A Preliminary Study on Unobtrusive Choice Support Using Rapid Alternating Stimuli Considering Individual Perceptual Characteristics

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Abstract

Human attention and choice behavior are not always determined solely by conscious decisions; they can also be influenced by visual stimuli and cues in the surrounding environment. In particular, previous studies have suggested that even visual stimuli that observers do not clearly notice, or cannot correctly report subjectively, may affect attention allocation and subsequent judgments. If such characteristics can be appropriately utilized, it may be possible to support attention and choice behavior without giving explicit instructions to observers. In this study, we focus on rapid alternating stimuli projected by a projector as a basic approach for realizing unobtrusive choice support in a real environment. Specifically, we used grayscale stimuli that alternated rapidly between $128 + c$ and $128 - c$ around a reference luminance of 128, and examined whether these stimuli could influence choice behavior even when observers could not clearly report the stimulated region.

First, we measured the perceptual threshold for rapid alternating stimuli with nine participants. The results showed large individual differences in the stimulus intensity at which the stimuli could be perceived, with an approximately 2.7-fold difference between the minimum and maximum thresholds. Next, we set the stimulus intensity based on each participant's perceptual threshold and investigated how the stimulated region and the reportability of that region affected the correct selection rate and gaze behavior in a search task in which participants selected the correct answer from four alternatives. The results showed that, in trials where participants could not correctly report the stimulated region, the correct selection rate tended to be higher when the stimulus was presented in the correct region and lower when it was presented in an incorrect region. In contrast, in trials where participants could correctly report the stimulated region, the difference in the correct selection rate corresponding to the stimulated region tended to become smaller. Although these results do not provide strong statistical evidence, they suggest the possibility that rapid alternating projection stimuli may influence attention and choice behavior when they are not clearly reported by observers, and that awareness of the stimulus may attenuate this influence.

Keywords

Spatial Augmented Reality, Projection-based interface, Rapid alternating stimulus, Preconscious stimulus, Choice support, Awareness

1. Introduction

Human attention and choice behavior are not determined solely by conscious decisions; they can also be influenced by visual cues and stimuli in the surrounding environment. In particular, previous studies have suggested that even visual stimuli that observers do not clearly notice, or cannot correctly report subjectively, may affect attention allocation and subsequent judgments [1, 2]. If such characteristics can be appropriately utilized, it may be possible to support attention and choice behavior without giving explicit instructions to observers.

Such unobtrusive attention support may be useful in educational and work-support contexts. For example, when learners work on printed materials or drill exercises, a subtle stimulus may naturally direct their attention to an important region without using explicit arrows or salient color changes. If learners then feel that they reached the answer by themselves, the support may preserve their sense of agency and achievement. In contrast, if guidance from the system is clearly perceived, learners may feel that they were led to the answer by the support system, which may undermine their sense of

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autonomous achievement. Therefore, a support method is needed that respects the user's agency while assisting attention and judgment in a form that is not overly salient.

Spatial Augmented Reality (SAR) is a promising means of realizing such support in a real environment. SAR can directly present visual stimuli on paper materials or real objects using projectors, and therefore does not require users to wear devices such as head-mounted displays [3]. Moreover, because stimuli can be superimposed on the real object itself, the presentation is not limited to a display screen; attention can be directed to actual learning materials or work objects. This property may enable support for attention and choice behavior toward real-world targets while keeping the user from being strongly aware of the support.

In this study, we focus on rapid alternating projection stimuli as a basic approach for realizing unobtrusive choice support. Stimuli presented in rapid alternation may be difficult to perceive as clear flicker because of temporal integration in the human visual system. At the same time, even when observers cannot clearly report the stimulus, temporal components are still input to the visual system and may influence attention allocation, gaze behavior, and choice behavior.

However, unobtrusive stimuli are not always effective. If the stimulus is too weak, it may not sufficiently affect attention or choice behavior; if it is too strong, it may be perceived as flicker, and the observer may recognize it as an external intervention. In addition, whether a stimulus is perceived is expected to differ among individuals. Therefore, to examine choice support using projection stimuli that are difficult to notice, it is necessary to consider both stimulus intensity and individual perceptual characteristics, and to analyze how the influence of the stimulus changes depending on whether the stimulated region can be correctly reported.

The research question addressed in this study is whether rapid alternating stimuli set according to individual perceptual characteristics show a tendency to influence attention and choice behavior even when observers cannot clearly report them, and whether this influence is weakened when the stimulus is reported. To answer this question, we first measured flicker perception thresholds for each participant and confirmed individual differences in stimulus detectability. We then set the stimulus intensity based on each participant's threshold and analyzed the effects of the stimulated region and the reportability of the stimulus on the correct selection rate and gaze behavior in a four-choice search task.

The contributions of this study are threefold. First, we show that there are large individual differences in the perceptual thresholds for rapid alternating projection stimuli. Second, we show that, in trials where participants could not correctly report the stimulated region, the correct selection rate tended to vary depending on whether the stimulated region was the correct region or an incorrect region. Third, we show that, in trials where participants could correctly report the stimulated region, this difference in the correct selection rate tended to become smaller, suggesting that awareness of the stimulus may attenuate the influence of rapid alternating stimuli on choice behavior. Because this study is a preliminary investigation with a limited number of participants, the results should not be interpreted as strong statistical evidence, but rather as basic findings for further investigation.

2. Related Work

This study aims to present projection stimuli on targets in the real environment and support attention and choice behavior in a form that is not strongly noticed by observers. Therefore, this section reviews projection-based attention guidance in real environments, unobtrusive gaze guidance using high-speed modulation stimuli, and preconscious visual processing, and clarifies the relationship between these studies and the present work.

2.1. Attention guidance in real environments using projection

Several studies have attempted to guide users' gaze or attention by changing the appearance of real objects using projectors. Miyamoto et al. proposed a method for gaze guidance by changing the saturation of real objects using a projector-camera system and thereby modifying their visual saliency

[4]. This study is related to the present work in that it uses real objects as presentation targets and manipulates observers' attention from the environment side.

However, methods that clearly change the appearance of objects make the guidance stimulus likely to be consciously perceived by the observer. If learners recognize that they have been guided by a system, the feeling that they noticed the answer by themselves may be reduced. Therefore, for choice support that preserves the user's sense of agency, a method is required that can guide attention by projection without making the observer strongly aware of the guidance. The present study inherits the idea of influencing attention and choice behavior by projecting stimuli onto real-world targets, but differs in that the stimulus is presented in a form that is difficult for observers to perceive clearly.

