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Construction of a measurement system for simultaneity judgment using odor and taste stimuli

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HIGHLIGHTS

- Simultaneity judgment with three cross-modal combinations of odor, taste and light stimuli was performed.
- The presented stimuli were monitored in real time during the task.
- The temporal distribution of simultaneous response rates was calculated.
- All three temporal distributions were approximated by a Gaussian distribution.
- This result suggests that we developed a high accurate measurement system.

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ABSTRACT

Background: The modalities examined in previous simultaneity judgment (SJ) were limited to vision, audition, and touch. By contrast, olfaction and gustation have not been addressed to date in SJ.
New method: In this study, we constructed a measurement system for performing SJ with three cross-modal, combinations of odor, taste, and light stimuli. Odor and taste stimulators were able to stimulate to only the receptors corresponding to the modalities of each stimulus, without inducing tactile sensation. Furthermore, in order to precisely calculate the time points at which stimulus reached receptors in each trial, we monitored the presented stimuli in real time. After we calculated the actual values of stimulus onset asynchrony (SOA) between standard and comparison stimuli on the basis of the records of real-time monitoring, we evaluated the temporal distributions of simultaneous response rates in each cross-modal combination.
Results: When we fitted a Gaussian distribution to these temporal distributions, we observed low error rates in all cross-modal combinations, as demonstrated in SJ using visual, audio, and tactile stimuli.
Comparison with existing method(s): SJ using chemical stimuli and SJ using physical stimuli exhibit the same degree of measurement accuracy.
Conclusions: We succeeded in development a high accurate measurement system for SJ using chemical stimuli. We attribute this success to the use of strict real-time monitoring of stimulus presentation.

1. Introduction

An observer's perception of temporal simultaneity between sensations of different modalities is one of the factors that affect their judgment regarding whether sensory inputs into receptors of different modalities belong to the same event (Powers et al., 2012). Previous studies of this topic have generally employed two tasks in which a pair of cross-modal stimuli are presented with varying degrees of stimulus onset asynchrony (SOA): simultaneity judgment (SJ), in which the participant reports whether two stimuli were presented simultaneously (Foucher et al., 2007; Vatakis et al., 2008), and temporal order judgment (TOJ), in which the participant reports which of two stimuli was presented first (Laasonen et al., 2002; Virsu et al., 2003). Based on participant's responses during the tasks, the following values are calculated: "just noticeable differences," the interval between two stimuli needed in order for the participant to correctly judge their temporal order with a probability of 75% in TOJ (Santangelo and Spence, 2009; Vatakis and Spence, 2006a); half width at half height (HWHH), the interval between two stimuli corresponding to one half of the peck on the temporal distribution of simultaneous response rate in SJ (Fujisaki and Nishida, 2009); and point of subjective simultaneity (PSS), the SOA at which the participant was most likely to report the two stimuli

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were presented simultaneously (Lewald and Guski, 2004; Vatakis and Spence, 2006b). Many previous studies examined the factors that affect PSS, such as intensity of stimuli (Boenke et al., 2009; Kopinska and Harris, 2004), attention to the stimulus of a particular modality (Spence et al., 2001; Zampini et al., 2005b), spatial location of the present stimuli (Keetels and Vroomen, 2007; Zampini et al., 2005a), distance between the observer and the presented stimulus (Engel and Dougherty, 1971; Harrar and Harris, 2005; Harris et al., 2010), and adaptation the observer to a specific SOA before the start of the task (Fujisaki et al., 2004; Vroomen et al., 2004).

The modalities examined in previous SJ and TOJ were limited to vision, audition, and touch. By contrast, the chemical senses, olfaction and gustation, have not been addressed to date in studies of SJ and TOJ. Psychophysical or psychological studies dealing with chemical senses are far less frequent than those that deal with other modalities, because odors exist as gases and tastes exist as liquids, and it is difficult to control the presentation of these types of stimuli.

In this study, we tried to construct a measurement system for conducting SJ with three cross-modal combinations of odor, taste, and light stimuli. In order to confirm the accuracy of this measurement system, we prepared not only a combination of two chemical stimuli, i.e., odor and taste, but also combinations of one chemical stimulus and one physical stimulus, i.e., odor and light, or taste and light. In order to exclude variation in the data due to individual differences, we adopt a within-subjects design in which every participant performed SJ for all three combinations. Odor stimuli were presented on the odor stimulator developed by Kobal and his colleagues (Kobal, 1985; Kobal and Hummel, 1988), and taste stimuli were presented on the taste stimulator developed by Kobayakawa and his colleagues (Kobayakawa et al., 1996, 1999). We monitored presented stimuli in real time during measurement, and precisely calculated the time between onset of stimulus and arrival of stimulus at receptors in each trial.

