**ARE STROOP FACILITATION AND INTERFERENCE EFFECTS ENHANCED BY AN ACCOMPANYING AUDITORY WORD?**

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**Abstract**

*Cross-modal enhancement was investigated using Stroop color words and spoken words. Stroop color words consisted of printed color words in semantically congruent or incongruent colors. The visual stimuli had two dimensions (color and word), and the auditory stimuli had one dimension. The combination of two dimensions of visual color words and auditory words produced five possible conditions: corresponding to all dimensions; corresponding to two dimensions and non-corresponding to one dimension, including three subconditions according to the combination of dimensions; and non-corresponding to all dimensions. These combinations varied randomly from one trial to the next. Stimulus onset asynchrony (SOA) between visual and auditory stimuli was blocked within participants across five blocks. The block order was counterbalanced across the participants. Consequently, the Stroop facilitation effect was enhanced by the accompanying congruent auditory words, especially in auditory-word-first SOA, in which the auditory word was presented before the visual color word.*

Recently reported evidence has indicated that the Stroop effect (Stroop, 1935; see MacLeod, 1991, for a review) is impacted by a phonological code of reading (Roelofs, 2003, 2005). Roelofs' model proposes that the Stroop effect is produced at the phonological stage of reading. However, it is surprising that little research has been carried out on the cross-modal Stroop effect until fairly recently (Shimada, 1990; Eliott, Cowan, & Valle-Inclan, 1998; Roelofs, 2005). We determined that no research had been reported regarding the effect of spoken words on both color and word dimensions of visual color words. In the present study, we manipulated the item congruency in both printed and spoken color words produced from one trial to the next. This approach was in contrast to that of our other presentation in this meeting (Ashitaka & Shimada, 2010), in which we describe the manipulation of the response set effect produced by the spoken and printed distractor words. In contrast, the present experiment produced item congruency, in which the spoken words varied semantically independently from both dimensions (color and word) of the printed color words.

## Method

*Participants.* The participants were 12 undergraduate students at Kobe University. All participants reported that they had normal or corrected-to-normal visual acuity and auditory acuity and that they had no problems with their color vision in daily life.

*Materials and Devices.* An E-Prime 1.2 program (Psychology Software Tools, Inc.) presented the visual–auditory stimuli and collected response latency data. Three printed, colored color words (赤, 緑, and 青, in Japanese kanji referring to *red*, *green*, and *blue*, respectively) consisted of congruent (e.g., the word *red* printed in red) and incongruent (e.g., the word *red* printed in green) stimuli. Before the experiment, three spoken words corresponding to the printed color words were also prepared in synthesized voice by using the computer software. The item congruency consisted of five conditions between three factors (color and word dimensions of the printed word and spoken word) as follows: (1) Triple dimensions are congruent in the printed color and word and the spoken word (TC) (e.g., color [C] in the printed color word is RED; word [W] is *red,* and the spoken word [A] is red). (2) Both dimensions in the printed color word are congruent each other (CW). (3) The color dimension of the printed color word is congruent with the spoken word (CA). (4) The word dimension of the printed color word is congruent with the spoken word (WA). (5) All three dimensions are incongruent with each other (IC).

*Design.* The basic design included two within-subject factors: Independent variables were 2 (Item Congruency: TC, CW, CA, WA, IC) × 5 (SOA: –200 ms, –100 ms, 0 ms, 100 ms, 200 ms) as within-subject design. The dependent variable was response latency.

*Procedure.* After they completed a practice block, including 16 trials, the participants completed 5 experimental blocks that included 96 trials each in each SOA. The order of the trial blocks was counterbalanced across the participants. In each trial, the fixation point was presented at the center of the screen for 500 ms, followed by one of three types of printed color words in kanji. The instructions emphasized that participants should respond to color dimension but ignore the printed word dimension and auditory word as soon as possible without giving an incorrect response. The participants' responses were recorded using a microphone, and the experimenter in the adjacent room listened to the correct responses through a wireless computer-loudspeaker.

## Results and Discussion

Before analyzing the data of reaction times (RTs), we eliminated 21 trials with an RT of less than 300 ms (0.22% of trials) or greater than 1,500 ms (0.24% of trials). We also eliminated trials with error responses (106 trials; 2.4%). Consequently, 2.82% of the trials were excluded from analysis. The analysis of variance (ANOVA) with two repeated factors indicated the significant main effect of Congruency, $F(4, 36) = 39.75$, $p < .00$, no significant effect of SOA, $F < 1$, and the significant interaction between Congruency and SOA, $F(16, 144) = 2.79$, $p < .0001$ (Figure 1). Figure 1 revealed the difference in trends between the congruent conditions in the printed word (TC, CW) and the incongruent conditions (CA, WA, and IC). This difference was confirmed by ANOVA, indicating that Congruency (TC, CW and CA, WA, IC) had a significant main effect, $F(1, 9) = 69.5146$, $p < .0001$. Furthermore, the ANOVA revealed no main effect of SOA ($F < 1$) and significant interaction, $F(4, 36) = 4.4443$, $p = .005$. Thus, we conducted two separate ANOVAs with two repeated factors of Congruency and SOA for these conditions. For the congruent conditions (TC, CW) in the printed word, the ANOVA produced the significant main effect of Congruency, $F(1, 9) = 20.787$, $p < .0014$, no main effect of SOA ($F < 2.6$), and interaction ($F < 1$), whereas for the incongruent conditions (CA, WA, and IC), the ANOVA produced a significant main effect of Congruency, $F(2, 18) = 4.2332$, $p < .032$, no main effect of SOA ($F < 1$), and significant interaction, $F(8, 72) = 2.295$, $p < .030$.