2.2. Unobtrusive attention guidance using high-speed modulation stimuli

Research has also investigated rapid color or luminance modulation as a way to guide attention without making observers aware of the guidance. Tosa et al. proposed ChromaGazer, a method that guides gaze by presenting rapid color changes that are difficult for observers to notice clearly [5]. Waldin et al. investigated the possibility of guiding observers' attention by introducing high-frequency flicker into images [6]. These studies are related to the present work in that they demonstrate the possibility of influencing attention and gaze while suppressing apparent visual changes through high-speed modulation.

Whether a stimulus is noticed, however, depends not only on modulation frequency but also on stimulus intensity, presentation region, observation conditions, and individual differences. Therefore, to realize attention guidance using high-speed modulation stimuli, it is necessary to experimentally evaluate whether the stimulus is perceived and to take individual perceptual characteristics into account. In this study, we measure the perceptual threshold for rapid alternating stimuli for each participant and set the stimulus intensity based on that threshold. Thus, while the present study follows the concept of unobtrusive guidance using high-speed modulation stimuli, it is characterized by explicitly incorporating individual perceptual characteristics into the design of projection stimuli.

2.3. Preconscious stimuli and their influence on choice behavior

Human visual processing occurs even before a stimulus becomes subjectively reportable in consciousness. Dehaene et al. organized states of stimulus processing using concepts such as conscious, preconscious, and subliminal processing [1]. It has also been discussed that even stimuli that are not consciously perceived can undergo limited processing in the visual system and may influence subsequent judgments and actions [2].

These findings provide the basis for the present study, which presents rapid alternating stimuli in a state that is difficult for observers to notice clearly and examines whether such stimuli affect attention and choice behavior. The goal of this study is to support judgments toward the correct answer without making the guidance of choice behavior strongly perceptible. However, this paper does not claim that the stimuli are strictly subliminal or preconscious. Instead, we classify trials based on post-task reports into trials in which the stimulated region was correctly reported and trials in which it was not. This allows us to evaluate how the presence or absence of awareness of the stimulus changes its influence on choice behavior.

As described above, this study is based on findings from projection-based attention guidance in real environments, unobtrusive gaze guidance using high-speed modulation, and preconscious visual processing. In relation to these studies, the present work focuses on a search task in a real environment, sets projection stimuli based on individual perceptual thresholds, and evaluates how awareness of the stimulus affects the correct selection rate and gaze behavior.

3. Proposed Method

The proposed method is not merely a way of presenting projection stimuli, but an unobtrusive attention guidance method using rapid alternating stimuli that takes individual perceptual characteristics into account. In this method, the perceptual threshold for rapid alternating stimuli is first measured for each user. Based on this result, a stimulus intensity that is difficult to perceive clearly as flicker is determined. The stimulus is then projected onto a specific region in a choice task, with the aim of influencing attention and choice behavior without giving explicit instructions to the observer.

3.1. Assumed support scenario and task setting

The application scenario assumed in this study is educational support in which learners select the correct information from multiple candidates on learning materials. For example, learners may search for the correct answer among multiple shapes, words, equations, or options in printed materials or drill exercises. If a system explicitly indicates the correct location using an arrow or color change, learners may feel that they were guided to the answer by the system, and their feeling of discovering the answer by themselves may be weakened. In contrast, if an unobtrusive stimulus can naturally direct attention to the correct region, it may be possible to support the learner's arrival at the correct answer while preserving their sense of agency and achievement.

In this paper, we use a search task in which participants select one different shape among four shapes as a simplified version of this support scenario. One of the four regions is the correct answer, and observers select the region that they think is correct while moving their gaze. This task simplifies the situation of discovering a correct target from multiple candidates and serves as a basic task setting for evaluating whether projection stimuli influence attention and choice behavior.

In actual educational support, the system is assumed to know the correct region and to naturally guide the learner's attention toward it by presenting an unobtrusive stimulus in that region. In this study, however, we include not only a condition in which the stimulus is presented in the correct region, but also a condition in which it is presented in an incorrect region, in order to examine the characteristics of the method. Presenting the stimulus in an incorrect region is not intended as practical support; rather, it is a comparison condition for confirming whether the stimulus affects choice behavior. If the stimulus attracts attention, presenting it in the correct region may increase the correct selection rate or fixation ratio, whereas presenting it in an incorrect region may decrease the correct selection rate.

3.2. Rapid alternating stimulus

In this study, we use rapid alternating stimuli as visual stimuli that are difficult to notice. The stimuli are generated as grayscale images, with the reference luminance set to 128. Let c denote the parameter representing stimulus intensity. The two stimulus frames are defined as follows:

$$S_1(x) = 128 + c, \tag{1}$$

$$S_2(x) = 128 - c, \tag{2}$$

where x denotes a pixel or region in which the stimulus is presented. By alternately presenting these two stimuli frame by frame, the luminance in the stimulated region rapidly switches between $128 + c$ and $128 - c$. In this study, a 60 Hz projector is used to present the two frames alternately on a frame-by-frame basis, which corresponds to an alternation frequency of 30 Hz.

In this presentation method, the average luminance of the two frames is close to the reference luminance of 128; therefore, the apparent change in brightness is expected to be suppressed by temporal integration in the observer's visual system. At the same time, the presented region actually contains temporal luminance changes, and thus change components are input to the visual system even when

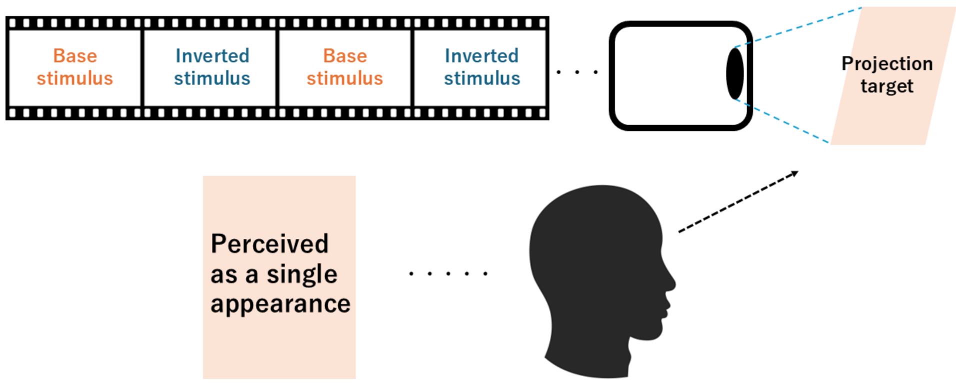


Figure 1: Concept of the rapid alternating stimulus. A base stimulus and its inverted stimulus are alternately presented frame by frame, aiming to suppress apparent changes through temporal integration in the visual system.

the observer cannot report clear flicker. We hypothesize that these change components attract attention in a bottom-up manner and consequently influence gaze behavior and choice behavior.