2. Materials and methods

2.1. Odor stimulation

Essence of cherry tree leaves (68.4 mM coumarin [Wako Pure Chemical Industries, Ltd., Tokyo] dissolved in propylene glycol) was used as the odor stimulus. In order to present the odor stimulus, we used the odor stimulator developed by Kobal and his colleagues ("Olfactometer OM4": Burghart Instruments, Wedel, Germany). The high-speed ultrasonic gas sensor (described below) and a small-diameter Teflon tube were placed at the outlet of odor stimulator. The participant was instructed to insert the Teflon tube about 1 cm into one nostril, as shown in Fig. 1(a) and (b). In order to avoid changes in pressure and temperature in the nasal cavity, humidified pure air was presented in the nasal cavity at all times, and odor bubbled with humidified nitrogen was inserted to the air flow as a pulse. Furthermore, two experimenters smelled the tip of Teflon tube and confirmed the perceived intensity of the odor stimulus. We conducted real-time monitoring of stimulus presentation, and recorded the time points at which odor stimulus passed through the high-speed ultrasonic gas sensor by converting gas molecular weight into voltage values (Toda and Kobayakawa, 2008; Toda et al., 2005), as shown in Fig. 2(a). Additionally, white noise was presented at all times during measurement in order to prevent the participant from determining the timing of stimulus presentation from the noise of switching between the air and odor lines.

The perceived intensity of odor stimulus was adjusted to be approximately 'moderate' [3] on the labeled magnitude scale ('no detectable' [0], 'barely detectable' [1], 'weak' [2], 'moderate' [3], 'strong' [4], and 'very strong' [5]: see Saito, 1994). Duration of stimulus presentation was 400 ms, and flow rate was 7.5 l/min. Two experimenters confirmed whether the perceived intensity of odor stimulus at the tip of the Teflon tube was appropriate for

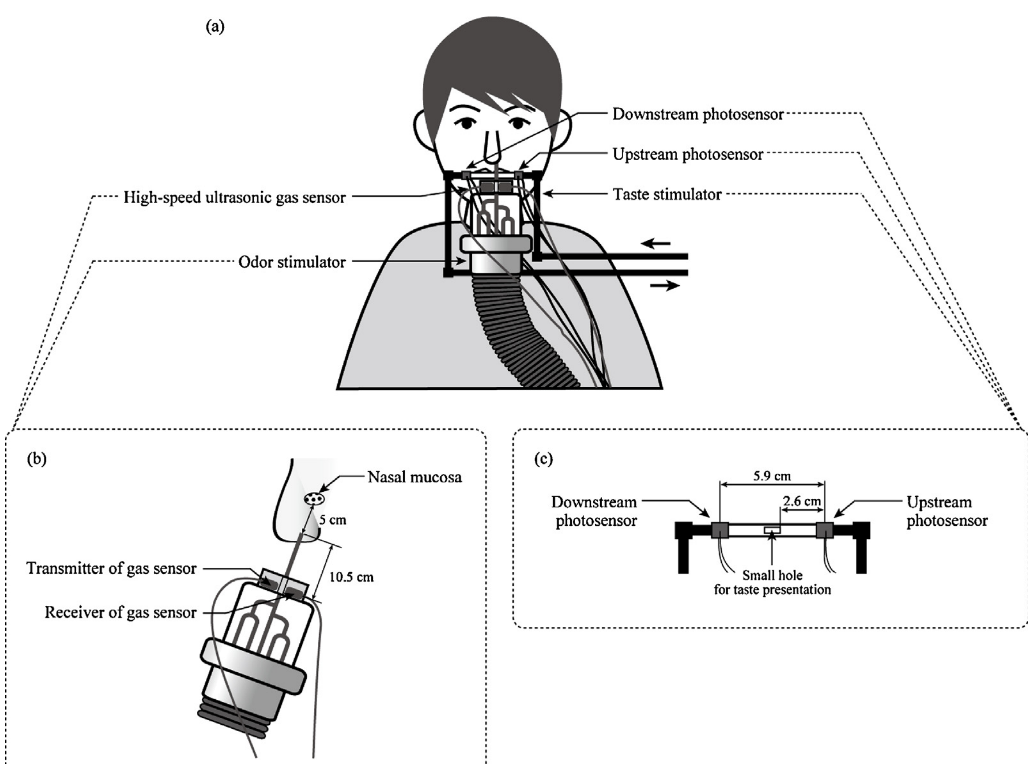

Fig. 1. Stimulus presentation for combinations involving odor and taste stimuli. (a) Stimulators used for combinations involving odor and taste stimuli. (b) Presentation of the odor stimulus. (c) The presentation of the taste stimulus.