# The influence of peripheral information on a proactive process during multitasking



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The influence of peripheral information on a proactive process during multitasking

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### Abstract

The aim of this study was to examine whether peripheral information facilitates proactive processes during multitasking. For this purpose, peripheral information was presented regularly during multitasking and its effects on the performance of a tracking task (main task: reactive process) and a discrimination task (sub-task: proactive process) were examined. Experiment 1 presented peripheral information (white circles) in the same sensory modality (visual) as the information used for multitasking and the number of circle presentations was manipulated. In Experiment 2, a pure tone (auditory) was presented as peripheral information. We found that, in both experiments, the difficulty of the tracking task influenced discrimination performance, showing that as the difficulty of the tracking task (reactive process) increased, more cognitive resources were consumed in the tracking task, resulting in a decrease in cognitive resources available for the discrimination task (proactive process). In addition, regular presentation of peripheral information facilitated discrimination task performance in both experiments. Interestingly, this peripheral information also facilitated the tracking task performance (reactive process) even if the tracking task was difficult. Moreover, this promoting effect of the peripheral information occurred regardless of the sensory modality. This study revealed that processing of peripheral information facilitates the proactive process even if more cognitive resources are consumed, and that this facilitating effect does not conflict with multitasking and provides a margin of cognitive resources and also facilitates the reactive process. Our results provide evidence of how peripheral information and cognitive resources are used during multitasking.


**Keywords**: Prediction; Peripheral information; Dual mechanism of cognitive control theory; Perceptual load theory





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## 1. Introduction

Prediction is one of the main cognitive functions of the brain. We adapt to the environment by predicting a subsequent event, detecting a gap between a prediction and an event, and correcting the prediction (e.g., Friston, 2010; Clark, 2013). To correct this gap, improved prediction accuracy minimizes prediction errors and reduces the cost of correcting predictions and behaviors. Previous prediction studies reported that peripheral information in the environment improves predictions for subsequent events. Specifically, peripheral information related to a subsequent event (task-relevant information) makes it easier to predict that event. For example, cues to the appearance of a stimulus in a particular space or to characteristics of a stimulus, such as color, facilitate responses to and discrimination of subsequent stimuli (e.g., Folk, Remington, & Johnston, 1992; Posner, 1980; Treisman, 1988; Wolfe, 2014). In parallel, recent studies reported that even information that is not directly related to the subsequent event (task-irrelevant information) influences the predictions for this event. For example, the multiple and regular presentation of task-irrelevant stimuli facilitates temporal prediction and feedback processing for a subsequent stimulus even if it is not related to the location or characteristics of the subsequent stimulus (e.g., Kimura, 2023; Kimura & Katayama, 2020; Kimura & Kimura, 2016). For example, during a color-discrimination task, the reaction time for the color-discrimination task is shortened when visual stimuli are presented repeatedly until the discrimination stimulus is presented, even if this stimulus is not predictive of subsequent stimulus color (Kimura, 2023). This result is considered to be an improvement in the prediction





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accuracy of task-related stimuli using peripheral information not directly related to the task. This facilitation of prediction by regular presentations of a peripheral stimulus is likely generated by predictive coding based on tracking the regularities between peripheral information and subsequent events (Clark, 2013; Mento, 2013). Previous studies on predictive coding have proposed that perceptual inference to input information and perceptual learning of the context of input information are the basis of prediction (Friston, 2005, Friston, 2009). Perceptual inference is a process related to the property of the input stimulus, and perceptual learning is a process related to the context and pattern of the stimulus. The presentation pattern of the stimulus is predicted by perceptual learning, and it is interpreted that the regular presentation of the peripheral stimulus reduces the uncertainty regarding the presentation pattern and facilitates the prediction of subsequent events (Kimura, 2023).

This peripheral information (both task-relevant and task-irrelevant information) is related to processing multiple types of information in daily life. In daily life, we need to process multiple types of information in parallel. For example, in the case of driving a car, it is necessary to control the steering wheel and depress the accelerator, and in parallel, to prepare to depress the brake pedal in anticipation of the deceleration of a vehicle ahead or of a person running out into the street. Based on the dual mechanism of cognitive control (DMC) theory (Braver, 2012; Braver, Gray, & Burgess, 2007), parallel information processing and peripheral information processing are thought to be carried out by two types of information processing: reactive and proactive processes. Each process is defined as follows (Braver, 2012): reactive process:





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"attention is recruited as a 'late correction' mechanism that is mobilized only as needed, in a just-in-time manner, such as after a high interference event is detected (pp. 2)"; proactive process: "goal-relevant information is actively maintained in a sustained manner, before the occurrence of cognitively demanding events, to optimally bias attention, perception and action systems in a goal-driven manner (pp. 2)." For example, in the Stroop task, the reactive process is thought to be a strategy for detecting interference between words and colors and then resolving this interference in a just-in-time manner, whereas the proactive process is thought to be a strategy of sustained bias of ignoring the words and detecting the colors for the task. Thus, these processes are thought to be cognitive controls utilized in situations where processing conflicts occur. In addition, these processes have been extended to include complementary trade-offs of cognitive resources between tasks, not limited to intra-task interference (Braver, 2012). For example, when driving a car, information that is directly related to the current action, such as accelerator pedal operation while driving, is prioritized. The accelerator pedal operation is continuous, but fine tuning of the accelerator pedal operation is required to maintain the distance from the car in front. In other words, it is necessary to react whenever the car in front decelerates or accelerates (reactive process). In addition, in some cases, information not directly related to the current actions may be processed to prepare for future events, such as a driver deciding which lane to drive in given future traffic conditions (proactive process). In this situation, each process is a relationship of complementary trade-offs, where consuming cognitive resources for the reactive process depletes cognitive resources for the proactive process (and vice versa). Thus, reactive







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and proactive processes share cognitive resources and need to switch between these processes in a timely manner. The current study aimed to examine whether task-irrelevant information influences reactive and proactive processes during multitasking. Here, we set a tracking task as a task for a reactive process that constantly processes information about current target movements for target tracking. We also set a detection task for a proactive process that predicts the timing of the presentation in preparation for the future presentation of colored circles.

It is unclear what determines the processing of peripheral information while facing task-related information. To examine whether peripheral information is processed, it is necessary to consider the circumstances under which this information is processed. In the perceptual load theory (Lavie, 2005, 2010), it is proposed that task-irrelevant (peripheral) information is used so as not to miss useful information in the environment when participants have a margin of cognitive resources available during an easy task, whereas, during a difficult task, this information is not used because cognitive resources are used to focus on the task and maintain task performance. In parallel, DMC theory (Braver, 2012; Braver, Gray, & Burgess, 2007) suggests that when task demand is high, working memory processing is interrupted and the proactive process, which is peripheral information processing not directly related to the current behavior, does not occur. This is believed to be the case because cognitive resources are finite, and when multiple types of information are processed, cognitive resources are preferentially allocated to the processing of task-relevant information.




