Effects of Various Visual and Auditory Information Upon Reaction Time of Direction Judgment
-A Study on Cognition of Environmental Information from the Viewpoint of Cross Modal Effect-

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Abstract
In the way finding system, visual and auditory information should be easily understood, and one information should not disturb the other. In the present study, the effects of additional information upon reaction time to simultaneously presented auditory and visual information was investigated. The results suggest that participants collated simultaneously presented information in order to make judgment. As compared with judgment based on a single piece of presented information, under some circumstances, the act of collation sped up reaction time, whereas in other circumstances collation slowed down this process. The following three conclusions can be drawn. 1) Reaction time decreases when additional information is easier to process than the information that the participant is tasked to focus on. 2) Reaction time increases when additional information is more complex than the information that the participant is tasked to focus on. 3) If the additional information requires a long processing time, collation of information does not occur, and reaction time does not differ from that of the reaction time when not presented with additional information.

Keywords: cross modal effects; visual information; auditory information; reaction time; direction judgment

1. Introduction
In Japan, there are the number of big shopping malls and underground shopping centers. These spaces are complex because of the large amount of facilities with widely varying uses. As a result, fear of becoming lost or being unable to find the destination often causes visitors to feel stress. Facility planners often solve these problems by using written language, symbols, and spoken language delivered through a public announcement system. In public transportation facilities such as train stations or airports, there are regulations specifically for presentation of visual information in order to facilitate user mobility1). In addition, the Oto Sign dounyu Manual presents guidelines for integration of audio information2). Following these rules and guidelines, properly planned presentation of written, symbolic, and auditory information can increase accessibility and allow first-time visitors to easily find their destination. Currently, however, an overflow of information often makes it difficult for visitors to find essential information or understand its meaning.

It is necessary to research not only the presentation of visual and auditory information, but also the way visitors process this information for wayfinding. Funahashi3) reported that wayfinding behavior is affected by how information relating to the location of the destination is presented. Watanabe et al.4) reported that proper implementation of wellholes and wide corridors can help visitors locate both destination and present location. Raubal et al.5), 6) reported that visitor solved some subtasks for going to destination from a formal model of the process of wayfinding in built environments. And, Lawton et al.7) reported that wayfinding strategies or anxiety about wayfinding is different in gender and cultural differences from the questionnaire to students at a commuter university in American and Hungarian. It is said that visual information can be more easily understood by adjusting sign size, color, character size, and luminance ratio8). However, it is reported that although many public locations such as shopping centers presently display a lot of visual information, visitors often have limited awareness9). Alan Kwok Lun Cheung10) reported that to use verbal based navigation system was significantly better than to use map or image based navigation.
system in wayfinding because presented information were not too much. And, in train stations, visitors feel dissatisfaction because signs are often unintelligible\(^1\). In addition, auditory information is necessary but oftentimes either difficult to understand or overused\(^2\). This can cause visitors to feel inconvenienced or dissatisfied.

In order to facilitate effective wayfinding, it is necessary not only to improve visual and auditory information in isolation, but also to take into account cross modal stimulation using both visual and auditory senses in integration. In their study of train stations in the Tokyo metropolitan area, Yang et al.\(^3\) recommended proper integration of visual and auditory information would result in a smooth flow of pedestrian traffic. Akita\(^4\) performed experiments measuring reaction time to directional stimuli such as pictograms signs and symbolic sounds. The results showed that understanding and reaction time to visual information improved when the information was integrated with corresponding auditory information. However, when auditory information was presented with visual that had different directional meaning, reaction time to auditory information was negatively affected.

When information signs are used on going to the destination, this behavior can be classified into "Looking for" that is to search signs or "Understanding" that is to understand its contents. (Fig.1.). It is suggested that the use of connected auditory and visual information can help aid "Understanding" from conventional research about the combined effects of visual and auditory sense. The purpose of this study is to add to knowledge relating to the presentation of information by using the combined effect of visual and auditory senses. In our previous study, we experimented with low level cognitive processing such as that accompanying pictogram signs and symbolic sounds. However, in real-life practice, complex characters and speech information is used. If more complex information had been used in the above experiment, the result may have been different because character and speech information require a higher level of cognitive processing than do pictogram signs and symbolic sounds. Our intent was to study the effect of cross modal stimuli using characters and speech information requiring high level cognitive processing.

