simultaneity of multi-modal information from the environment and their own bodies and integrating (or not integrating) the information. For example, when people are dancing with their partners, they need to sway in time with the music and also keep up with the pace of their partners, such as holding hands with each other, in which accurate perception of simultaneity of sound and information to eyes is very important for the dancers to decide what to do the next. The PSS represents the amount of time by which people mostly perceive two stimuli as occurring simultaneously. The PSSs are usually non zero in multi-modal temporal integration. The PSS shifts to visual-lead stimulus between visual and auditory stimuli, which means that the visual stimulus should be presented earlier than auditory stimulus to be accepted as simultaneity [1-3]. The doctrine of prior entry, which means that attended stimuli are perceived earlier than unattended stimuli, have also been found to affect the shift of PSS and this might be caused by the accelerative effect on perceptual arrival times by attention [4-5]. Indeed, the PSS could be shifted by even just a few minutes in exposure to a repeated time-staggered auditory and visual pair [6-8]. Besides the above examples, the PSSs would also be affected by individual difference, which means that the PSS values are participants specific [9-10]; and even the response which first or second the participants should answer [4, 11-12].

Some previous studies have found that the PSSs close to zero by voluntary movement. For example, voluntary movement decreased the PSS of visual and haptic stimuli was found in the research of Shi *et al.* [13], and Nishi *et al.* proved that the PSS of auditory and tactile stimuli was decreased in voluntary condition, compared to involuntary and no-movement conditions [14]. However, there is also different result appeared, in which active movement did not influence the PSS [15].

The PSSs are usually measured by TOJ task, in which a pair of stimuli is presented to participants with the various stimulus onset asynchronies (SOAs). So, the diverse SOAs used in the previous researches and a little defective method might produce divergent results, which cannot be compared immediately.

In order to overcome the influence of methodological difference on these results and reveal the effect of movements, especially voluntary movement, on subjective simultaneity, we improved the procedures of experiment in Nishi *et al.* on the temporal simultaneous perception of auditory-tactile stimuli in movements.

II. METHODS

A. *Participants*

Seventeen right-handed graduate students (3 female and 14 males; mean age: 25 years) from Tokyo Institute of Technology participated in the experiment and with no problems in moving their right index fingers. They were given informed consent before the experiment and paid for their participations. The Tokyo Institute of Technology ethics committee approved the experiment.

B. *Apparatus and stimuli*

Auditory stimulus was a sinusoidal wave sound (2000 Hz, 50 dB, 15 ms) in both ears by earphones (HP-RHF41, radius, Japan). Tactile stimulus was impulse force (4.5N, 15 ms, rectangular pulse) provided by the PHANToM@ Desktop haptic device (SensAble Technologies, USA). These sensory stimulation systems were operated by computer programs installed on a PC workstation (HP xw4600/CT, Hewlett-Packard, USA), which were developed with the Open Haptics software development toolkit (SensAble Technologies, USA) on the Microsoft@ Visual C++ 2008 platform (Microsoft, USA). The timing of the two presentations and the movement form the device were controlled to an error margin of 1 ms.

C. *Task, Conditions and procedure*

This auditory-tactile TOJ task, in which a pair of stimuli was presented to participants with the distinct SOAs, was performed under voluntary, involuntary, and no-movement conditions. The three conditions were counterbalanced across participants, who were asked to answer "which first" between auditory and tactile stimuli using the "Z" and "X" keys on the keyboard to make "auditory stimulus first" and "tactile stimulus first" responses, respectively. The SOAs, which were the intervals between an auditory and tactile stimuli pair, were designed as following values: ±240, ±120, ±60, ±30, and 0 ms (where the negative values indicated that the tactile stimulus preceded the auditory stimulus).

In this experiment, the participants completed three blocks each for all of the conditions in random. Each block consisted of 45 trials, in which each SOA randomly selected from nine SOAs was repeated for 5 trials. It took about five minutes for them to complete one block in all of the conditions. The participants were given several minutes of rest between blocks as they liked. They completed a total of 405 trials in the formal experiment, and the entire procedure took about 2 hours. In addition, they conducted practice runs of 10 trials presented only with the tactile stimulus just before each block of the voluntary condition to accustom to the appropriated speeds. Before the day of the formal experiment, the participants were given enough practice sessions so as to accustom to TOJ task and move their right index fingers at a speed as constant as possible.