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In this high-demand situation, peripheral information may be utilized even during multitasking by efficiently processing limited cognitive resources. For example, the saliency map weights information according to the importance of peripheral information (relevance) and changes the priority of processing (e.g., Zelinsky & Bisley, 2015). Moreover, a recent study reported that task-irrelevant information is not processed uniformly but is preferentially processed immediately before a task-relevant stimulus or immediately after the start of a trial, even if the information is not related to the task (Kimura, 2023). Therefore, task-irrelevant information processed without conflicting with the processing of task-relevant information may reduce the working memory load in a proactive process. If this is true, providing task-irrelevant information that can be utilized efficiently (without conflicting with the processing of task-relevant information) while multitasking may help leverage this information and predict future events.

The purpose of this study was to examine the hypothesis that peripheral information facilitates proactive processes during multitasking, especially when peripheral information is presented regularly. To test this hypothesis, we manipulated the peripheral information given during multitasking and examined the effects on task performances for the main task (reactive process) and the sub-task (proactive process). In Experiment 1, participants performed a tracking task to track a visual stimulus moving on the screen with a computer mouse (main task). In this tracking task, participants tracked the visual stimulus constantly, and were given ongoing feedback on their tracking performance. Therefore, the tracking task was set up as a reactive




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process that requires a constant response to a tracking stimulus. In parallel, participants performed a discrimination task in response to a visual stimulus on the screen with a keyboard (sub-task). In this discrimination task, the color of the visual stimulus should be separately identified during the tracking task, and the frequency of presentation was about once every few seconds. Therefore, this discrimination task was set up as a proactive process that predicts and discriminates the appearance of a visual stimulus while performing a tracking task.

Peripheral stimuli were also presented during the multitasking of the tracking and discrimination tasks. Previous studies reported that the multiple and regular presentation of a peripheral stimulus facilitates the prediction of subsequent events (e.g., Kimura, 2023; Kimura & Katayama, 2020; Kimura & Kimura, 2016). Here, we presented the peripheral stimulus and manipulated its regularity. This peripheral stimulus was a white circle, and this stimulus did not predict the color of the visual stimulus for the discrimination task. The regularity of the peripheral stimulus was manipulated by the number of these stimuli. In the triple condition, a trial was composed of three peripheral stimuli and one subsequent discrimination task stimulus; therefore, peripheral stimuli were presented continually during the discrimination task. In the single condition, a trial was composed of one peripheral stimulus and one subsequent discrimination task stimulus; therefore, it had a long delay from the presentation of the peripheral stimulus to the appearance of the discrimination task stimulus. These two conditions of the number of the peripheral stimulus were administered in separate blocks. With this manipulation, we examined whether the regularity of peripheral information during multitasking facilitates







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prediction for a proactive process. We predicted that if the regularity of peripheral stimuli facilitates the proactive process during multitasking, as shown in previous reports (e.g., Kimura, 2023; Kimura & Katayama, 2020), the reaction time (RT) for the discrimination task under the triple condition will be shorter than under the single condition.

We also examined the performance of the tracking task during this multitasking to determine whether the peripheral information inhibits the main task (tracking task: reactive process). The use of cognitive resources in the proactive process may reduce the cognitive resources available for the reactive process and inhibit processing (Braver, 2012). Therefore, even if the regularity of the peripheral stimuli was useful for the discrimination task, if their processing depleted the cognitive resources available for the entire task (e.g., Kahneman, 1973), it is predicted the performance of the tracking task will decline due to a lack of cognitive resources available for the tracking task (main task). We examined whether the reactive process is inhibited by the proactive process by using peripheral information.

Furthermore, we examined the relationship between the difficulty of the main task and the use of peripheral information. According to the perceptual load theory (Lavie, 2005; 2010) and the DMC theory (Braver, 2012; Braver et al., 2007), as the difficulty of the main task (reactive process) increases, large amounts of cognitive resources are used and peripheral information (task-irrelevant information) may not be processed. We examined whether regular peripheral stimuli facilitate prediction for the proactive process (discrimination task) even when a large amount of cognitive resources is used for the main task. We controlled the difficulty of the main







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task (tracking task) by the size, trajectory, and speed of the visual stimulus used for tracking. In the easy tracking task, the tracking stimulus, a large black square (visual angle: 3.8° by 3.8°), moved slowly (6.5 cm/s) in the horizontal direction only, and when this stimulus reached the edge of the monitor, it moved in the opposite direction. In the difficult tracking task, the tracking stimulus, a small black square (visual angle: 3.0° by 3.0°), moved fast (13 cm/s) and in a circular motion, and this motion changed to the opposite direction randomly. The two conditions of task difficulty were administered in separate blocks. With this manipulation, we examined the relationship between the difficulty of the main task and the peripheral information. If the difficulty of the main task is so high that peripheral stimuli are not processed (Lavie, 2005; 2010), then it is predicted that the performance of the discrimination task would not differ between the triple and single conditions. On the other hand, if peripheral stimuli could be processed without conflicting with the multitasking (Kimura, 2023), then even if the difficulty of the tracking task is high, there is no shortage of cognitive resources available for the entire task, and the triple condition may facilitate the performance of the identification task by the effect of multiple and regular presentations of peripheral information (Kimura, 2023; Kimura & Katayama, 2020).

In Experiment 2, we further examined by using an auditory stimulus as a peripheral cue. The peripheral stimulus was a white circle in Experiment 1, and this stimulus did not predict the color of the visual stimulus for the discrimination task. However, attention to a visual modality might be increased because the peripheral stimuli (white circle) occur in the same sensory





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modality as the discrimination task stimuli (color circle; e.g., Mondor & Amirault, 1998; Spence, 2010). However, a previous study reported that peripheral information influences even different sensory modalities (Kimura & Katayama, 2020). Therefore, using auditory peripheral stimuli, we examined whether the promoting effect of peripheral information for the discrimination task (proactive process) was influenced by a specific sensory modality. In Experiment 2, only the sensory modality of the peripheral stimuli was modified from Experiment 1, and the main task (tracking task) and sub-task (discrimination task) were the same as in Experiment 1. This peripheral stimulus was a pure tone, and this stimulus did not predict the color of the visual stimulus for the discrimination task. If the influence from peripheral stimuli will decrease because the modality of these stimuli was different from that of the tasks (e.g., Mondor & Amirault, 1998; Spence, 2010), it is predicted that the performance of the tracking task and the discrimination task will not be influenced and will not differ between conditions. However, if the peripheral stimuli will have an influence even if the tasks occur in a different sensory modality (Kimura & Katayama, 2020), it is predicted that the performance of the tracking task and the discrimination task will be the same as in the Experiment 1.





