Visual-auditory intersensory effects: A trade-off relationship between facilitation and inhibition

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VISUAL-AUDITORY INTERSENSORY EFFECTS: A TRADE-OFF RELATIONSHIP BETWEEN FACILITATION AND INHIBITION

By

NAKANO YOSHIKI (中野良樹)[1]

(*Tohoku University*)

Visual reaction time (RT) is facilitated by a simultaneous or near simultaneous auditory event. This auditory stimulus is called "accessory" in the sense that subjects need not attend to perform the task. This study investigated the intersensory facilitation between the visual imperative stimulus and the auditory accessory. In Experiment 1, the facilitation effect by the accessory caused the inhibition in without-accessory trials. Furthermore, the magnitude of inhibition was larger in a Go/Nogo task than in a choice RT task. These results suggested that subjects expected the auditory accessory, then it's absence inhibited processing of the following visual stimulus. Experiment 2 examined whether the expectation caused both of the intersensory effects. Twenty-seven subjects were divided equally into three groups, in each the accessory appeared with 20, 50 and 80% probability. As a result, degrees of facilitation were not different between groups, while the inhibition increased with probability of the accessory. These findings manifest that the facilitation does not necessarily accompany the inhibition. Thus, the author concluded that the auditory accessory facilitated RTs automatically, and it's frequent appearance conditioned subjects to expect to appear the auditory event, which inhibited processing in visual one.

Key words: intersensory effect, facilitation, inhibition, trade-off, accessory stimulus, stimulus probability.

INTRODUCTION

In a reaction time (RT) task, subjects respond to the imperative stimulus (IS) faster when it is accompanied by an irrelevant stimulus in a different modality. This phenomenon called "intersensory facilitation" of reaction time, and the irrelevant stimulus called an "accessory" or a "redundant" stimulus. In most studies of the intersensory facilitation, the IS was presented on a visual modality and the accessory was on an auditory one. Two types of models have been advanced to account for the intersensory facilitation. The first is the "energy summation" model postulating the summation of stimulus energy across sensory modalities (Bernstein, Rose, & Ashe, 1970). The second is the "preparation enhancement" model that conceives of the auditory stimulus as an alerting cue which facilitates the movement related processes (Nickerson, 1973; Schmidt, Gielen, & van den Heuvel, 1984).

In previous studies, there have been more findings that support the preparation

1. Department of Psychology, Faculty of Arts and Letters, Tohoku University, Kawauchi, Aoba-ku, Sendai 980-77, Japan.

enhancement than the energy summation. Nakano and Maruyama (1994) found that the accessory initiated the movement related activity at the cortical level. They recorded the lateralized readiness potential (LRP; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988) as the real-time index of hand specific motor preparation. The LRP showed negative deflection about 100 msec after the auditory accessory. Evidently, this psychophysiological result supports the preparation enhancement. Furthermore, Gray and Ulrich (1993) reported that the accessory stimulus affected processes after initiating the response signal. From these findings, it is reasonable to consider that the intersensory facilitation, at least partially, caused in movement related processes.

Now, let us think about whether the intersensory facilitation is a true facilitation. The term of "facilitation" means that the accessory bring the positive effect for processing of a IS. The magnitude of facilitation denotes the difference between RTs to an IS presented alone and those with the accessory stimulus. This comparison, however, assumes that RTs in a with-accessory condition are independent of RTs in a without-accessory condition. If they are inhibited by the accessory presented in other trials, the intersensory effect is not a facilitation but a trade-off. Between the speed and the accuracy of a response such the trade-off relationship observed in some intersensory facilitation studies (Schmidt et al., 1984). The more RT is reduced by the accessory the more subjects made erroneous response. The speed accuracy trade-off is primary concerned with a response preparation, because errors caused by premature responses (Sanders, 1980). Thus this phenomenon can be explained as follows: the accessory enhances the preparation for a response, it initiates the movement before terminating processing for the IS completely. Possibly, the trade-off exist not only between speed and accuracy but between speed and speed. In detail, while RTs in a with-accessory condition are reduced by the accessory, RTs in a without-accessory condition could be slower by the absence of it.