2. Method of Experiments

Visual and auditory information indicating directions was used for investigating reaction time in the experiment. Ten Japanese subjects (7 male, 3 female, age 18 - 28) with normal eyesight and hearing participated in the experiment. The experiment was carried out in a dark room. All light sources other than the computer screen, such as LED indicator lights on equipments were covered (Fig.2.). The experiment consisted of twelve different tasks (Table 1.). Of V1-Xv tasks measuring the processing speed of visual information, V1-V5 included corresponding auditory information, whereas Xv did not. For example, in task of V2, judgment information that is a triangle is presented and addition information that is pink noise, sweep tone, spoken Japanese, spoken English or meaningless tones is simultaneously presented (Fig.3.). But only judgment information that is a circle, a triangle, the kanji, the English, or the figure is presented in task of Xv. Of A1-Xa tasks measuring the processing speed of auditory information, A1-A5 included corresponding visual information, whereas Xa did not. For example, in task of A1, judgment information that is pink noise is presented and addition information that is pink noise, sweep tone, spoken Japanese, spoken English or meaningless tones is simultaneously presented (Fig.4.). But only judgment information that is pink noise, sweep tone, spoken Japanese, spoken English or meaningless tones is presented in task of Xa. The order in which these tasks were presented to each subject was randomized. Participants were first allowed ten
minutes to adapt to the dark room, and experiments were carried out after ample practice (Fig.5.). Each task was followed by a short intermission. The experiment was conducted in sets consisting of three tasks. For this reason, each participant required a few days to complete all twelve tasks.

### 2.1 Task of Visual Information Judgment

V1-V5 measuring the processing speed of visual information were accompanied by corresponding auditory stimuli. Participants indicated the direction shown by choosing one of two keys corresponding to either left or right. Participants were instructed to press the corresponding key as quickly as possible. Visual and auditory information were presented simultaneously. If auditory and visual information indicated opposite directions, participants were instructed to choose direction corresponding to that indicated visually. A 19-inch non-reflective TFT monitor was used as well as isolating headphones. The reaction time was measured between the presentation of visual information and the press of the directional key (Fig.6.). The reaction time was not recorded when the key that was pressed indicated the wrong direction.

Inter-information interval was random from 1 to 3 seconds. When information was not being presented, participants were instructed to look at a white circle (angle of 3.9 degrees and luminance of 210 cd/m²)
in the center of the display screen. Additionally, pink noise of 50dB(A) was presented to both ears as background noise throughout the experiment. Each task presented one of five kinds of visual information indicating directions (Table 2.): a moving white circle, a triangle pointing left or right, the kanji (Chinese character) for left or right, the English word “left” or “right”, and two figures that do not imply any direction. Five kinds of auditory information were presented simultaneously (Table 3.): pink noise, sweep tone, spoken Japanese, spoken English, and symbolic tones that do not imply any direction. Auditory information of S/N ratio 3dB(A) or 20dB(A) was presented by headphones. Visual and auditory information was presented in both matching and mismatching pairs (i.e. indicating same or opposite directions). All possible combinations including matching and mismatching pairs as well as high and low decibel auditory information were presented (40 patterns), including two patterns without auditory information, totaling 42 patterns for each pair of visual symbol. Order of presentation was randomized. Each pattern using both visual and auditory information was presented three times. In addition, Xv consisted of ten patterns showing visual information without auditory information presented five times each. All patterns were presented in random order.

2.2 Task of auditory information judgment

For the part of the experiment measuring participant response to auditory information, the methodology was identical to that of the part concentrating on visual information described above, except as indicated below. A1-A5 were based on the same five pairs of auditory information used in the section focusing on visual information, as well as Xa without visual information. If auditory and visual information indicated opposite directions, participants were instructed to choose direction corresponding to that indicated by auditory information. In addition to all possible combinations of visual and auditory information being given together, auditory information was also presented without visual information (in which case the screen displayed the circle presented during inter-information times). This totals 40 auditory/visual patterns, plus an additional four auditory-only patterns. Again, as was the case with the section concentrating on visual information, all auditory information was given at both S/N ratio 3dB(A) and 20dB(A). The 44 visual/auditory patterns were presented three times each, but the 20 auditory-only patterns were presented four times each in Xa.