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## 2. Experiment 1

### 2.1. Method

#### 2.1.1. Pre-registration

The procedure and analysis plan for Experiments 1 and 2 were pre-registered prior to data collection and can be found at https://osf.io/guja3.

#### 2.1.2. Participants

Thirty-two undergraduate and graduate students (16 females, 16 males; age range: 19–25 years; mean: 21.6 years (SD = 1.72)) participated in the experiment. This sample size was decided by a power analysis using R and the pwr.f2.test function in the pwr package (Champely et al., 2018). We set the alpha level, effect size and power beforehand and then determined a sample size. In the power analysis, the effect size was set to medium of $f2 = 0.25$ based on Kimura (2023), to a significance level of $\alpha = 0.05$ and to a power of $1 - \beta = 0.80$ for the two-way repeated measures analysis of variance (ANOVA) on tracking rate and RT (Cohen, 1992, 2013). All participants were right-handed, according to their self-report, and had normal or corrected-to-normal vision. The participants were healthy adults and they did not report a history of psychiatric or neurological disease. This experiment was approved by the Institute of Scientific and Industrial Research's Research Ethics Review Board under Osaka University Regulations.





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Written informed consent was obtained from all participants, and their rights as experimental subjects were protected.

### 2.1.3. Stimuli and apparatus

The participants were seated and put their left hand on a keyboard and right hand on a computer mouse at the front of their desk. Black squares were used as tracking stimuli (visual angle for easy condition: 3.8° by 3.8°; visual angle for difficult condition: 3.0° by 3.0°); a black circle as a tracking pointer (visual angle: 0.5° by 0.5°), a white circle as a peripheral stimulus, and blue and red circles as detection task stimuli (visual angle: 3.8° by 3.8°). All were presented in the monitor against a gray background from an observation distance of 60 cm. The tracking stimulus and tracking pointer were presented continuously during the task. The duration of the presentation of these detection task stimuli was 200 ms. The presentation of stimuli was controlled with MATLAB R2010b (MathWorks, Inc.) and Psychtoolbox (Kleiner, Brainard, & Pelli, 2007) installed on a laptop computer (ThinkPad X1, Lenovo). In addition, a 23-inch LCD monitor (P2317H, Dell) was put on the desk to present these stimuli.



### 2.1.4. Procedure

Figure 1 illustrates the experimental procedure. In all conditions, participants performed the tracking task and the detection task in parallel. In the tracking task, they were instructed to track a black square as a tracking stimulus using by a black circle as a tracking pointer stimulus as


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accurately as possible. The tracking pointer was synchronized with the movement of the computer mouse. When the tracking pointer stimulus overlapped with the tracking stimulus (i.e., when tracking was successful), the color of the tracking stimulus changed from black to white. Participants were asked to make the tracking stimulus as white as possible. In the detection task, the detection task stimuli (i.e., blue and red circles) were presented on the monitor. Participants were instructed to respond as quickly and accurately as possible to the blue and red circles by pressing the "f" or "j" key with their left index or middle finger, and they were required to ignore the white circles as peripheral stimuli. Half of the participants used the "f" key to respond to the blue circles and the other half used the "j" key. The presentation probability of detection task stimuli, i.e., the presentation probability of blue or red circles, was equal, and this information was told to participants before the block. The peripheral stimulus did not predict which color of detection task stimulus would be presented.

The conditions were distinguished by the difficulty of the tracking task and presentation of the peripheral stimulus, and this presentation was administered in separate blocks. In the easy-triple condition, a trial was composed of an easy tracking task and detection task with three peripheral stimuli. The large black square as tracking stimulus (visual angle: 3.8° by 3.8°) moved slowly (6.5 cm/s) and only in the horizontal direction, and this stimulus moved in the opposite direction when it reached the edge of the monitor (easy tracking task). In parallel, a blue or red circle as detection task stimulus was presented and three white circles as peripheral stimuli were presented during this stimulus (triple condition). The stimulus interval (SOA) for detection task







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was set to 1,000 ms; therefore, the SOA from the first peripheral stimulus to the detection stimulus was 3,000 ms. In the easy-single condition, a trial was composed of an easy tracking task and detection task with one peripheral stimulus. The blue or red circle as detection task stimulus was presented and one white circle as peripheral stimulus was presented during this stimulus (single condition) in parallel for the easy tracking task. The SOA for the detection task was set to 3,000 ms; therefore, the SOA from the peripheral stimulus to the detection task stimulus was 3,000 ms. In the difficult-triple condition, a trial was composed of a difficult tracking task and detection task under the triple condition. The small black square as tracking stimulus (visual angle: 3.0° by 3.0°) moved fast (13 cm/s) and in a circular motion, and this motion changed to the opposite direction randomly (difficult tracking task). In parallel, participants performed a detection task under the triple condition. In the difficult-single condition, a trial was composed of a difficult tracking task and detection task under the single condition.

Each condition was composed of 80 trials (presentation of blue circle for detection task: 40 trials; presentation of red circle for detection task: 40 trials), which took approximately 6 min. One block was presented for each condition; therefore, the overall number of trials was 320 trials per participant. The interval between blocks was 2 min, and after the two blocks, the participants rested for 10 min and then started the remaining two blocks. The order of conditions was randomized between participants.







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In the experiment room, the participants were asked to sit in a chair and to place their left hand on a keyboard and right hand on a computer mouse at the front of their desk. They were required to not move their eyes and bodies more than necessary in each condition.

**2.1.5. Data analyses**

The performance of the tracking task was calculated as the percentage of successful tracking (tracking rate). The ratio of how many frames in which the tracking pointer overlapped in the tracking stimulus was calculated for each trial of the detection task, and the average percentage was calculated for each condition. The performance of the detection task was calculated as reaction times (RTs) for the detection task stimulus.[1] Participants were removed if their task performance for the tracking task was less than 50% under the easy condition, because it is thought that they could not perform this task even under easy conditions. In addition, trials were removed for each participant if they had outlier RTs of less than 200 ms or more than 1500 ms, as followed by Kimura (2021). After data removal, no additional participants were removed and the numbers of remaining trials ranged from 69 to 80 (0–14% removed), 77 to 80 (0–4% removed), 62 to 80 (0–23% removed), and 65 to 80 (0–19% removed) for the easy-triple condition, easy-single condition, difficult-triple condition, and difficult-single condition, respectively. These indexes were assessed with a two-way repeated measures ANOVA (2 difficult for tracking task (easy and difficult) × 2 peripheral stimulus for detection task (triple and single)). These ANOVAs were conducted by applying Greenhouse-Geisser corrections to the





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degrees of freedom (Greenhouse & Geisser, 1959) when Mauchly's sphericity test was significant. The effect sizes have been indicated in terms of partial eta squared ($\eta_p^2$). Post hoc comparisons were made using Shaffer's modified sequentially rejective multiple test procedure, which extends Bonferroni *t* tests in a stepwise fashion (Shaffer, 1986). The significance level was set at α = .05 for all statistical analyses.