EXPERIMENT 1

Experiment 1 examine whether RTs in without-accessory trials are inhibited by the facilitation effect in with-accessory trials performing in a same session. This purpose needs to manipulate magnitude of facilitation. Stimulus onset asynchrony (SOA) between the accessory and the IS should be the most appropriate parameter for that purpose, because the effectiveness of the accessory is a monotonical function of the SOA (Nickerson, 1970). Degrees to which the accessory will facilitate a RT to the IS depends on how much time the former precedes the latter. If the facilitation effect of the accessory inhibits the processing in the without-accessory condition, RTs will be increased with preceding the accessory to the IS.

METHOD

Subjects: Sixteen volunteered graduates and undergraduates at Tohoku University participated in the experiment (2 female; age range, 21-27). They had normal or corrected-to-normal vision and hearing. Two of them were left-handed. All had some experience

with RT tasks.

Apparatus: The visual stimuli were vertically located three light emitting diodes (LEDs). The middle of the LEDs was red and it's luminance was 0.5 cd/m^2. This LED served as a fixation point. The upper and the lower were green and 0.3 cd/m^2. These served as an IS. They were separated 1 cm above and below from the red LED. Subjects observed the visual stimuli apart from 50 cm. Auditory stimulus was a 1000-Hz tone (80 msec in duration) and presented binaurally over headphones.

Procedure: The experiment was conducted in a dimly lit and sound-attenuated room. The subjects were assigned to either of two groups. In one, they performed a Go/Nogo task, and the other was a choice reaction time (CRT) task. At the start of each trial, click sound bursts were presented as a warning signal over a speaker located in front of them, then the fixation point appeared. After a random foreperiod ranged from 2.2 to 3.5 sec, the upper or lower LED lit for 10 msec as an IS. In the Go/Nogo task, the subjects required to press the key with right index finger if that was a Go signal, and withhold a response when it was a Nogo signal. The Nogo signal occurred on 25% of the trials. The assignment of Go or Nogo signal to LEDs was balanced over the subjects. In the CRT task, half of the subjects instructed to perform right hand response for the upper LED, and left hand for the lower one. The other half of the subjects were given the reverse instructions. One second after the presentation of the IS, the fixation point was disappeared. When a wrong response was made or a RT exceeded 450 msec, the trial was regarded as an error, and a beep tone was presented to the subject. There was a 2 sec interval before the beginning of the next trial.

At the temporal proximity to the onset of the IS, the auditory stimulus was presented as an accessory. It appeared on randomized 50% of the trials. The subjects were instructed that they could ignore this tone, for it was irrelevant to the task. The auditory stimulus was presented either of twenty SOA points ranged from 400 msec before (SOA = −400 msec) to 300 msec after (SOA = 300 msec) the IS.

Design: A single experimental session was consisted of 3 blocks in the Go/Nogo task and 2 blocks in the CRT task. Each block contained 40 trials and lasting about 5 min. Between blocks, there was a 1 min. rest period. The SOA point was held constant throughout the session. Before each session the subjects participated in a practice of 20 trials for that SOA condition. This experimental session repeated for all the 20 SOA points. When the experiment continued more than 40 min., the next session was conducted on separated day.

Results

Figure 1 showed averaged RTs for with- and without-accessory condition at each SOA point. Solid and dotted lines were logistic function fitted to these data in each condition[1]. In

1. Logistic curves were fitted by algorithm in Sigma Plot (Jandel). This program found parameters that gave best fit between the RT data and the following equation.
$f(x) = a/(1 + (b \times \exp(c \times x)) + d$

a: range of mean RT, b: a slope coefficient, c: a SOA point at the maximum rate of change, d: convergent value, x: SOA.

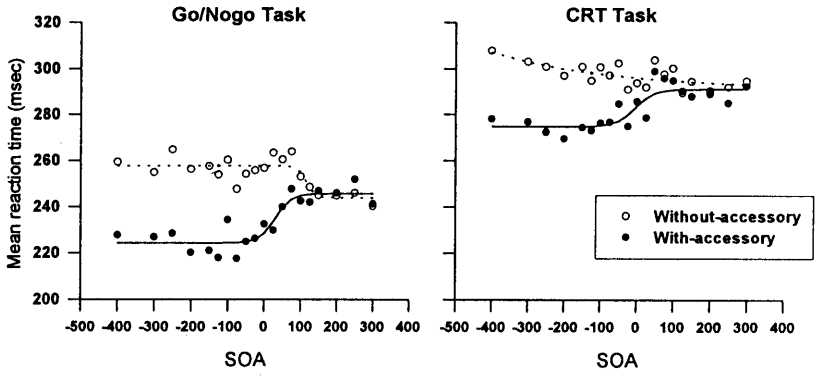

Fig. 1. Mean reaction time of correct response as a function of SOA and the accessory condition in the Go/Nogo task (left) and the CRT task. The solid and dotted curves is a logistic function fitting to data in each accessory condition.