3.3. Stimulus intensity setting based on individual perceptual characteristics

Whether a rapid alternating stimulus is perceived as flicker depends not only on the alternation frequency but also on the luminance difference between frames, the presentation region, observation conditions, and individual differences. Even if the same stimulus intensity is used, it may be clearly perceived as flicker by one participant and hardly perceived by another. Therefore, in the proposed method, the perceptual threshold of each participant is measured before the choice task.

The quantity to be examined in the preliminary experiment is the stimulus intensity c at the boundary where the rapid alternating stimulus can be perceived as flicker. In this study, we varied the stimulus intensity c and measured either the intensity at which the participant noticed the flicker or the intensity at which the participant could no longer detect it. This boundary was measured multiple times using ascending and descending series, and the average value was used as the perceptual threshold for each participant.

In the choice task, we used a stimulus intensity lower than each participant's perceptual threshold. As a preliminary setting, the stimulus intensity was set to three-quarters of each participant's perceptual threshold. For example, if a participant's perceptual threshold was $c = 60$, the stimulus intensity used in the choice task was $c = 45$. This setting was intended to reduce the number of trials in which the stimulus was clearly perceived as flicker while still inputting a stimulus with temporal changes to the visual system.

However, even stimuli below the perceptual threshold may become reportable depending on the participant's attentional state and gaze position during the task. Therefore, in addition to setting the stimulus intensity based on the preliminary experiment, participants were asked after each choice task trial to report which region they thought had flickered. This allowed us to determine, on a trial-by-trial basis, whether the participant could correctly report the stimulated region, and to separately analyze trials in which the stimulated region was correctly reported and trials in which it was not.

3.4. Stimulus presentation conditions and hypotheses about the influence on choice behavior

In this paper, we do not simply refer to the stimulated region as the "guided target." Instead, we define the experimental conditions according to the region in which the rapid alternating stimulus was presented. We call the condition in which the stimulus is presented in the correct region the "correct-region stimulus condition," the condition in which the stimulus is presented in an incorrect region the "incorrect-region stimulus condition," and the condition in which no stimulus is presented in any region the "no-stimulus condition." In this paper, the phrase "influence on choice behavior" refers to changes in the correct selection rate or fixation ratio depending on the stimulus presentation condition.

Based on the stimulated region and the presence or absence of awareness, we formulate the following hypotheses. First, even when participants cannot correctly report the stimulated region, if the rapid alternating stimulus attracts attention, the fixation ratio toward the stimulated region may increase. Second, when the stimulus is presented in the correct region, attention may be directed more easily to the correct region, and the correct selection rate may increase. Third, when the stimulus is presented in an incorrect region, attention may be drawn to the incorrect region, causing the correct selection rate to decrease.

On the other hand, these effects may be attenuated when the participant can correctly report the stimulated region. If participants notice the flicker, they may recognize it as an external intervention related to the task and may consciously ignore it or prioritize their own judgment. Therefore, in this study, we evaluate not only whether the stimulated region is correct or incorrect, but also whether the participant could correctly report the stimulated region.

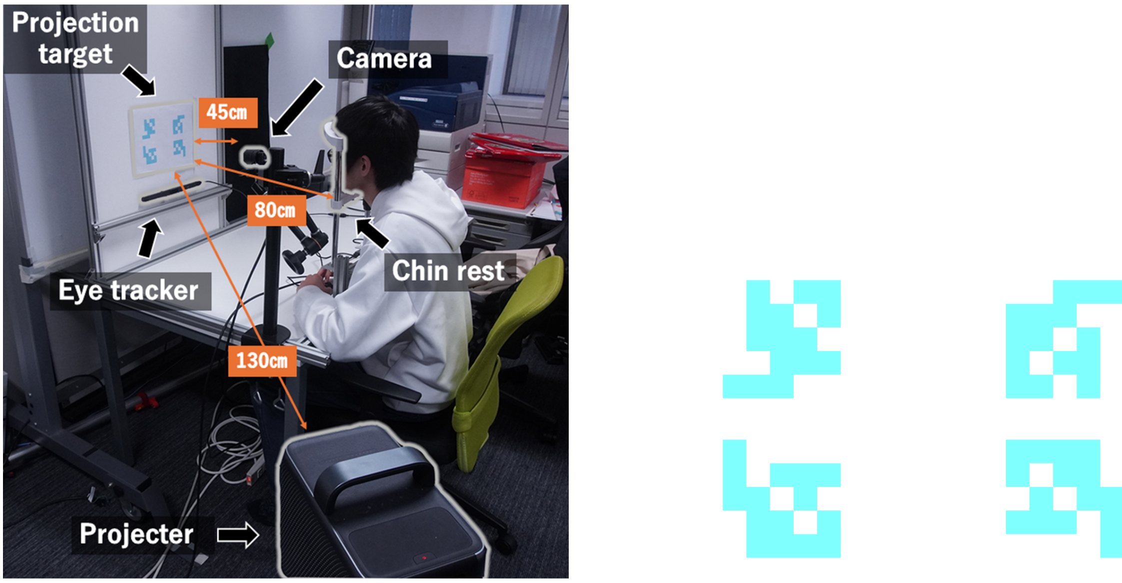
3.5. Stimulus presentation procedure in the choice task

In the proposed method, the rapid alternating stimulus is applied to a search task in which participants select one different shape among four shapes. In each trial, one of three conditions is assigned: a stimulus is presented in the correct region, a stimulus is presented in an incorrect region, or no rapid alternating stimulus is presented in any region. When a stimulus is presented, the intensity is set to three-quarters of the perceptual threshold measured beforehand for each participant. For example, if a participant's perceptual threshold is $c = 60$, the stimulus intensity used in the choice task is $c = 45$.

In each trial, participants select the region that they think is correct from the four alternatives. After that, they report which region they think flickered. This response is used to confirm, for each trial, whether the stimulated region could be correctly reported. In this study, trials in which the participant correctly reported the stimulated region were treated as "trials where the stimulated region was correctly reported," and trials in which the participant could not correctly report the stimulated region were treated as "trials where the stimulated region was not correctly reported." Trials in which the participant reported a region different from the stimulated region were few in number, and were included in the trials where the stimulated region was not correctly reported.

This procedure allows us to evaluate both whether the stimulated region is the correct region or an incorrect region and whether the participant could correctly report the stimulated region. Therefore, rather than simply examining changes in the correct selection rate due to the presence or absence of the stimulus, this study investigates whether stimuli presented in an unobtrusive state influence choice behavior and whether awareness of the stimulus weakens that influence.

As described above, the proposed method consists of measuring individual perceptual thresholds, setting stimulus intensity based on those thresholds, projecting rapid alternating stimuli onto the correct or an incorrect region, and analyzing the results based on awareness of the stimulus. Using this method, we examine how attention guidance in an unobtrusive projection condition affects the correct selection rate and gaze behavior in a search task.