3. Result

For each task variation, results were obtained by averaging the reaction time of participants. The task of only judgment information (Xv, Xa) and the patterns of only judgment information in V1-V5 or A1-A5 were focused (Figs.7., 8.). Three-way analysis of variance was performed to reveal the effects of visual information, tasks, and participants on reaction time. And four-way analysis of variance was performed to reveal the effects of auditory information, S/N ratio, tasks, and participants on reaction time. Of tasks focusing on visual information, reaction time for [Circle] was fastest, [Triangle] was next fastest, and the reaction time for [Kanji], [English], and [Meaningless figure] did not show any difference (Fig.7.). Of tasks concentrating on auditory information, participants reacted most quickly to [pink noise], followed by [sweep tone], [spoken Japanese], and finally [spoken English] (Fig.8.). Regarding the task presenting [Meaningless tone], reaction time was faster in the
These results indicate that easiness of cognition was different with kinds of representation. In addition, simple information such as symbolic signs or sounds was quicker for processing of cognition than complex information such as letters or spoken language.

Next, one-way analysis of variance was performed to reveal the effects of the patterns of presentation on reaction time in V1-V5. And two-way analysis of variance was performed to reveal the effects of S/N ratio and patterns of presentation on reaction time in A1-A5. As a result, there was significant difference between the averages of the pattern of presented only visual or auditory information and the average of the other patterns (Tables 4., 5.). In the significant case (p<0.05), "◎" was more quicker than presented only visual or auditory information, "×" was more slower than. "−" was the other case.

From the Table 4., there was little "◎". Participant reaction time was not faster when auditory information was added than reaction time when only visual information was presented. There were a lot of "×" in cases presenting auditory information of 3dB(A) or when mismatched information was added. This was especially pronounced in tasks that when judged [Circle] or moreover added [Spoken Japanese]. In the case of tasks focusing on auditory information (Table 5.), participant reaction time was faster when [Circle] was added than it was to auditory-only information. In the other cases, there was not "×" when matched...
information was added, there were more "◎" than "×" when mismatched information was added.

Four-way analysis of variance was performed to reveal the effects of added information, S/N ratio, consistency of information, and subjects on reaction time (Table 6., 7., Figs. 9., 10.). As a result, all main effects were significant from Table 7. However, from Fig. 10., the main effect of added information was significant by quick reaction time when [Circle] was added. On the other hand, four-way analysis of variance showed that the interaction between added information and consistency of information was significant (Table 6., 7.). Therefore, the absolute value of average difference of matching and mismatching information was obtained from each piece of added information, and a 95% confidence interval was

Two-way analysis of variance was performed to reveal the effects of added information and S/N ratio on reaction time (Table 6., 7.). As a result, all main effects were significant from Table 7. However, from Fig. 10., the main effect of added information was significant by quick reaction time when [Circle] was added. On the other hand, four-way analysis of variance showed that the interaction between added information and consistency of information was significant (Table 6., 7.). Therefore, the absolute value of average difference of matching and mismatching information was obtained from each piece of added information, and a 95% confidence interval was

Table 6. ANOVA in Five Tasks that Judged Visual Information

| Addition information (A) | Circle | Triangle | Kanji | English | Meaningless figure |
|--------------------------|--------|----------|-------|---------|-------------------|
| S/N ratio (B)            | -      | -        | **    | **      | **                |
| Consistency (C)          | -      | **       | **    | **      | **                |
| A × B                    | -      | -        | -     | -       | -                 |
| A × C                    | -      | **       | -     | -       | -                 |
| B × C                    | -      | -        | -     | -       | -                 |
| A × B × C                | -      | -        | -     | -       | -                 |
| Subjects (R)             | **     | **       | **    | **      | **                |
| A × R                    | -      | -        | -     | -       | -                 |
| B × R                    | -      | -        | -     | -       | -                 |
| C × R                    | -      | -        | -     | -       | -                 |
| A × B × R                | -      | -        | -     | -       | -                 |
| A × C × R                | -      | -        | -     | -       | -                 |
| B × C × R                | -      | -        | -     | -       | -                 |