with accessory conditions, logistic curves showed a sigmoid shape. At larger SOA points, RTs maintain a constant maximum level. Then the curves were reduced monotonically as SOA going negative, and it continued until about -100 msec SOA. Once the curves reach a minimum level, it kept the plateau. The curves of without-accessory conditions show a near inverse relationship to those of with-accessory one, such that they increase monotonically as SOA going negative. Their magnitudes of deflection from the baseline, however, are less than those in the with-accessory condition. The curves in both accessory conditions converged on almost the same value at larger SOA points. A value of δt depicted the difference between the convergent value and the maximum deviation. Figure 2 showed values of mean δt in each

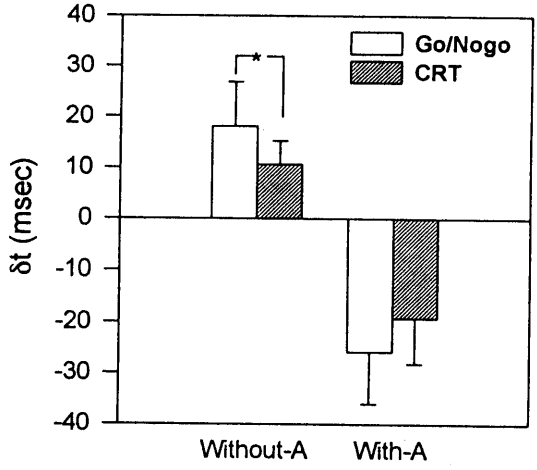

Fig. 2. δt Values of δt in each task and accessory condition.

condition and task. The positive δt indicated the deviation was larger than the convergent value, and the negative value indicated smaller deviation. Two way (accessory × task) ANOVA showed that δt was significantly larger in the without-accessory condition than in the with accessory, $F(1,14) = 200.5$, $p < .01$. There was a significant interaction between two factors, $F(1,14) = 7.38$, $p < .05$. Further analysis by LSD method showed that δt was larger in the Go/Nogo task than in the CRT task for the without accessory condition, $F(1,14) = 4.66$, $p < .05$.

Discussion

Experiment 1 examined whether trials with- and without-accessory are independent of each other. In the Go/Nogo task, logistic curves showed a trade-off relationship between both conditions. Two logistic curves converged after the 200 msec SOA, so the accessory exerted no effect at larger SOA points. These curves deflected to opposite directions as SOA going negative. If two conditions were independent of each other, the logistic curve in the without-accessory condition was constant. So this trade-off relationship manifests that the accessory facilitates response processes when it is presented, while its absence inhibits the processing of the visual IS in other trials.δt was an index of magnitudes of the accessory effect. Apparently, the positive δt manifests that the accessory caused inhibition in the without-accessory trials. In addition, such inhibition was larger in the Go/Nogo task than in the CRT task. Probably, this result indicated that the inhibition occurred in processes that mediated the response preparation. In the Go/Nogo task, the subjects preliminary know which hand they will move. So, the subjects can enhance the response preparation for a specific hand almost near the movement execution before the IS was presented. If the following IS is a Nogo signal, they can withhold the movement as far as the ballistic process is not launched (Osman, Kornblum, & Meyer, 1986). In the CRT task, the subjects did not know a direction of response hand until the IS was presented. So the accessory had only a general alerting effect (Welch & Warren, 1986). Considering from these findings, the subjects could not ignore the accessory in spite of the instruction. Rather they used the accessory to respond as fast as possible. Thus the subjects expect the appearance of the accessory in all trials, although its probability was a chance level. In without-accessory trials, the absence of the accessory conflicted to such the expectation, and it inhibited the following processing for the IS.