(a) Experimental environment (b) Example of the search task

Figure 2: Experimental environment and an example of the search task. (a) Experimental environment. (b) Example of the search task in which participants select one different shape among four shapes.

4. Experiment

This section describes two experiments conducted to examine the effectiveness of the proposed method. In Experiment 1, we measured the perceptual threshold for rapid alternating stimuli for each participant and confirmed whether there were individual differences in stimulus intensity. In Experiment 2, we set the stimulus intensity based on the perceptual thresholds obtained in Experiment 1 and investigated how the stimulated region and awareness of the stimulus affected the correct selection rate and gaze behavior in a search task.

4.1. Experimental environment and search task

The experiment used a projector, a projection target, and an eye-tracking device. A Nebula Cosmos Laser 4K projector was used, with a resolution of 1920 × 1080 and a refresh rate of 60 Hz. A Tobii Eye Tracker 5 was used for gaze measurement. Participants sat in front of the projection target and answered the task while viewing the target. The distance from the projector to the projection target was approximately 130 cm, and the distance from the participant's eyes to the projection target was approximately 80 cm. The experimental environment is shown in Fig. 2(a).

The search task required participants to select one different shape among four shapes. An example of the search task is shown in Fig. 2(b). The four shapes were placed in the upper-left, upper-right, lower-left, and lower-right regions. In each trial, participants observed the four regions and selected the region that they thought was correct. This task simplifies the situation of discovering the correct target from multiple candidates and was used to evaluate the effect of projection stimuli on attention and choice behavior.

4.2. Experiment 1: Measurement of perceptual thresholds for rapid alternating stimuli

4.2.1. Purpose

The purpose of Experiment 1 was to examine how strongly participants perceived rapid alternating stimuli and to set the stimulus intensity used in Experiment 2 for each participant. Because the detectability of rapid alternating stimuli is expected to differ among individuals, using a uniform

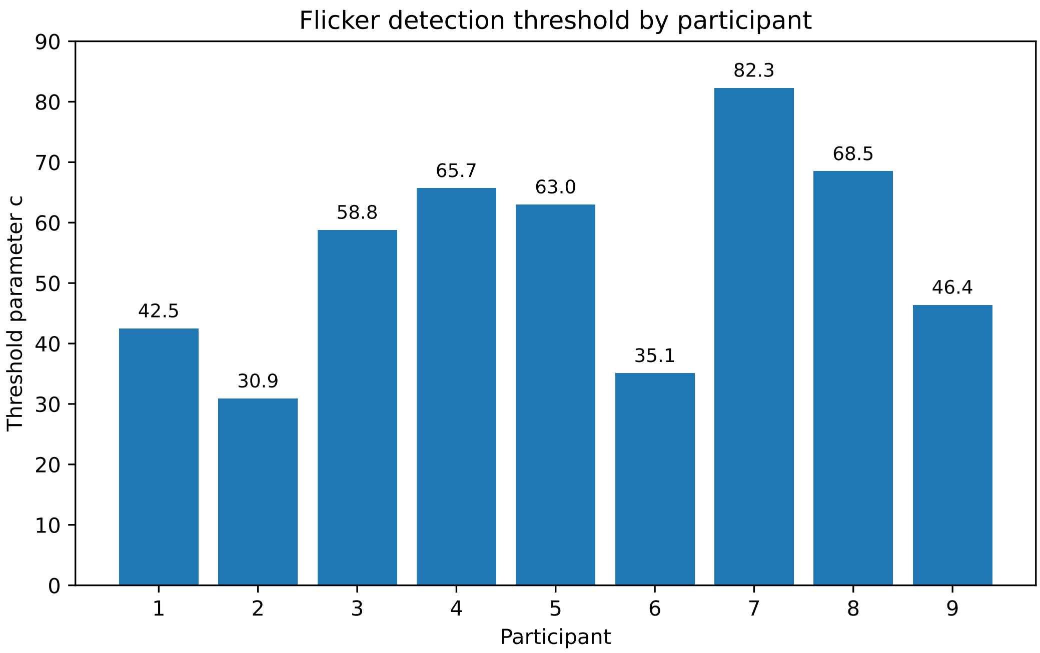


Figure 3: Perceptual thresholds for rapid alternating stimuli for each participant. The vertical axis represents the stimulus intensity parameter c.

stimulus intensity may result in a stimulus that is too strong and clearly perceived as flicker by some participants, while being too weak to affect attention or choice behavior for others. Therefore, in this experiment, we measured the stimulus intensity at the boundary where each participant could perceive flicker.

4.2.2. Procedure

Nine participants took part in the experiment. The stimulus was a grayscale rapid alternating stimulus centered on the reference luminance of 128, alternating between $128 + c$ and $128 - c$. Here, c is a parameter representing stimulus intensity.

Participants performed five ascending series and five descending series. In the ascending series, the stimulus intensity was gradually increased from a state where the stimulus could not be detected, and participants pressed a button when they noticed flicker. In the descending series, the stimulus intensity was gradually decreased from a state where flicker was detectable, and participants pressed a button when they could no longer detect the flicker. For each participant, the average stimulus intensity obtained from the ascending and descending series was used as the perceptual threshold.

4.2.3. Results

The results of Experiment 1 are shown in Fig. 3. Large individual differences were observed in the threshold at which the stimulus could be perceived. The lowest threshold was $c = 30.9$ for Participant 2, and the highest threshold was $c = 82.3$ for Participant 7, indicating a maximum difference of approximately 2.7 times.

This result indicates that, if the same stimulus intensity is applied to all participants, the stimulus may be too strong and perceived as flicker by some participants, whereas it may be too weak to influence behavior for others. This result is also consistent with previous findings that the detectability of high-speed modulation stimuli depends on stimulus intensity and individual differences. Therefore, in Experiment 2, we did not use the same stimulus intensity for all participants; instead, the stimulus intensity was set based on each participant's perceptual threshold obtained in Experiment 1.

4.2.4. Stimulus intensity setting for Experiment 2

In Experiment 2, we used three-quarters of each participant's perceptual threshold as the stimulus intensity. For example, if a participant's perceptual threshold was $c = 60$, the stimulus intensity used in Experiment 2 was $c = 45$. This setting was intended to reduce the number of trials in which the stimulus was clearly perceived as flicker while still inputting a stimulus with temporal changes to the visual system.

However, setting the stimulus intensity to three-quarters of the perceptual threshold is only a stimulus setting based on preliminary measurements and does not guarantee that the stimulated region cannot be reported in all trials during the experiment. The detectability of the stimulus may vary depending on attentional state and gaze position during the task. Therefore, in Experiment 2, after each task trial, participants were asked to report which region they thought had flickered, and we checked on a trial-by-trial basis whether the stimulated region was correctly reported.