## 2.2. Results

### 2.2.1. Tracking task

Figure 2 (a) illustrates the tracking rates of all participants. The averaged tracking rates of all participants were 97.96% (SE = 0.003), 96.90% (SE = 0.004), 65.62% (SE = 0.014), and 60.94% (SE = 0.013) for the easy-triple condition, easy-single condition, difficult-triple condition, and difficult-single condition, respectively. The results of the ANOVA for averaged tracking rate revealed that the main effect of difficulty was significant ($F(1, 31) = 1049.01$, $p < .001$, $\eta_p^2 = .97$), and that the tracking rate of the easy condition was higher than that of the difficult condition. Moreover, the main effect of peripheral stimulus was significant ($F(1, 31) = 52.08$, $p < .001$, $\eta_p^2 = .63$), and the tracking rate of the triple condition was higher than that of the single condition. Furthermore, the interaction of difficulty and peripheral stimulus was significant ($F(1, 31) = 23.48$, $p < .001$, $\eta_p^2 = .43$). Post hoc comparisons showed that the tracking rate of the triple condition was higher than that of the single condition in each difficulty



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condition ($ps < .05$; easy condition: $d = .22$; difficult condition: $d = .72$). In addition, the tracking rate of the easy condition was higher than that of the difficult condition in each peripheral stimulus condition ($ps < .05$; single condition: $d = 6.35$; triple condition: $d = 4.23$).

**2.2.2. Detection task**

Figure 2 (b) illustrates RTs of all participants. The averaged RTs of all participants were 610 ms (SE = 0.011), 635 ms (SE = 0.011), 638 ms (SE = 0.013), and 684 ms (SE = 0.010) for the easy-triple condition, easy-single condition, difficult-triple condition, and difficult-single condition, respectively. The results of the ANOVA for averaged RTs revealed that the main effect of difficulty was significant ($F(1, 31) = 53.54$, $p < .001$, $\eta_p^2 = .63$), and that the RT of the easy condition was shorter than that of the difficult condition. Moreover, the main effect of peripheral stimulus was significant ($F(1, 31) = 44.11$, $p < .001$, $\eta_p^2 = .59$), and the RT of the triple condition was shorter than that of the single condition. Furthermore, the interaction of difficulty and peripheral stimulus was significant ($F(1, 31) = 8.37$, $p = .007$, $\eta_p^2 = .21$). Post hoc comparisons showed that the RTs of the triple condition were shorter than those of the single condition in each difficulty condition ($ps < .05$; easy condition: $d = .38$; difficult condition: $d = .51$). In addition, the RTs of the easy condition were shorter than those of the difficult condition in each peripheral stimulus condition ($ps < .05$; single condition: $d = .74$; triple condition: $d = .31$).



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**2.3. Discussion**

Experiment 1 aimed to investigate whether task-irrelevant information facilitates a proactive process during multitasking in which a tracking task is the main task (reactive process) and a discrimination task is the sub-task (proactive process). For this purpose, the performances of multiple types of tasks were examined from three viewpoints. First, to examine the influence of peripheral information on the proactive process, RTs for a discrimination task (proactive process) were compared between the triple condition and the single condition during multitasking. Second, to confirm whether the peripheral information inhibits the main task as the tracking task (reactive process), the tracking rates for the tracking task were compared between conditions during multitasking. Third, to examine the relationship between the difficulty of the main task and the peripheral information, tracking rates for tracking task and RTs for the discrimination task were compared for a combination of difficulty level (easy and difficult) and peripheral information (triple and single).

The RTs for the discrimination task under the easy condition were shorter than under the difficult condition. This condition of difficulty was a factor for the tracking task; therefore, it is thought that the task difficulty for the tracking task (main task) was appropriately manipulated, and as the task difficulty for the main task increased, more cognitive resources were consumed in the main task (e.g., Kahneman, 1973), resulting in a decrease in cognitive resources available for the discrimination task (sub-task). Moreover, RTs for the discrimination task under the triple condition were shorter than under the single condition. The only difference between the







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peripheral conditions was the number of peripheral stimuli preceding the discrimination task stimulus, and these stimuli did not function as cues for distinguishing the color of peripheral stimuli. Previous studies reported that peripheral information facilitates the prediction of subsequent events (e.g., Kimura & Katayama, 2020; Kimura & Kimura, 2016) and the RTs (Kimura, 2023). This result corresponds to the first viewpoint, suggesting that peripheral information facilitates the proactive process even if participants perform multiple types of tasks.

Interestingly, this promoting effect for the proactive process by regular presentations of peripheral information occurred under both difficulty conditions. A previous study reported that cognitive resources were allocated efficiently for peripheral stimuli during a discrimination task for peripheral stimuli (Kimura, 2023). In our study, the promoting effect under the triple condition can be interpreted as a result that peripheral stimuli were processed without interfering with the multitasking under the triple condition. This result corresponds to the second viewpoint; it is thought that efficient processing of peripheral stimuli allowed the processing of these stimuli under the difficult condition with limited cognitive resources, resulting in this promoting effect.

The tracking rates for the tracking task under the easy condition were higher than under the difficult condition. This result showed that the task difficulty for the tracking task was appropriately manipulated. Moreover, tracking rates for the tracking task under the triple condition were higher than under the single condition, and interestingly, the promoting effect for the reactive process occurred under both difficulty conditions. Taken together with the RT results of the discrimination task, this result corresponds to the third viewpoint, it can be interpreted that







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efficient processing of task-irrelevant stimuli under the triple condition provided a margin of cognitive resources, and the use of this margin improved the performance of the tracking task.

Taking the results of Experiment 1 together, the proactive process was facilitated by task-irrelevant information during the multitasking, and this promoting effect occurred even if the reactive process was difficult and required more cognitive resources. Moreover, this benefit to the proactive process also facilitated the performance of the reactive process. These results suggest that efficient processing of peripheral information facilitates the proactive process even if more cognitive resources are consumed. This promoting effect would provide a margin of cognitive resources and facilitates the reactive process.

## 3. Experiment 2

### 3.1. Method

#### 3.1.1. Participants

Thirty-two undergraduate and graduate students (16 females, 16 males; age range: 19–25 years; mean: 21.6 years (SD = 1.72)) participated in the experiment. All of them also participated in Experiment 1 on the same day after a 15-minute break: the order of Experiments 1 and 2 was counterbalanced.





