Reducing Perceived Waiting Time with Peripheral Visual Motion: Directional and Device-Specific Effects

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Waiting times during digital interactions such as application launches or web content loading can negatively impact user experience. Although progress bars are commonly used to mitigate this effect, their visual design typically engages only the central field of vision. This study investigates how peripheral visual stimuli presented alongside progress bars influence users' perception of time. A preliminary experiment was conducted to identify effective motion patterns for peripheral stimuli. A subsequent large-scale crowdsourced experiment revealed that stimuli moving in the same direction as the progress bar, especially those with intermittent motion, significantly reduced perceived waiting time. Furthermore, a follow-up lab-based study compared the effects across device types and found that horizontal peripheral stimuli were more effective on PC displays, while vertical stimuli had greater impact on smartphones. These findings suggest that peripheral visual information can modulate perceived waiting time and offer actionable insights for designing user interfaces that improve the experience of waiting across different platforms.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**; *User studies*; *User interface design.*

Additional Key Words and Phrases: Perceived Waiting Time, Progress Bar, Peripheral Vision, Visual Stimuli, Time Perception, User Experience, Visual Feedback, Mobile Devices, Desktop Computing

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1 INTRODUCTION

Users frequently encounter waiting times when interacting with digital systems, such as during the launch of applications, the loading of web content, or the transfer of files. Even when these delays last only a few seconds, they are often perceived as significantly longer, potentially causing psychological stress and leading to user dissatisfaction or abandonment [29, 34, 35, 44, 48]. As such, designing user interfaces that can alleviate the subjective burden of waiting remains an important challenge in enhancing user experience.

One widely adopted approach to mitigate perceived waiting time is the use of visual feedback, particularly in the form of progress indicators. Prior research has shown that progress bars are more effective in reducing perceived waiting time than textual countdowns, static icons, or the absence of feedback [18, 27, 32, 34, 44]. This effect is partly attributed to the sense of control and predictability they provide, as users tend to experience increased anxiety when progress is not visually represented. Moreover, this effect can be further amplified through the addition of animations or interactive elements within the progress bar [20, 21].

In this study, we extend this line of research by incorporating findings from visual perception science, with a focus on the distinction between central and peripheral vision. Central vision supports detailed recognition of stimuli in direct focus, while peripheral vision allows for coarse detection of spatial structure and motion outside the focal area [52, 57]. Importantly, peripheral vision processes visual input in an automatic and unconscious manner, enabling users to perceive motion and spatial patterns with minimal cognitive effort [42]. Based on these properties, we hypothesize that presenting dynamic visual stimuli in the peripheral field can subtly influence time perception without requiring focused attention.

By augmenting conventional progress bar feedback, which primarily engages central vision, with peripheral visual stimuli, we aim to further reduce users' perceived waiting time. Although previous studies have largely focused on PC environments, it is not yet well understood whether similar effects hold across devices with differing display characteristics. For instance, smartphones are generally used in portrait orientation and offer a narrower visual field, which may lead to different perceptual dynamics. Therefore, a comparative investigation across device types is essential to determine whether the efficacy of peripheral visual stimuli varies with screen layout and usage context.

This research explores strategies for shortening perceived waiting time by combining centrally and peripherally targeted visual stimuli. In addition, it examines how the effectiveness of such stimuli may differ between PC and smartphone platforms.

The primary contributions of this study are as follows:

- We conducted a preliminary lab experiment (Pilot Study) to identify which types of peripheral visual motion are effective in reducing perceived waiting time. The results indicated that simple directional stimuli, such as horizontally sliding dots, were particularly effective, especially when presented intermittently.
- We carried out a large-scale online experiment (Experiment 1) to examine the effects of motion direction on perceived waiting time. This study showed that stimuli moving in the same direction as the progress bar tended to shorten the perceived waiting time, while those moving in the opposite direction tended to extend it. Intermittent stimuli were also found to be more effective than continuous ones.
- We performed a controlled device comparison experiment (Experiment 2) to investigate how the effects of peripheral visual motion vary between PCs and smartphones. The findings revealed that horizontal motion was more effective on PC, while vertical motion had a stronger impact on smartphones, likely due to differences in screen orientation and user viewing behavior.

2 RELATED WORK

2.1 Visual Feedback in Progress Indicators

Many studies have focused on reducing perceived waiting time through the use of visual feedback, particularly progress indicators. Among these, the shape and style of the progress bar itself have been shown to influence users' perception of time. For example, bar-type and ring-type formats can affect how long a wait feels to the user [2, 36, 38].

Li et al. [28] examined how different progress bar presentations affect subjective time perception and stress levels. They found that clearly advancing indicators were perceived more positively than looping animations. However, looping animations were associated with shorter perceived waiting times despite being rated less favorably overall.

The speed and acceleration of progress animations also play a critical role. Prior research has shown that progress bars with accelerating motion or non-linear progression can reduce perceived waiting time and increase user satisfaction [6, 18, 19, 24, 26, 50, 58].

Several studies have explored the impact of embedded animations within progress bars. For instance, Harrison et al. [20] and Nontasil et al. [36] investigated the effects of ribbed stripe animations moving across the progress bar.

Notably, animations that move in the direction opposite to the bar's actual progression were found to shorten perceived time by approximately 11 percent compared to conventional animations.