4.3. Experiment 2: Choice task considering awareness of the stimulus

4.3.1. Purpose

The purpose of Experiment 2 was to investigate how rapid alternating stimuli set based on individual perceptual thresholds affect the correct selection rate and gaze behavior in a search task. In particular, by separating trials in which participants could not correctly report the stimulated region from trials in which they could correctly report it, we evaluated how awareness of the stimulus changed its influence on choice behavior.

4.3.2. Procedure

In Experiment 2, we used the search task in which participants selected one different shape among four shapes. In each trial, one of the following conditions was assigned: a stimulus was presented in the correct region, a stimulus was presented in an incorrect region, or no rapid alternating stimulus was presented in any region. When a stimulus was presented, its intensity was set to three-quarters of each participant's perceptual threshold obtained in Experiment 1.

In each trial, participants selected the region that they thought was correct from the four alternatives. After that, they reported which region they thought had flickered. This response was used to confirm, on a trial-by-trial basis, whether the stimulated region could be correctly reported. In this study, trials in which the participant correctly reported the stimulated region were treated as "trials where the stimulated region was correctly reported," and trials in which the participant could not correctly report the stimulated region were treated as "trials where the stimulated region was not correctly reported." Trials in which a region different from the stimulated region was reported were few in number and were included in the trials where the stimulated region was not correctly reported.

4.3.3. Analysis method

In the analysis, trials without a defined correct answer were excluded. For each trial, the participant's response was treated as correct if it matched the correct answer. The stimulus presentation conditions were classified, based on the relationship between the stimulated region and the correct region, into the correct-region stimulus condition, the incorrect-region stimulus condition, and the no-stimulus condition. In addition, the stimulus-present conditions were further classified into trials where the stimulated region was correctly reported and trials where it was not correctly reported depending on whether the stimulated region was correctly reported.

Based on this classification, the correct selection rate was calculated for the following five conditions:

1. No-stimulus condition
2. Correct-region stimulus and not-correctly-reported condition
3. Incorrect-region stimulus and not-correctly-reported condition

4. Correct-region stimulus and correctly reported condition
5. Incorrect-region stimulus and correctly reported condition

We divided the data into these five conditions because the effect of stimulus presentation on choice behavior may depend not only on whether the stimulated region was correct or incorrect, but also on whether the participant could correctly report the stimulated region. In particular, this study examines whether changes in the correct selection rate corresponding to the stimulated region appear mainly when the stimulated region is not correctly reported, and whether these changes are attenuated when the stimulated region is correctly reported. Therefore, in presenting the results, we first compare the two not-correctly-reported conditions using the no-stimulus condition as a reference, and then examine the two correctly reported conditions.

For the correct selection rate, we calculated both trial-based averages for each condition and condition-specific correct selection rates for each participant. Paired t-tests were used to compare conditions using the participant-wise correct selection rates. In addition, as an exploratory supplementary index, Cohen's d_z was calculated for paired comparisons by dividing the mean of the paired differences by the standard deviation of those differences. Figure 4 also shows 95% confidence intervals as error bars. The confidence intervals were calculated based on the condition-wise correct selection rates. However, because the number of participants in this experiment was limited to nine, we interpreted the results mainly based on differences in mean values rather than drawing conclusions solely from p-values or effect sizes.

For gaze behavior, we calculated the total fixation time on the four regions in each trial. We then compared the fixation time ratio for the stimulated region with the average fixation time ratio for the three regions other than the stimulated region. In this study, fixation time was calculated based on the number of frames recorded at 60 fps.

4.3.4. Correct selection rate

Figure 4 shows the correct selection rates for each condition in Experiment 2. The error bars in the figure represent 95% confidence intervals. First, the correct selection rate in the no-stimulus condition, which served as the baseline, was 89.13%. Next, in the conditions where participants could not correctly report the stimulated region, the correct selection rate was 96.00% when the stimulus was presented in the correct region and 72.73% when it was presented in an incorrect region. Thus, in trials where the stimulated region was not correctly reported, the correct selection rate was higher than that in the no-stimulus condition when the stimulus was presented in the correct region, whereas it was lower than that in the no-stimulus condition when the stimulus was presented in an incorrect region.

In contrast, in conditions where participants could correctly report the stimulated region, the correct selection rate was 84.44% for the correct-region stimulus condition and 88.61% for the incorrect-region stimulus condition. Both values were close to the no-stimulus condition, and the large difference corresponding to whether the stimulated region was correct or incorrect, as observed in the not-correctly-reported conditions, was not observed.

In paired t-tests using the correct selection rates for each participant, the comparison between the incorrect-region stimulus and not-correctly-reported condition and the no-stimulus condition did not reach statistical significance ($t(8) = -1.65$, $p = 0.14$, $d_z = -0.55$). No significant difference was also found between the correct-region stimulus and not-correctly-reported condition and the no-stimulus condition ($t(7) = 0.09$, $p = 0.93$, $d_z = 0.03$). Therefore, this experiment does not allow us to strongly conclude a statistically significant effect of projection stimuli on choice behavior.

Nevertheless, looking at the mean correct selection rates, there was a 23.27 percentage-point difference between the correct-region stimulus and incorrect-region stimulus conditions when participants could not correctly report the stimulated region. In contrast, when participants could correctly report the stimulated region, the difference between these two conditions was 4.17 percentage points. This suggests that, when the stimulated region was not correctly reported, the correct selection rate changed according