The experiment was carried out in a darkened sound-attenuated room. The participants seated in front of the sensory stimulation systems with their palmer side of their right index fingers held in the haptic device and also wore sound-insulating earmuffs over the earphones and eye mask to eliminate confounding effects by visual stimuli during the

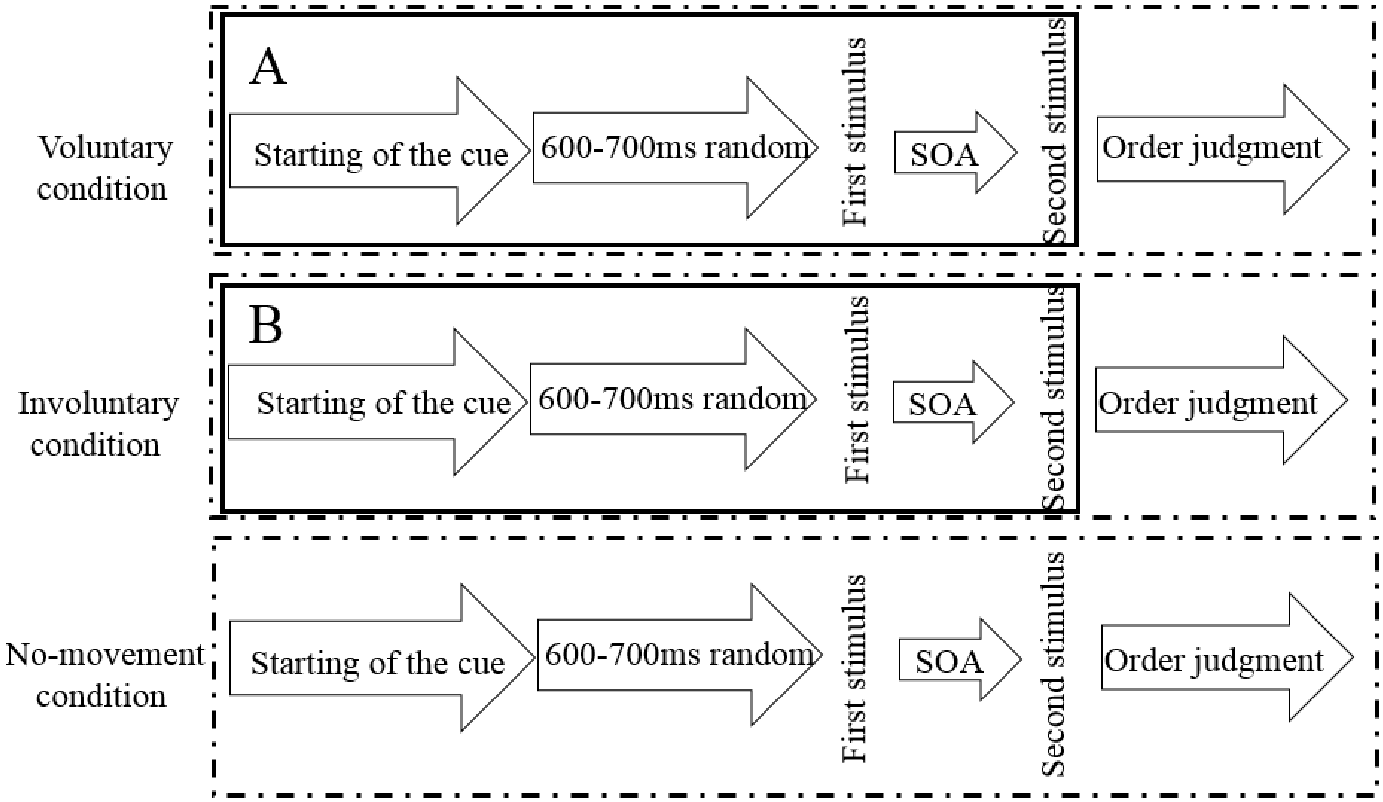

Fig.1 Schematic flow chart of one trial in the voluntary, involuntary, and no-movement conditions. The cue was a sound, which was different with the auditory stimulus and the direction of arrow is along with the time in one trial. The SOA was randomly chosen from the nine SOAs. The first stimulus and second stimulus both represented the auditory or tactile stimulus. In order judgment, participants were asked to answer "which first" between auditory and tactile stimuli using the "Z" and "X" keys on the keyboard. A meant that the participants voluntarily started to move their right index fingers at their own timings in voluntary condition. B meant that haptic device started to move the participants' right index fingers as they like after the interval between trials in involuntary condition.

experiment. Throughout the experiment, white noise was playing to mask any sounds made by the device by earphones or the environment. Additionally, the participants were asked to pay constant attention to the tactile stimulus in order to control for the 'prior entry' effect [7-8], which relatively facilitates the processing of an attended stimulus compared with an unattended stimulus.