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### 3.1.2. Stimuli and apparatus

Except for the peripheral stimulus, the stimuli and stimulus devices were identical to those used in Experiment 1. The pure tone as a peripheral stimulus (1000 Hz, 75db/SPL) was presented via an audio interface (OCTA-CAPTURE UA-1010, Roland) and headphones (MDR-CD900ST, SONY). The duration of this stimulus was 200 ms.

### 3.1.3. Procedure

Figure 3 illustrates the experimental procedure. The task, procedure, instructions, and conditions were identical to those used in Experiment 1 except for the kind of modality of the peripheral stimulus.

### 3.1.4. Data analyses

As in Experiment 1, the participants were not removed and the numbers of remaining trials ranged from 72 to 80 (0–10% removed), 62 to 80 (0–23% removed), 66 to 80 (0–18% removed), and 62 to 80 (0–23% removed) for the easy-triple condition, easy-single condition, difficult-triple condition, and difficult-single condition, respectively. The tracking rates and RTs were calculated and these indexes were assessed with a two-way repeated measures ANOVA (2 difficult for tracking task × 2 peripheral stimulus for detection task). The corrections to the







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degrees of freedom, effect sizes, post hoc comparisons and significance level were calculated using the same method as in Experiment 1.

### 3.2. Results

#### 3.2.1. Tracking task

Figure 4 (a) illustrates tracking rates of all participants. The averaged tracking rates of all participants were 97.37% (SE = 0.005), 97.67% (SE = 0.003), 67.33% (SE = 0.014), and 65.69% (SE = 0.017) for the easy-triple condition, easy-single condition, difficult-triple condition, and difficult-single condition, respectively. The results of the ANOVA for averaged tracking rate revealed that the main effect of difficulty was significant ($F(1, 31) = 654.21$, $p < .001$, $\eta_p^2 = .95$), and that the tracking rate of the easy condition was higher than that of the difficult condition. Moreover, the main effect of peripheral stimulus was significant ($F(1, 31) = 4.45$, $p = .043$, $\eta_p^2 = .13$), and the tracking rate of the triple condition was higher than that of the single condition. Furthermore, the interaction of difficulty and peripheral stimulus was significant ($F(1, 31) = 7.64$, $p = .010$, $\eta_p^2 = .20$). Post hoc comparisons showed that the tracking rate of the triple condition was higher than that of the single condition in the difficult condition ($p < .05$, $d = .21$). In addition, the tracking rate of the easy condition was higher than that of the difficult condition in each peripheral stimulus condition ($p$s < .05; single condition: $d = 4.72$; triple condition: $d = 3.29$).


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### 3.2.2. Detection task

Figure 4 (b) illustrates RTs of all participants. The averaged RTs of all participants were 603 ms (SE = 0.011), 634 ms (SE = 0.010), 610 ms (SE = 0.011), and 667 ms (SE = 0.012) for the easy-triple condition, easy-single condition, difficult-triple condition, and difficult-single condition, respectively. The results of the ANOVA for averaged RTs revealed that the main effect of difficulty was significant ($F(1, 31) = 16.61$, $p < .001$, $\eta_p^2 = .35$), and that the RT of the easy condition was shorter than that of the difficult condition. Moreover, the main effect of peripheral stimulus was significant ($F(1, 31) = 84.23$, $p < .001$, $\eta_p^2 = .73$), and the RT of the triple condition was shorter than that of the single condition. Furthermore, the interaction of difficulty and peripheral stimulus was significant ($F(1, 31) = 14.74$, $p < .001$, $\eta_p^2 = .32$). Post hoc comparisons showed that the RTs of the triple condition were shorter than those of the single condition in each difficulty condition ($p$s < .05; easy condition: $d = .48$; difficult condition: $d = .65$). In addition, the RTs of the easy condition were shorter than that of the difficult condition in single condition ($p < .05$, $d = .51$).



### 3.3. Discussion

Experiment 2 aimed to investigate whether the effect of Experiment 1 occurs even for a different sensory modality by using an auditory stimulus as the peripheral stimulus. Overall, this promoting effect occurred for the proactive process and reactive process also Experiment 2. Previous studies reported that cognitive resources are shared among the different sensory





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modalities when these resources are allocated for task-based attention (e.g., Spence, Ranson, & Driver, 2000; Wahn & König, 2015, 2017). This explanation for the sharing of cognitive resources corresponds to our results that efficient processing of peripheral information facilitates the proactive process even if more cognitive resources are consumed. This efficient promoting effect provides a margin of cognitive resources and facilitates the reactive process. These results suggest that the promoting effect of the peripheral information increases the performance of the proactive process and the reactive process regardless of the sensory modality.



**4. General Discussion**

The aim of this study was to examine whether peripheral information facilitates a proactive process during multitasking. For this purpose, peripheral information was presented during multitasking and the effects on task performances for the main task (reactive process) and a sub-task (proactive process) were examined. In Experiment 1, the stimuli of these processes and peripheral information were presented in the same sensory modality (visual), and in Experiment 2, it was presented in a different sensory modality (auditory).

In both experiments, the tracking performances in easy conditions were higher than those in difficult conditions, indicating that the task difficulty of the tracking task was appropriately manipulated. Moreover, the high difficulty of the tracking task also delayed the response to the discrimination task in both experiments. These results are interpreted to imply that as the task difficulty of the tracking task (reactive process) increased, more cognitive resources were



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consumed in the tracking task, resulting in fewer cognitive resources being available for the discrimination task (proactive process). This interpretation corresponds with the explanation of the limitation of cognitive resources (e.g., Kahneman, 1973) and priority for reactive processes based on DMC theory (Braver, 2012; Braver et al., 2007).

The discrimination responses in the triple conditions were faster than in the single condition in both experiments. These results correspond to our hypothesis that peripheral information facilitates proactive processes during multitasking, especially when peripheral information is presented regularly. Interestingly, this promoting effect also occurred when the tracking task (reactive process) was difficult. These results are seemingly contradictory from the perspective of the perceptual load theory (Lavie, 2005; 2010) and DMC theory (Braver, 2012; Braver et al., 2007). In the perceptual load theory (Lavie, 2005; 2010), peripheral information is not used when the main task is difficult and cognitive resources are used to focus on the main task. In the DMC theory (Braver, 2012; Braver et al., 2007), cognitive resources are preferentially allocated to the processing of peripheral information when multiple information is processed, as a result, cognitive resources available for tracking tasks may be decreased.