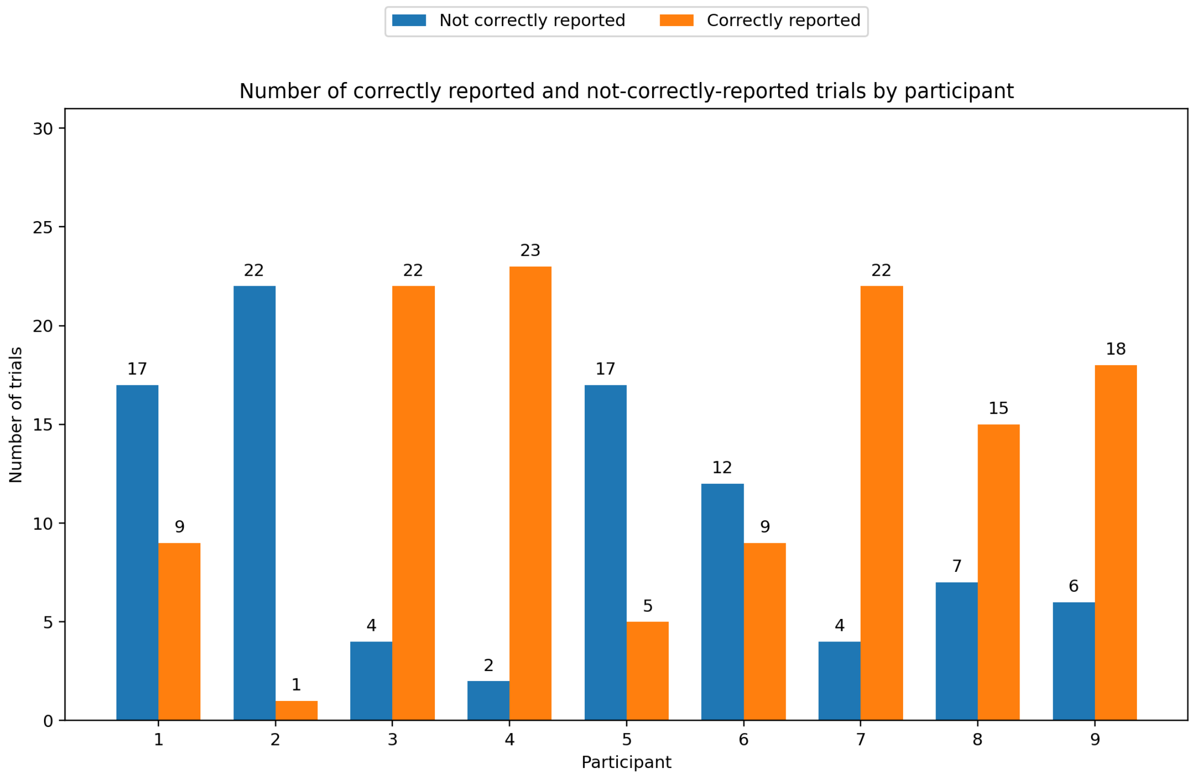


Figure 4: Correct selection rates by stimulus presentation condition and report accuracy. The no-stimulus condition is shown as the baseline, followed by the conditions in which the stimulated region was not correctly reported and those in which it was correctly reported. Error bars represent 95% confidence intervals.

to the stimulated region, whereas this change may have weakened when the stimulated region was reported.

4.3.5. Participant-wise tendency of awareness

Figure 5 shows the numbers of trials in which the stimulated region was correctly reported and not correctly reported for each participant. In stimulus-present trials, there were large individual differences in the number of trials in which the stimulated region was correctly reported and the number of trials in which it was not. For example, Participants 3, 4, 7, 8, and 9 had a relatively large number of trials in which they could correctly report the stimulated region. In contrast, Participants 1, 2, 5, and 6 had many trials in which they could not correctly report the stimulated region.

As shown in Fig. 5, participants who could report the stimulated region in many trials and participants who often could not report it coexisted. This indicates that the detectability of rapid alternating stimuli differs substantially among participants. Together with the individual differences in perceptual thresholds confirmed in Experiment 1, these results suggest that, to provide subtle support using projection stimuli, it is necessary to adjust stimulus intensity according to the user's perceptual characteristics and actual responses rather than using a uniform stimulus intensity.

4.3.6. Gaze behavior in trials where the stimulated region was not correctly reported

Figure 6 shows the fixation time ratio for trials in which participants could not correctly report the stimulated region. In this analysis, the total fixation time on the four regions in each trial was treated as 100%, and we calculated the fixation ratio for the stimulated region and the average fixation ratio for the three regions other than the stimulated region. The fixation time ratio for the stimulated region was 27.74%, whereas the average fixation time ratio for the other three regions was 24.09%.

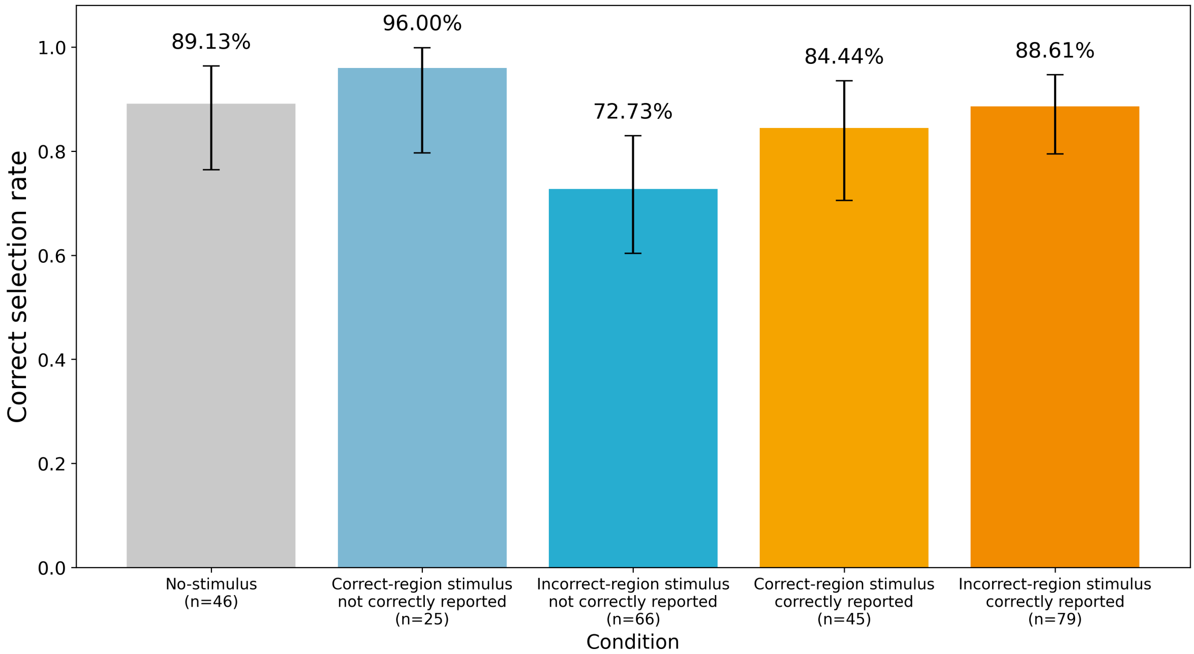


Figure 5: Numbers of trials in which each participant correctly reported and did not correctly report the stimulated region. Only stimulus-present trials with a valid correct answer were included.

If participants fixated randomly on the four regions, the fixation ratio for each region would be 25%. In the present results, the fixation ratio for the stimulated region was slightly higher than this value. However, a paired t-test using participant-wise averages did not show a significant difference ($t(8) = 1.34$, $p = 0.22$, $d_z = 0.45$); therefore, this result does not allow us to conclude that the stimulus reliably guided gaze. Nevertheless, the fact that the fixation ratio for the stimulated region tended to be higher than that for the other regions even in trials where the stimulated region could not be correctly reported supports the observed changes in the correct selection rate.