Experiment 2

The results of Experiment 1 suggested that the expectation to the appearance of the accessory caused the inhibition effect in without-accessory trials. Nevertheless, it would be premature to conclude that the expectation caused by the presentation of the auditory stimulus itself. It is also possible that the subjective experience of the facilitation made subjects to expect to appear the accessory. In detail, subjects learned as repeating trials that they could respond faster when the accessory was presented. So they would try to maximize the facilitation effect to perform a response as fast as they could. Consequently, they prepare to

process the auditory event. If this inference is true, the expectation is a product of the facilitation effect itself, which is repeatedly experienced by subjects. In Experiment 2, a probability of an accessory is manipulated to examine this inference. Frequent appearance of an accessory makes subjects are more biased to the auditory modality as in Experiment 1. While the accessory is less probable, subjects will not expect to appear of it. The author is interest in this condition. If the intersensory effects caused by the subjects' intention to use the auditory accessory to respond faster, both the facilitation and inhibition effect should be reduced in that condition. On the other hand, if less probable accessory facilitates RTs as much as in more probable conditions, the intersensory effect is independent of subjective expectation.

METHOD

Subjects: Twenty-seven volunteered undergraduate students at Tohoku University participated in Experiment 2 (10 male; age range, 19 - 21). They had normal or corrected-to-normal vision and hearing. All of them were right-handed and naive about the bimodal RT task.

Apparatus and Procedure: The visual and the auditory stimuli were the same as those used in Experiment 1. The subjects performed the CRT task which was identical to Experiment 1 excepting the accessory and foreperiod settings. A foreperiod duration was ranged from 1.2 to 2.0 sec. The accessory is presented constantly 300 msec before the IS (SOA = −300 msec). The subjects were assigned equally to either of three groups that differed in a probability of the accessory. The probability of the appearance was 20%, 50%, 80% respectively. Before the experimental session, the subjects participated training session of 40 trials without presenting the accessory. An experimental session was consisted of 4 blocks each contained 40 trials. In each group, the probability of the accessory was almost the same in all experimental blocks.

RESULTS

Table 1 and Fig. 3 showed averaged RTs for with- and without-accessory condition in each probability. Three way (Probability × Accessory × Block) repeated measure ANOVA showed that RTs were significantly shorter in the with-accessory condition than in the without one, $F(1,24) = 83.1$, $p < .01$. Results were rather complicated, since every combination of two-way interactions showed a significant effect. First was Probability × Accessory, $F(2,24) = 9.59$, $p < .01$. As a result of simple main effect test of this interaction, the accessory effect was significant in 80%, $F(1,24) = 32.4$, $p < .01$, and 50% group, $F(1,24) = 66.0$, $p < .01$. In 20% group the effect did not reach significant but marginal level, $F(1,24) = 3.9$, $p < .1$. Furthermore, the effect of the probability reached marginal level in the without-accessory condition, $F(2,24) = 3.36$, $p < .1$, while it was not significant in with-accessory one. The second interaction was Probability × Block, $F(6,24) = 9.59$, $p < .05$. The effect of block was significant only in 50% group, $F(1,24) = 3.2$, $p < .05$. The third is Accessory × Block, $F(3,24) = 9.59$, $p < .01$. In the with-accessory condition RTs were significantly different between blocks, $F(2,24) = 7.78$, $p < .01$.

Table1 Experiment 2: RT (msec) as a function of Probability, Accessory Condition and Block

	Block	1	2	3	4	Avg.
Without - accessory	20%	300.0	306.6	302.5	304.0	303.2
	50%	322.8	320.7	316.8	313.7	318.5
	80%	324.2	323.5	339.0	335.1	330.5
With - accessory	20%	310.2	297.1	284.6	285.4	294.
	50%	301.0	299.2	287.1	283.3	292.8
	80%	298.8	287.3	295.0	293.0	293.5

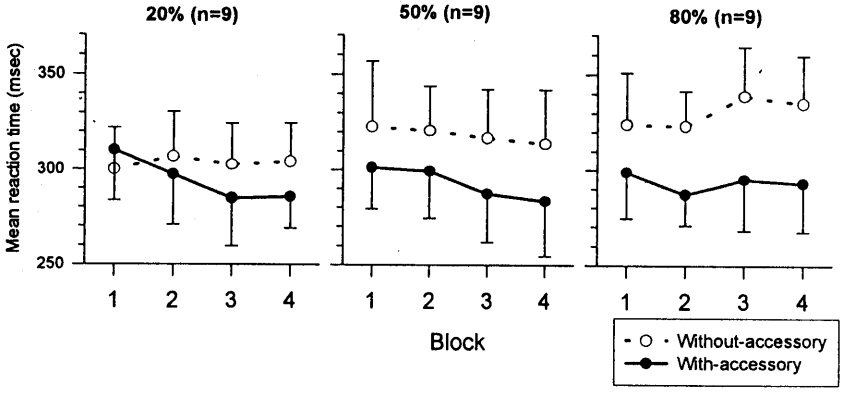

Fig. 3. Mean reaction time and *SD* as a function of probability, block and accessory condition.