This discrepancy could be interpreted by assuming a mechanism that efficiently handles the regular presentation of peripheral information. Previous studies reported that the regular presentation of peripheral information facilitates the processing of subsequent events (e.g., Kimura & Katayama, 2020; Kimura & Kimura, 2016). In addition, a previous study on contingent negative variation (CNV), an event-related potential (ERP) index of time prediction







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(e.g., Walter, Cooper, Aldridge, McCallum, & Winter, 1964), reported that regular presentation of peripheral information is not uniformly processed (Kimura, 2023). This is considered to be due to the efficient processing of peripheral information for the temporal prediction of subsequent events. Therefore, also in our study, it is possible that the peripheral information was not processed uniformly, but was processed efficiently for the discrimination task (proactive process). This efficient processing could be interpreted to promote the performance of the discrimination task (reactive process) by efficiently utilizing the remaining cognitive resources even if the tracking task (reactive process) is difficult. This interpretation corresponds to our concern about whether regular peripheral stimuli facilitate prediction for the proactive process (discrimination task) even when a large amount of cognitive resources is used for the main task.

Moreover, the regular presentation of peripheral information also increases the accuracy of the tracking performance (reactive process). It could be interpreted that efficient processing of peripheral stimuli under the triple condition provided a margin of cognitive resources, and the use of this margin improved the performance of the tracking task. This interpretation corresponds to our question about whether the reactive process is inhibited by the proactive process by using peripheral information. Thus, this study is the first to report that the relationship between the reactive process and the proactive process in multiple types of cognitive information processing is determined not only by how cognitive resources are used for the reactive process, but also by how information related to the proactive process (peripheral information) is presented and utilized.





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Furthermore, the regular presentation of the peripheral information increases the performance of the proactive and reactive processes regardless of the different sensory modalities. This result corresponds to our concern about whether the effect of peripheral information on prediction for a proactive process was influenced by a specific sensory modality. These results show that this promoting effect might be not an effect of increased attention within the sensory modality (e.g., Mondor & Amirault, 1998; Spence, 2010), but a supramodal effect beyond the different sensory modalities (e.g., Spence, Ranson, & Driver, 2000; Wahn & König, 2015, 2017). However, these results can also be explained by different mechanisms for sensory processing. For example, auditory stimuli may increase the saliency of visual stimuli (e.g., Noesselt et al., 2008), and if so, our result in Experiment 2 might have been caused by this multisensory effect. The difference in promoting effects by modality of peripheral information will be necessary to further examine in a future study.

**Conclusion**

This study revealed that efficient processing of peripheral information facilitates a proactive process even if more cognitive resources are consumed. This efficient promoting effect provides a margin of cognitive resources and facilitates the reactive process. Moreover, we showed that this promoting effect might be not an effect of increased attention within the sensory





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modality, but a supramodal effect beyond the different sensory modalities. Our results provided evidence of how peripheral information and cognitive resources are used during prediction.

**Conflict of Interest Statement**

The author declares that the research was conducted in the absence of any commercial or financial relationship that could be construed as a potential conflict of interest.



**Author Contributions**

Tsukasa Kimura: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data curation, Writing- Original draft preparation, Visualization, Supervision, Validation, Writing- Reviewing and Editing, Project administration, Funding acquisition. Tomoya Kawashima: Conceptualization, Formal Analysis, Writing- Reviewing and Editing.

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**Data Availability Statement**

The datasets presented in this article are not readily available because these data contain personal information. Requests to access the datasets should be directed to the corresponding author, Tsukasa Kimura (kimura@ai.sanken.osaka-u.ac.jp).

**Notes**

1. The normality of RTs in both experiments was checked by the Shapiro-Wilk test using the R function shapiro.test (*p*s > .05). In addition, the results of RTs showed a similar pattern with and without log transformation. The authors thank the reviewers for this suggestion.





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Figure captions:

Figure 1. The procedures of Experiment 1. Black squares as tracking stimuli (easy condition: 3.8° by 3.8°; difficult condition: 3.0° by 3.0°) and dashed lines in the images represent the trajectories of these stimuli (easy condition: slowly (6.5 cm/s) and only in the horizontal direction; difficult condition: fast (13 cm/s) and in a circular motion, and this motion changed to the opposite direction randomly). Black circle as tracking pointer (visual angle: 0.5° by 0.5°), white circle as peripheral stimulus, and blue and red circles as detection task stimuli (3.8° by 3.8°).

Figure 2. (a) Tracking rate (%) for the tracking task and (b) RTs (ms) for the discrimination task in Experiment 1. The raincloud plots illustrate of data distribution with raw data and boxplots.

Figure 3. The procedures of Experiment 2. Except for peripheral stimulus (pure tone: 1000 Hz, 75db/SPL), the stimuli were identical to those used in Experiment 1.

Figure 4. (a) Tracking rate (%) for the tracking task and (b) RTs (ms) for the discrimination task in Experiment 1. The raincloud plots illustrate of data distribution with raw data and boxplots.





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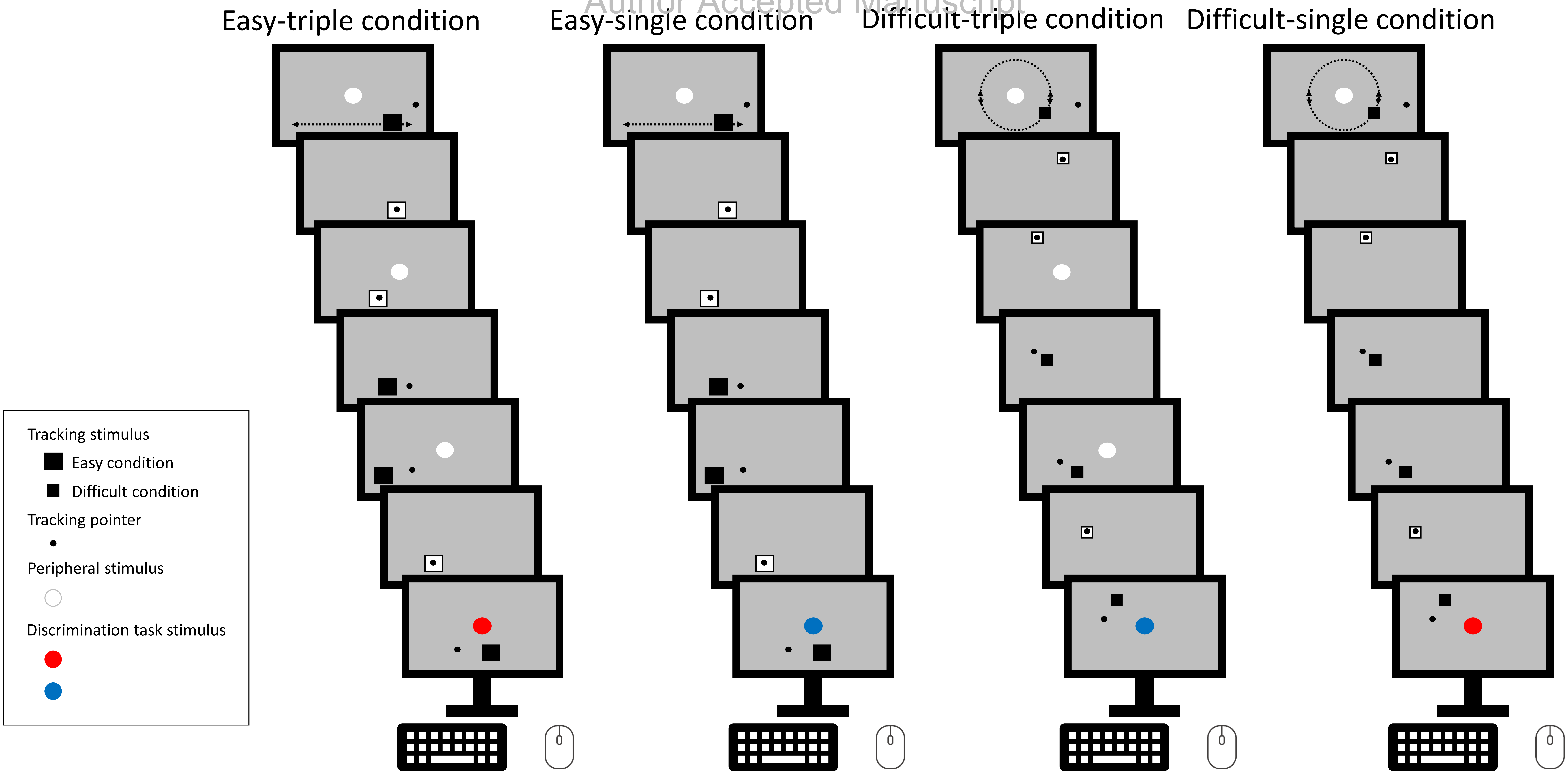