5. Discussion

This section discusses whether rapid alternating stimuli that take individual perceptual characteristics into account can function as unobtrusive choice support, based on the results of the evaluation experiments. The previous section showed that perceptual thresholds differed greatly among participants, that the correct selection rate tended to change according to the stimulated region in trials where the stimulated region could not be correctly reported, and that this change tended to weaken in trials where the stimulated region could be correctly reported. Below, we discuss these results from the perspective of the goal of this study: choice support that is not strongly noticed by observers.

5.1. Need to consider individual perceptual characteristics

Experiment 1 showed that perceptual thresholds for rapid alternating stimuli differed by approximately 2.7 times among participants. This result indicates that it may be inappropriate to set a uniform stimulus intensity in support systems using rapid alternating stimuli. The same stimulus intensity may be perceived as clear flicker by one user but may be hardly perceived by another.

In this study, we used three-quarters of each participant's perceptual threshold as the stimulus intensity. Based on the preliminary measurement, this setting was considered to provide each participant with a stimulus intensity that was difficult to perceive clearly as flicker. However, in Experiment 2, there were both trials in which the stimulated region could be correctly reported and trials in which it could not. This shows that, even if the stimulus intensity is set based on a perceptual threshold, actual

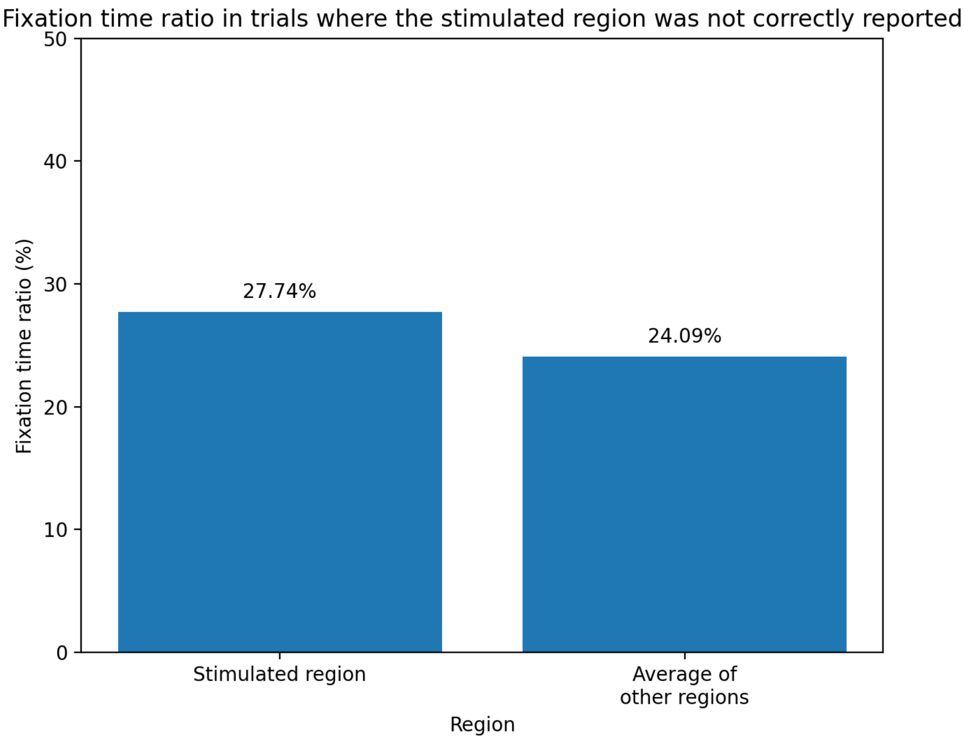


Figure 6: Fixation time ratio in trials where the stimulated region could not be correctly reported. The stimulated region is compared with the average of the other three regions.

awareness can vary depending on attentional state, gaze position, and individual sensitivity during the task.

Therefore, to realize choice support using projection stimuli that are difficult to notice, it is necessary not only to measure perceptual thresholds in advance but also to estimate the detectability of the stimulus during the task using participants' responses and gaze behavior, and to adaptively adjust the stimulus intensity.

5.2. Influence on choice behavior when the stimulated region was not correctly reported

In Experiment 2, in trials where participants could not correctly report the stimulated region, the correct selection rate tended to be higher than the no-stimulus condition when the stimulus was presented in the correct region, and lower than the no-stimulus condition when it was presented in an incorrect region. This result suggests that rapid alternating stimuli may influence attention and choice behavior even when observers cannot clearly report the stimulated region.

The decrease in the correct selection rate in the incorrect-region stimulus condition is particularly important. Participants did not know during the task that the stimulated region was incorrect, and in this condition they also could not correctly report the stimulated region after the task. Nevertheless, the correct selection rate decreased. This is consistent with the possibility that stimuli that are not clearly conscious increased attention or processing toward the incorrect region and interfered with correct judgment.

On the other hand, the increase in the correct selection rate in the correct-region stimulus condition was limited. One possible reason is that the search task used in this experiment already had a high correct selection rate in the no-stimulus condition, leaving little room for improvement by directing attention to the correct region. In other words, the task setting may have made the interference effect caused by increasing attention to an incorrect region easier to observe than the facilitation effect of guiding attention to the correct region. When considering applications to educational support, it will be necessary to examine whether presenting stimuli in the correct region works as support in more difficult tasks where learners have more difficulty reaching the correct answer by themselves.

5.3. Attenuation of the effect due to awareness of the stimulus

The central question of this study is whether awareness of the stimulus changes the influence of rapid alternating stimuli on choice behavior. In Experiment 2, there was a large difference in the correct selection rate between the correct-region stimulus and incorrect-region stimulus conditions when participants could not correctly report the stimulated region. In contrast, when participants could correctly report the stimulated region, the difference between these two conditions was small.

This result suggests that, when participants could report the stimulated region, they may have recognized the flickering region as an external intervention related to the task and consciously ignored it or prioritized their own judgment. In other words, when the stimulated region was not correctly reported, the stimulus containing temporal changes may have attracted attention in a bottom-up manner. When the stimulated region was correctly reported, however, top-down judgment may have intervened and weakened the change in the correct selection rate caused by stimulus presentation.

However, the comparisons in this experiment did not show statistically significant differences. Therefore, we cannot conclusively state that awareness attenuated the effect. What can be said from this study is that, as a tendency in the mean values, the difference in the correct selection rate according to the stimulated region was large when the stimulated region could not be correctly reported, and this difference became smaller when the stimulated region could be correctly reported. This tendency suggests that, in designing unobtrusive choice support, it is necessary to consider not only the physical intensity of the stimulus but also how the user perceives the stimulus.

5.4. Influence of stimulus presentation observed from gaze behavior

In trials where the stimulated region could not be correctly reported, the fixation time ratio for the stimulated region tended to be higher than the average for the three other regions. Similar to the changes in the correct selection rate, this result provides supplementary evidence that rapid alternating stimuli that cannot be clearly reported may influence gaze behavior.