Voluntary condition (Fig. 1): For each run of trials, the participants started to move their right index fingers voluntarily at their own timings. When they began their movements, a sound of cue, which was different with the auditory stimulus, was generated to announce the starting of each trial at the same time. The first stimulus, e.g. the tactile or auditory stimulus, was presented with a random delay (600-700 ms) after the beginning of the finger movement and starting of the cue. Then, the second stimulus, e.g. the auditory or tactile stimulus, was presented in synchronization with the first stimulus by one of the nine SOAs. The participants then judged a two-alternative forced choice test to provide the temporal discrimination of the auditory and tactile

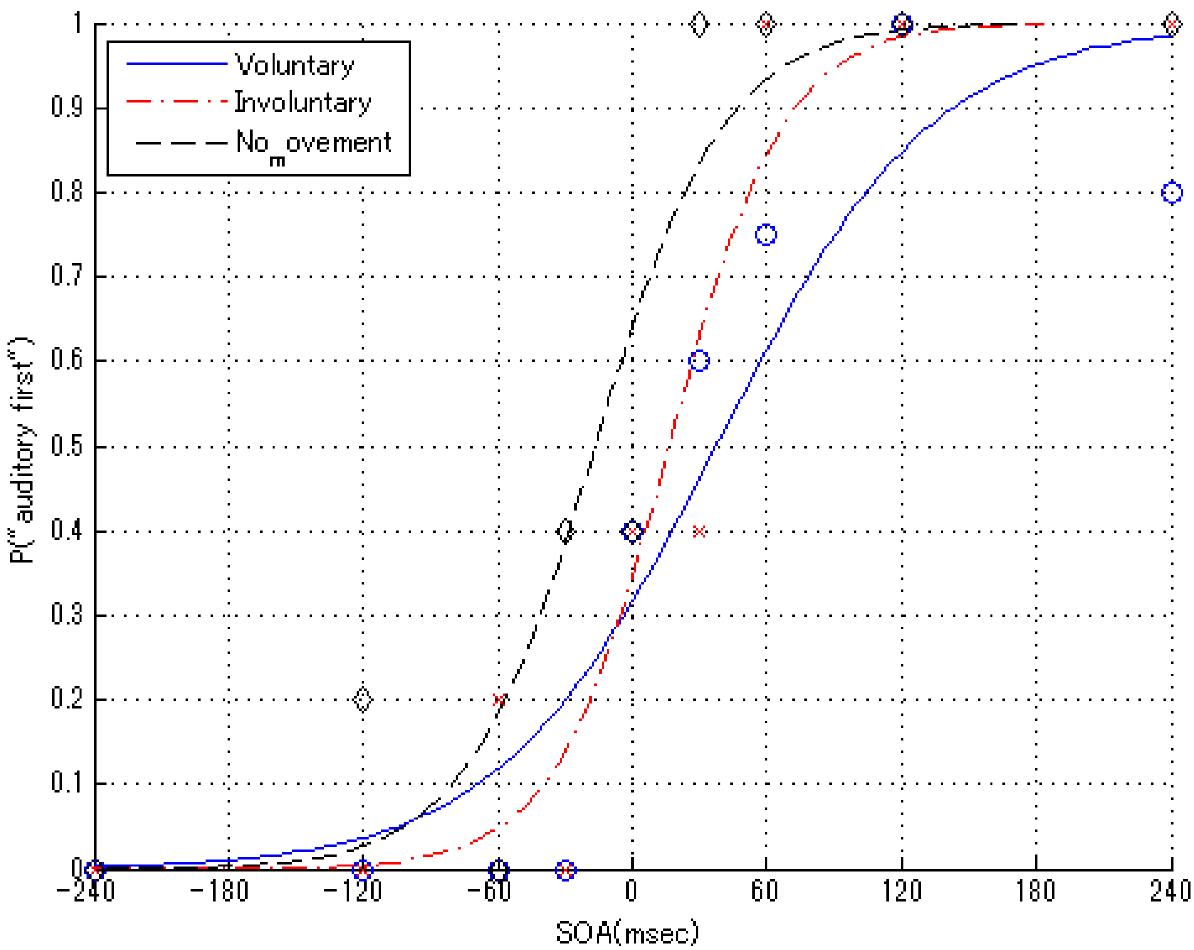

Fig. 2 Average individual psychometric function in the three conditions of one participant. Positive SOA values meant that auditory stimulus was presented before tactile one, and vice versa.

stimuli pair by answering which stimulus was presented first. If participants produced a speed that was not among 50 mm/s to 110 mm/s, they were supplied one more trial until all of the trials have been randomly completed [15-16].