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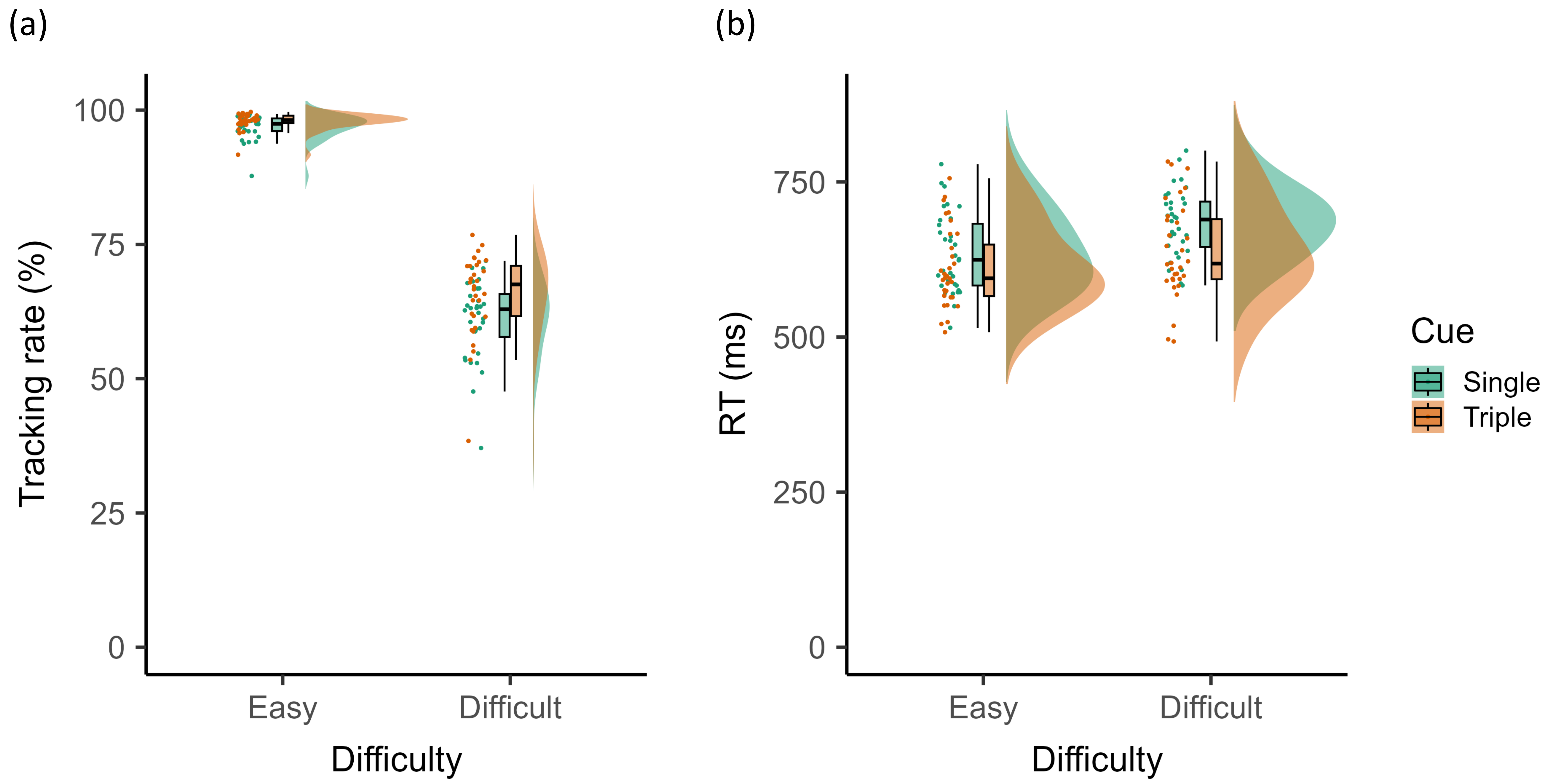