However, the difference in fixation time ratio was not large, and no statistically significant difference was found. Therefore, this result alone does not allow us to conclude that the stimulus reliably guided gaze. Rather, the meaningful point of this study is that the change in correct selection rate and the tendency in fixation time ratio were in the same direction. Specifically, in trials where the stimulated region could not be correctly reported, the fixation ratio for the stimulated region was slightly higher, and the correct selection rate decreased when the stimulus was presented in an incorrect region. These results suggest that the stimulus may have influenced attention allocation and, as a result, affected choice behavior.

In future work, it will be necessary to analyze the process by which the stimulus influences choice behavior in more detail by combining not only simple fixation time ratios but also the first fixated region, the order of gaze transitions, and reaction time.

5.5. Potential applications to educational support

The assumed application of this study is educational support that does not explicitly present the correct answer to learners, but instead supports attention in a way that allows learners to feel that they noticed the answer by themselves. The present results showed that, when observers could not correctly report the stimulated region, the correct selection rate tended to change depending on the stimulated region. This indicates the possibility of influencing attention and choice behavior without making learners strongly aware of the support.

At the same time, in this experiment, the facilitation effect of presenting the stimulus in the correct region was limited, while the interference effect of presenting the stimulus in an incorrect region was more apparent. Therefore, at this stage, we cannot conclude that the proposed method can reliably support learners in reaching the correct answer in educational settings. To use the method effectively as educational support, it will be necessary to clarify the conditions under which attention can be naturally directed to necessary information without interfering with the learner's process of reaching the correct answer. Such conditions include task difficulty, stimulus intensity, presentation timing, and the size of the presentation region.

Because a method that influences choice behavior using stimuli that are difficult to notice concerns users' decision making, ethical considerations are essential. The purpose of this study is not to secretly manipulate users' decisions, but to conduct a basic investigation into avoiding the loss of agency caused by overly explicit support in situations that benefit the users themselves, such as learning support or work support. For practical use, it will be necessary to limit the purpose of use, explain the system to users in advance, restrict stimulus intensity, and provide a mechanism that allows users to decline the support.

5.6. Limitations

This study has several limitations. First, the number of participants was small (nine), and the experiment did not have sufficient statistical power. Therefore, the results should be regarded as preliminary evidence for the possible influence of rapid alternating stimuli on choice behavior. Second, the task used in this study was a four-choice search task, which differs from complex judgments in actual educational or work-support situations. Third, awareness of the stimulus was classified based on self-reports after each task, and thus does not constitute a fully objective measurement of conscious state.

Furthermore, although this study used three-quarters of each participant's perceptual threshold as the stimulus intensity, it has not been shown that this ratio is optimal. If the stimulus intensity is too weak, its influence on choice behavior will be small; if it is too strong, it will be easily perceived as flicker. Therefore, future studies should vary the stimulus intensity across multiple levels and examine in more detail the relationship between detectability and the influence on choice behavior. In addition, because detectability may change depending on gaze position and attentional state during the task, real-time stimulus control using gaze information should also be investigated.

6. Conclusion

This study examined the possibility of unobtrusive choice support using rapid alternating stimuli that take individual perceptual characteristics into account. First, we measured the perceptual threshold for rapid alternating stimuli for each participant and confirmed that the thresholds differed by approximately 2.7 times among participants. Next, we set the stimulus intensity to three-quarters of each participant's threshold and analyzed how the stimulated region and awareness affected the correct selection rate and gaze behavior in a four-choice search task.

As a result, in trials where participants could not correctly report the stimulated region, the correct selection rate was 96.00% in the correct-region stimulus condition, 72.73% in the incorrect-region stimulus condition, and 89.13% in the no-stimulus condition. In contrast, in trials where participants could correctly report the stimulated region, the difference in the correct selection rate between the correct-region stimulus and incorrect-region stimulus conditions was small. Although these results did not reach statistical significance and therefore cannot be stated conclusively, the mean values suggest that the correct selection rate changed according to the stimulated region when the stimulated region was not correctly reported, and that this change may have weakened when the stimulated region was correctly reported. In addition, in trials where the stimulated region was not correctly reported, the fixation ratio for the stimulated region tended to be higher than the average for the other regions.

These results indicate that rapid alternating projection stimuli may influence attention and choice behavior when they are not clearly perceived by observers. In this study, the facilitation effect of presenting the stimulus in the correct region was limited, whereas the decrease in the correct selection rate caused by presenting the stimulus in an incorrect region was relatively pronounced. This suggests that the proposed stimulus may function not only as guidance toward the correct answer, but also as an interference stimulus that creates competition for attention.

Although such an interference effect appears at first to be an undesirable effect that reduces task performance, it may be used as a means of adjusting task difficulty in cognitive or learning tasks if appropriately controlled. For example, adding unobtrusive distracting stimuli to a task may be applied to attention-control training, in which learners practice directing attention to necessary information even under distraction, or to the adjustment of cognitive load in quiz or search tasks. In educational psychology, it has been discussed that temporary difficulties during learning can sometimes enhance long-term learning effects; the proposed method can be positioned as a new means of presenting visual interference load in a real environment.

However, the effects confirmed in this study are limited to tendencies in mean values, and this study does not directly show that distracting stimuli improve concentration or learning outcomes. Future work should control task difficulty, stimulus intensity, and presentation timing, and evaluate not only short-term correct selection rates but also reaction time, sustained attention, and retention after learning, in order to examine whether the proposed method can be applied to attention-control training and adaptive difficulty adjustment.

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Declaration on Generative AI

During the preparation of this work, the author(s) used ChatGPT in order to: translate the manuscript from Japanese to English and perform grammar and spelling checks. After using this tool, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the publication's content.

References

[1] S. Dehaene, M. Kerszberg, J.-P. Changeux, Conscious, preconscious, and subliminal processing: a testable taxonomy, Trends in Cognitive Sciences 10 (2006) 204–211.

[2] S. Kouider, S. Dehaene, Levels of processing during non-conscious perception: a critical review of visual masking, Philosophical Transactions of the Royal Society B: Biological Sciences 362 (2007) 857–875.

[3] O. Bimber, R. Raskar, Spatial Augmented Reality: Merging Real and Virtual Worlds, A K Peters, Natick, MA, USA, 2005.

[4] J. Miyamoto, H. Koike, T. Amano, Gaze guidance in the real-world by changing color saturation of objects, ACM Transactions on Applied Perception 14 (2017) Article 9.

[5] N. Tosa, H. Koike, Chromagazer: Unobtrusive visual modulation using imperceptible color vibration for visual guidance, IEEE Transactions on Visualization and Computer Graphics 21 (2015) 768–776.

[6] T. Waldin, H. Koike, Guiding attention using high-frequency flicker in images, Journal of Vision 14 (2014) 1085–1096.