Involuntary condition (Fig. 1): Similar to the voluntary condition, the haptic device randomly started to move the participants' right index fingers from 500 to 1000 ms determined to reproduce the variance in the onset timing of voluntary movement in preliminary experiments, and a sound of cue was generated to announce the starting of each trial at the same time. The first stimulus, e.g. the tactile or auditory stimulus, was presented with a random delay (600-700 ms) after the beginning of the finger movement and starting of the cue. Then, the second stimulus, e.g. the auditory or tactile stimulus, was presented in synchronization with the first stimulus by one of the nine SOAs. The speed of the finger movement was chosen for each experimental running at a speed of 76 mm/s, which was relative comfortable speed and nearly representative of normal surface exploration. The procedure for evaluating the temporal discrimination was the same as the voluntary condition. This involuntary condition is only a kind of proprioceptive sensation or sense of body movement, which also appears in voluntary condition.

No-movement condition (Fig. 1): A sound of cue was generated to announce the starting of each trial, and then the first stimulus, e.g. the tactile or auditory stimulus, was randomly presented after 600 to 700 ms delay from the presentation of the starting cue. Then, the second stimulus, e.g. the auditory or tactile stimulus, was presented in synchronization with the first stimulus by one of the nine SOAs. The participants remained stationary throughout the experiment in this condition. The procedure for evaluating the temporal discrimination was the same as the other two conditions.

D. Data analysis

The ratio of the answers as the earlier presentation of the auditory stimulus was calculated for all of the SOAs. Then with a generalized linear model, logistic regressions were conducted on the ratio data of each experiment. Individual psychometric functions were fitted to the distribution of the mean TOJ data for voluntary, involuntary and no-movement conditions (Fig. 2).

The PSS was calibrated for each participant with the regression analysis. Eq. (1) [17] was used in the logistic regression analysis, and α represents the estimated PSS.

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

III. RESULTS

From the mean values (Table 1), we could see that the

Table 1 Mean values and standard errors of the PSS in the three conditions.

Conditions	PSS (ms)	
	Mean	SE
Voluntary	32.6	10.2
Involuntary	13.9	5.9
No-movement	4.5	6.3

PSS was 32.6 ms in voluntary condition and 4.5 ms in no-movement condition. And the PSS of involuntary condition was among the middle of the two conditions already mentioned. These results meant that the PSS in voluntary condition shifted distinctly to the time point in which auditory stimulus should be presented earlier than tactile stimulus, compared to no-movement, and was more obviously affected by voluntary movement than involuntary movement.

IV. DISCUSSION

Compared to no-movement, voluntary movement, significantly affected the temporal perception of simultaneity of auditory-tactile stimuli in TOJ task. Compared to involuntary movement, the simultaneity was perceived in the interval, where auditory stimulus should be presented even earlier in voluntary movement. From the mean values of PSS, these results were similar to the results of Nishi *et al.* [14], but different with the results of Frieseen *et al.* [15], which might be caused by the methodological differences. We used impulse force as tactile stimulus and SOAs within ±240, ±120, ±60, ±30, and 0 ms, whereas they used force pulse as tactile stimulus and SOAs within ±300, ±225, ±150, ±75, and 0 ms. These results made us once more to suspect that it might be efference copy generated only in active movement, which is a copy of the motor command, rather than proprioceptive sensation or sense of body movement both in voluntary and involuntary movements, made the PSS shift to auditory-lead stimulus between auditory and tactile stimuli. The efference copy is available up to 250 ms to the brain before active movement occurs, and to predict the timing of an active movement [18-19]. As the efference copy provides voluntary movement with additional information, it might be expected to accelerate the speed of tactile stimulus or the processing times of making a decision in TOJ task, e.g. the temporal order of auditory-tactile stimuli in the brain. From actual results of the present study, it was not possible to claim how the efference copy affect the PSS. To get further evidence to confirm the mechanism on the shift of subjective simultaneity in voluntary movement, we need to investigate in the next experiment where the auditory-tactile stimuli of TOJ task and the voluntary movement are performed contralaterally.

In conclusion, the subjective simultaneity of auditory and tactile stimuli was influenced by voluntary movement in TOJ task, which meant that simultaneity was perceived if auditory stimulus came earlier than tactile stimulus.

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