Discussion

In Experiment 2, probabilities of the accessory were manipulated to assess the trade-off relationship between the facilitation and the inhibition. In the without-accessory condition RTs increased with the probability. This correlation between the probability and RTs manifests that the inhibition effect is caused by the frequent appearance of the accessory. These results can be explained by a subjects' expectation to the accessory as discussed earlier. When the accessory is presented frequently, the expectation becomes strong with repeating trials. Then the absences of the accessory interfere the processing of the following IS. On the other hand, when the accessory is infrequent, subjects would not expect its appearance. So they can respond to the IS as in a unimodal RT task.

Contrary to the inhibition effect, the accessory facilitated RTs regardless of probabilities in later blocks. The most notable result was obtained in the 20% probability. At the first block, RTs were not different between the with- and without-accessory condition. So the accessory exerted no effect at this point. Then RTs were reduced in the with-accessory condition as blocks going on, while they held constant in without-accessory one. This

asymmetry proves that the intersensory facilitation does not necessarily accompany the inhibition effect when the accessory is not presented.

General Discussion

This study investigated the intersensory facilitation that RTs to a visual imperative stimulus can be shortened if an auditory accessory stimulus is presented at approximately the same time. Experiment 1 examined whether RTs in without-accessory trials were constant regardless of magnitudes of the facilitation in with-accessory trials. This experiment showed that the visual auditory intersensory effects had a trade-off relationship between the facilitation and the inhibition. Furthermore in Experiment 2, magnitudes of the inhibition correlated with probabilities of the accessory. This finding confirmed that the inhibition was caused by the expectation to the auditory accessory. When subjects repeated an identical stimulus-response performance, they became to prepare it before the beginning of a trial (Gehring, Gratton, Coles, & Donchin, 1992). So in 50% and 80% groups, the subjects would prepare the visual RT task with expecting the auditory event. While in the 20% group most of the trials were the without-accessory condition, so the subjects could prepare only the visual event.

This difference of the expectation was reflected by magnitudes of the inhibition in the without accessory condition. A psychological refractory period mentioned in Nickerson (1970) brought a reasonable explanation about the inhibition by the absence of the accessory. As indicated in Experiment 2, the frequent accessory made subjects to expect its appearance. This finding suggests that the preparation to the auditory event occupies an main channel of the processing for some time. So they could not terminate the preparation to the auditory modality and switch the processing completely to the visual one, when the auditory accessory was not presented. Then the detection of the IS was delayed, if it followed the accessory closely.

Experiment 2 yielded a significant result for the facilitation effect that RTs in the with accessory condition did not differ regardless of the probability in later stages. In addition, effectiveness of the facilitation was not significantly different between the Go/Nogo and the CRT task in Experiment 1. These results were not consistent with those about the inhibition effect. This inconsistency between the two effects leads us to the conclusion that a different process or mechanism with the inhibition contributes to the intersensory facilitation. There is some evidence indicating that the facilitation effect is independent of subjective states as expectation or preparedness. For example, it was effective even if subjects were instructed to ignore the auditory stimulus as in this study, or not to respond so fast (Nakano & Maruyama, 1993). Above findings manifest that the intersensory facilitation is a largely automatic process. Previous studies stated that this process relates on a preparation or an execution of a movement (Diederich & Colonius, 1987; Nakano & Maruyama, 1994; Posner, Nissen, & Klein, 1976).

In summary, the auditory accessory forced to initiate automatically movement related processes, before the processing of a visual IS was completed. This earlier initiation of the

motor process resulted in reduction of visual RTs. On the other hand, when subjects experienced such the facilitation frequently, they expected to appear the auditory accessory. That caused inhibition of processing for the visual IS in without-accessory trials. Furthermore, the inhibition was observed in earlier stages even if the accessory was presented at a chance probability. Therefore, the expectation was not a strategy which adopted by the subjects to respond faster but a result of which the attention was captured to the auditory modality. Nevertheless, the expectation did not influence on the effectiveness of the intersensory facilitation itself.

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