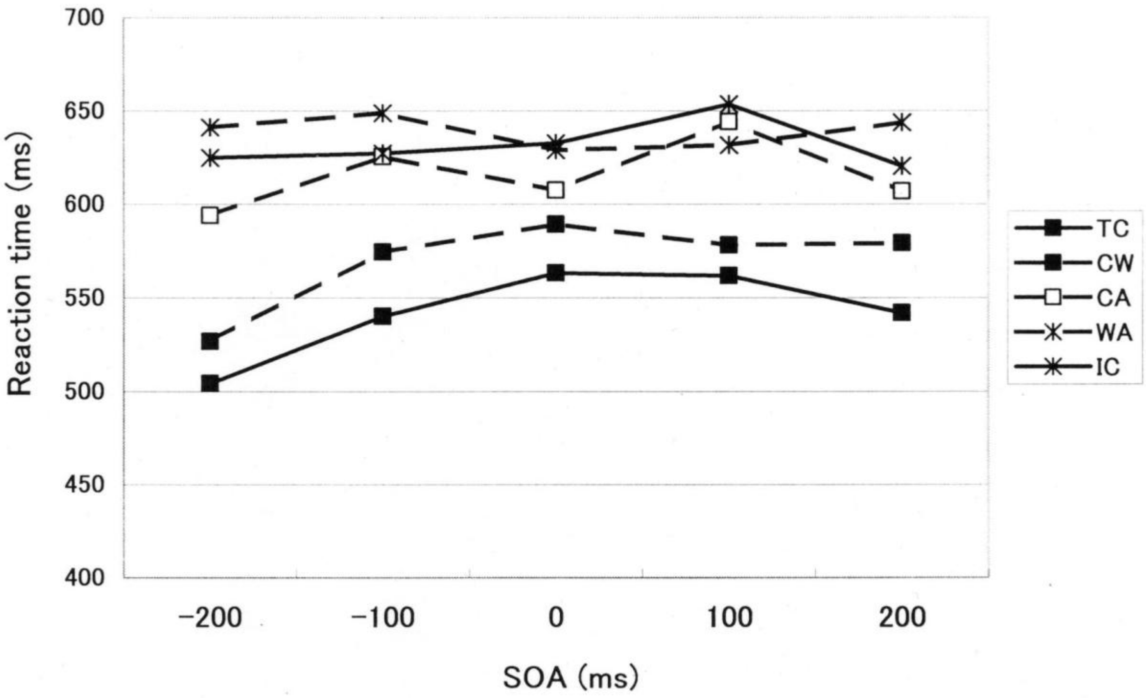


Fig. 1 Response latencies as a function of stimulus onset asynchrony (SOA) and Item Congruence (TC: triple dimensions are congruent, CW: color and word dimensions are congruent, CA: color dimensions and auditory word are congruent, WA: word dimension and auditory word are congruent, IC: all three dimensions are incongruent in the printed color word and spoken word). Preexposure of spoken word is indicated by SOAs with a minus sign.

To determine which incongruent combinations of auditory and visual dimension (CW, CA, and WA) have a larger effect on the Stroop congruency effect, we conducted another ANOVA with Item Congruency by excluding completely congruent and incongruent conditions from triple dimensions (TC and IC, respectively). Consequently, the ANOVA revealed a significant main effect of Congruency, $F(2, 18) = 24.99$, $p < .0000$, with the order of mean RTs from largest to smallest being WA (639.0 ms), CA (615.7 ms), and CW (569.7 ms; contrast between combinations of each congruency revealed significance, $p$s $< .003$) and significant interaction between Congruency and SOA, $F(8, 72) = 3.44$, $p < .002$. However, there was no significant effect of SOA, $F < 1$. These results indicate the interference effect from visual and auditory distractors and the facilitation effect from visual color and word dimensions. Furthermore, another ANOVA with WA and IC revealed no significant effect of Congruency or SOA ($F < 1.2$). There was a marginal interaction between Congruency and SOA. This result indicates that a double distractor with auditory word and printed word is sufficient to create the interference effect and does not always require the addition of the incongruent color dimension (three incongruent dimensions) for the interference effect. By contrast, ANOVA with TC and CW revealed the significant effect of Congruency, $F(1, 9) = 20.787$, $p < .0014$, with TC having shorter RT (542.40 ms) than CW (569.7 ms), and the marginal effect of SOA, $F(4, 36) = 2.585$, $p < .053$. This result indicated that the facilitation effect was emphasized by three congruent factors (2 visual components of printed color word and 1 factor of auditory word). ANOVA with minus and plus SOAs separately revealed that the former showed significance of SOAs [$F(2, 18) = 6.18$, $p < .009$; 515.55 ms, 557.49 ms, 576.34 ms, and –200 ms, –100 ms, 0 ms), whereas the latter had no effect of SOAs ($F$ <1).

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