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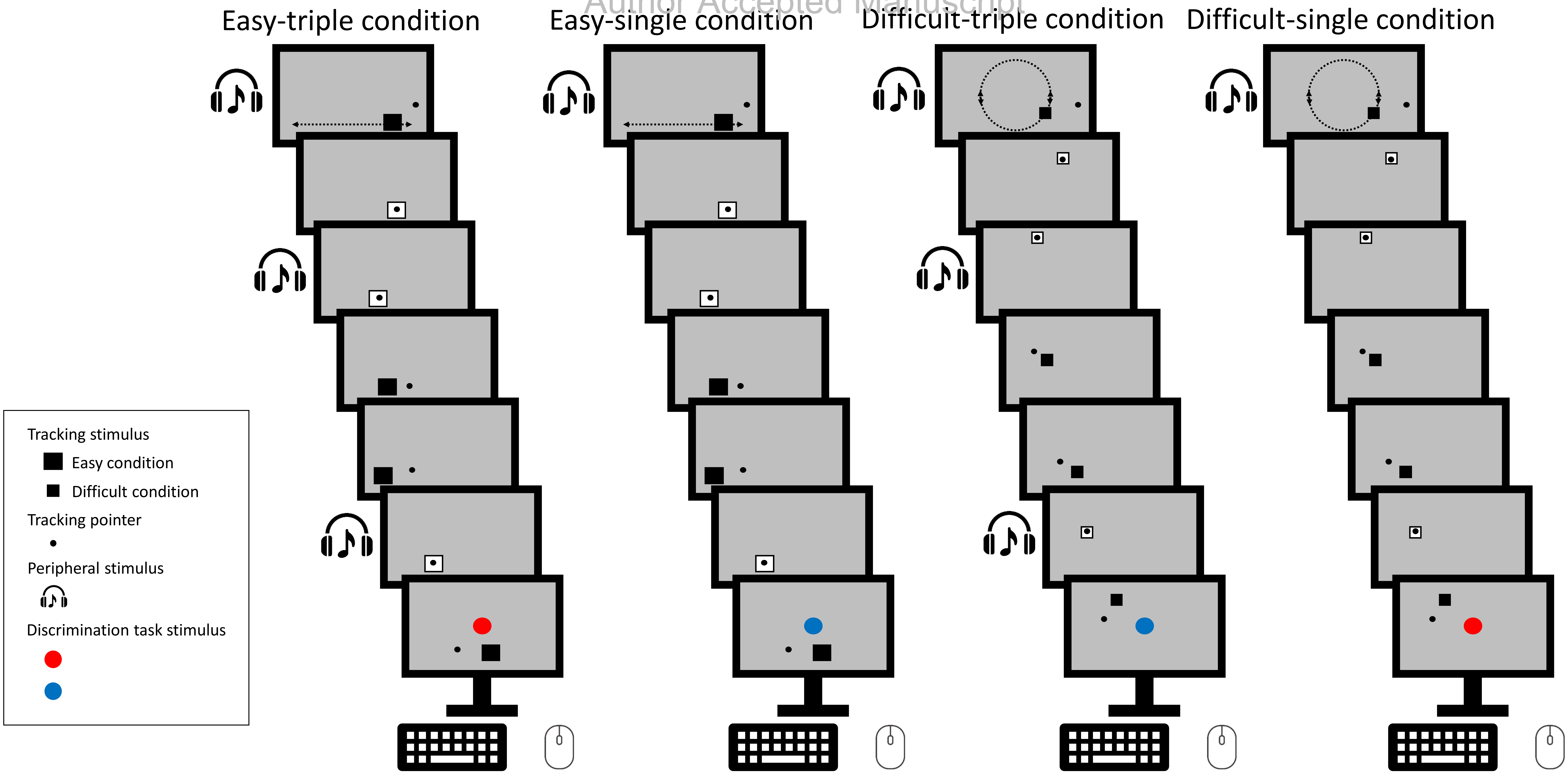



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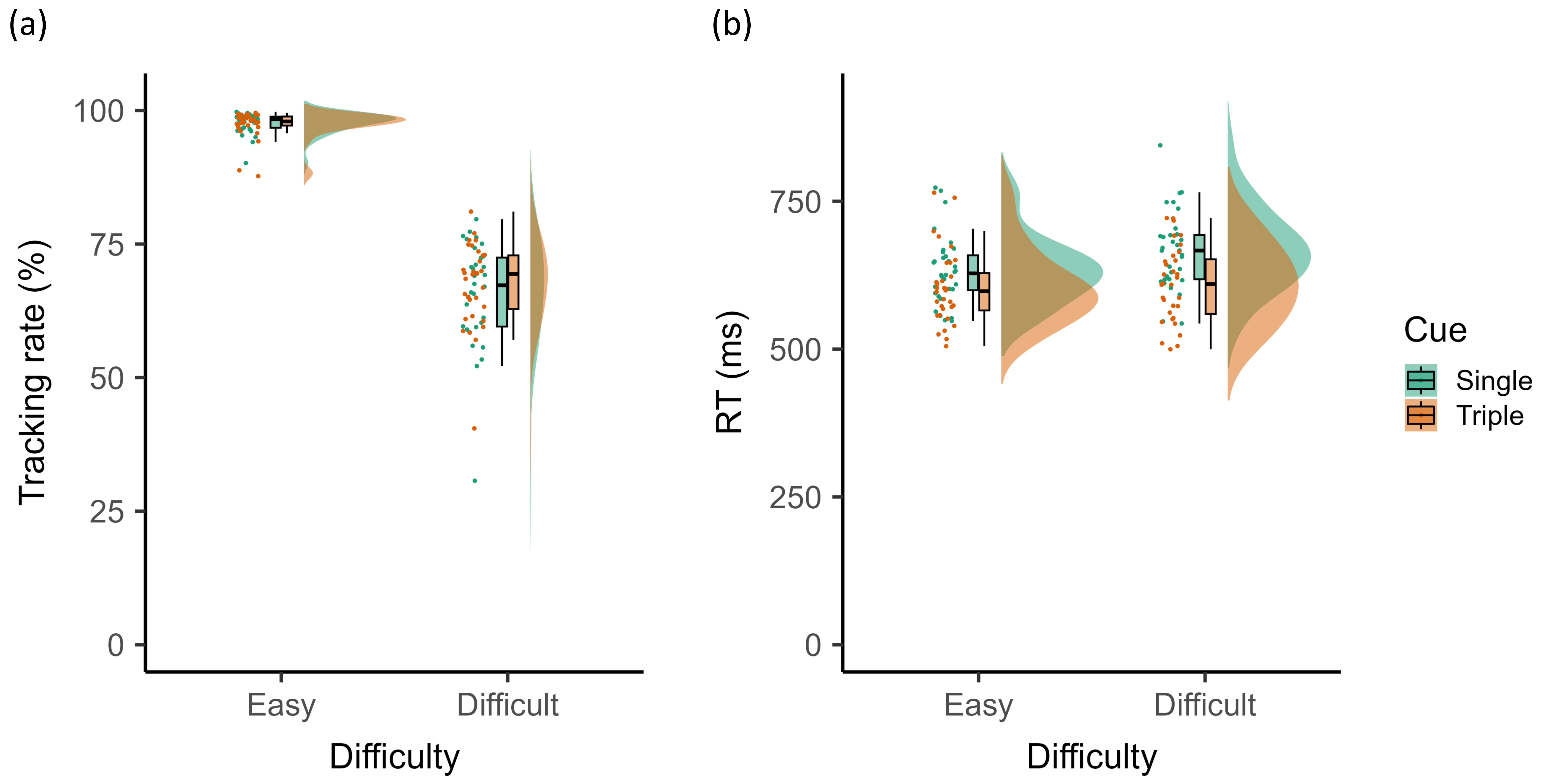



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