** : p<0.01  * : p<0.05

Table 7. ANOVA in Five Tasks that Judged Auditory Information

| Addition information (A) | Pink noise | Sweep tone | Spoken Japanese | Spoken English | Meaningless tone |
|--------------------------|------------|------------|-----------------|----------------|-----------------|
| S/N ratio (B)            | **         | **         | **              | **             | **              |
| Consistency (C)          | **         | **         | **              | **             | **              |
| A × B                    | -          | -          | -               | -              | -               |
| A × C                    | -          | **         | **              | *              | -               |
| B × C                    | -          | -          | -               | -              | -               |
| A × B × C                | -          | -          | -               | -              | -               |
| Subjects (R)             | **         | **         | **              | **             | **              |
| A × R                    | -          | -          | -               | -              | -               |
| B × R                    | -          | **         | -               | -              | -               |
| C × R                    | -          | -          | -               | -              | -               |
| A × B × R                | -          | -          | -               | -              | -               |
| A × C × R                | -          | -          | -               | -              | -               |
| B × C × R                | -          | -          | -               | -              | -               |

** : p<0.01  * : p<0.05

Fig. 9. Average of Reaction Time in Five Tasks that Judged Visual Information

Fig. 10. Average of Reaction Time in Five Tasks that Judged Auditory Information
obtained from each piece of judged information (Fig.11.). In the results, the reaction time difference was greater than the 95% confidence interval in the case of presented symbolic information such as [Pink noise] or [Circle]. The presentation of complex information such as [English] or [Spoken Japanese] resulted in a reaction time difference that was smaller than the 95% confidence interval.

4. Discussion

Reaction time was analyzed by comparing participant responses to various tasks. From this, the following results were found. 1) When judging visual information, simultaneous presentation of auditory information did not quicken up reaction time. 2) The delay occurred specifically when the auditory information was mismatching or low, the auditory information presented was spoken Japanese. 3) Regarding judgment of auditory information when presented with simultaneous visual information, reaction time decreased when visual information could be cognized quickly. 4) When simple information were presented simultaneously, whether the information was matching or not had a clear influence on reaction time.
These results suggest that, when auditory and visual information were presented simultaneously, judgment was made after collating both pieces of information (Fig.12.). Consequently, when direction of added information could be cognized quicker than judged information, reaction time decreased. Reaction time was made slow when added information needed cognition time. For example, when judging the moving circle, which was the visual task participants processed most quickly, the addition of auditory information slowed down reaction time due to collation of information. In addition, when the auditory information presented was low, reaction time was also slowed. Moreover, when presented information was mismatching, reaction time was slowed. When participants were tasked with judging auditory information, even when information was mismatched, the presentation of simple visual symbols such as moving circles sped up reaction time. However, when presented with more complex visual information or English, collation did not occur, as the cognition of such information takes longer time than judgment. This suggests that the collation process is not performed when judgment time exceeds cognition of addition information.

5. Conclusion
In this study, the effects of additional information upon reaction time to simultaneously presented auditory and visual information was investigated. The results suggest that participants collated simultaneously presented information in order to make judgment. As compared with judgment based on a single piece of presented information, under some circumstances, the act of collation sped up reaction time, whereas in other circumstances collation slowed down this process. The following three conclusions can be drawn. 1) Reaction time decreases when additional information is easier to process than the information that the participant is tasked to focus on. 2) Reaction time increases when additional information is more complex than the information that the participant is tasked to focus on. 3) If the additional information requires a long processing time, collation of information does not occur, and reaction time does not differ from that of the reaction time when not presented with additional information.

Visual information is often used in sign systems because it is easier to understand than auditory information. However, visual information does not become easy to understand by simultaneously presented auditory information. In order to accelerate processing speed when both auditory and visual information are presented, auditory information should be presented earlier because of the necessity of greater processing time \(^{15}\). In addition, auditory information can be used to direct attention to visual information. This anticipatory auditory information can, therefore, be a tool for increasing the accuracy of position and wayfinding judgment by visual. In future works, it is necessary that "looking for" is investigated about the combined effects.

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