These findings demonstrate that visual design choices in progress indicators, such as shape, motion, and animation patterns, can meaningfully alter the user's sense of elapsed time and overall experience during waiting periods.

2.2 Visual Motion and Peripheral Perception

Motion characteristics in visual stimuli have been shown to significantly affect both perceived waiting time and speed. A consistent finding in perceptual psychology is that faster motion leads to longer subjective time estimates. For example, studies by Brown et al. [7], Kaneko et al. [23], and Orgs et al. [39] demonstrate that visual motion speed has a strong impact on duration judgments, even when objective durations remain constant.

Tomassini et al. [56] further reported that both the direction and speed of visual motion influence perceived waiting time. Faster or more dynamic patterns tend to produce longer temporal estimates. Similarly, Allingham et al. [1] found that distortions in time perception caused by motion can occur even during passive observation.

Beyond the characteristics of motion itself, spatial aspects of the visual field also play a role in modulating time perception. The location of visual stimuli, especially whether they are presented within central or peripheral vision, has been shown to affect attentional processing and temporal evaluation. Rosenholtz [42] pointed out that peripheral vision, although less capable of fine detail recognition, is particularly sensitive to motion and the overall structure of a scene. This sensitivity makes it a potent yet underutilized channel for influencing perception without requiring focused attention.

Gavazzi et al. [17] showed that when the movement of visual stimuli aligns with natural human motor patterns, both the accuracy and precision of time estimation improve. This finding suggests that motion consistent with intuitive or embodied expectations may be more effective in altering subjective duration.

Despite these insights, only a limited number of studies have systematically examined how motion-based stimuli presented in peripheral vision affect perceived waiting time in interactive environments. Because peripheral motion tends to attract attention with minimal cognitive effort, it holds promise as an unobtrusive method of feedback in interface design. The present study seeks to explore this possibility by investigating how the spatial location of motion stimuli within peripheral vision influences users' perception of time.

2.3 Time Perception Beyond Vision: Auditory, Emotional, and Tactile Cues

While visual feedback has been extensively studied in the context of time perception, auditory and tactile modalities also play critical roles in shaping users' sense of temporal duration. These non-visual channels influence attention and arousal, both of which are known to modulate perceived time.

In the auditory domain, the tempo of music has been shown to significantly affect perceived waiting time, with faster tempos leading to longer subjective estimates of time [5, 10]. Additionally, younger adults have been found to overestimate durations more strongly in the auditory modality than in the visual one, indicating higher temporal sensitivity to sound [9].

Emotional content further amplifies these effects. Emotionally intense auditory or audiovisual stimuli have been reported to distort perceived time [13], with negative emotions such as fear or sadness particularly associated with lengthened time perception [14, 25, 37].

In the domain of tactile feedback, Tomassini et al.[56] demonstrated that perceived stimulus duration increases with stimulus speed, and that this trend is more pronounced for tactile stimuli than for visual ones. Francisco et al.[15]

further found that the amplitude of vibratory stimuli affects perceived waiting time; specifically, increasing amplitude makes participants more sensitive to temporal differences.

These findings suggest that in scenarios where visual attention is limited or already occupied, auditory and tactile feedback may serve as alternative or complementary channels for shaping perceived waiting time.

2.4 Peripheral and Non-focal Feedback in Interface Design

Cognitive load is a key factor affecting usability, and its reduction has been shown to improve user satisfaction in multiple studies [22, 43]. Recent research in human-computer interaction has increasingly focused on feedback presented outside the user's primary focus of attention as a means to enhance usability without increasing cognitive burden.

Ambient displays are a representative example of this approach. They convey system status or contextual information through subtle changes in color, motion, or light. When properly designed, ambient displays can inform users without interfering with their primary task, thus avoiding added cognitive load [46, 47]. Nagel et al. [33] conducted a systematic analysis of existing ambient lighting systems (ALS) and proposed design guidelines to inform future development. ALS aims to support peripheral awareness, enabling users to stay informed with minimal attentional resources.

However, several researchers have cautioned that overly dynamic or poorly designed feedback can lead to distraction [16, 49]. Furthermore, Rosenholtz [42] notes that although peripheral vision is highly sensitive to motion, it lacks the spatial resolution of central vision, thereby increasing the risk of visual overload.

While peripheral and non-central feedback techniques have shown promise for enhancing user experience, few studies have systematically examined their effects on perceived waiting time in interactive systems. This study investigates how motion-based peripheral visual feedback influences time perception in both PC and smartphone contexts.

3 OVERVIEW OF THE EXPERIMENTALS

This study investigates whether visual stimuli presented in the user's peripheral vision can shorten the perceived waiting time of centrally displayed progress indicators. To address this question, we designed and conducted three experiments that differ in objective, scale, and context.

- **Pilot Study** explores which peripheral motion patterns are most effective at reducing perceived waiting time, using a controlled laboratory setting.
- **Experiment 1** evaluates the generalizability of the findings from the Pilot Study through a large-scale online study with diverse participants.
- **Experiment 2** compares the effects of peripheral motion on time perception between PC and smartphone environments, considering differences in device interaction and field of view.

All experiments share a common structure and interface, which are described below. Specific modifications for each experiment are detailed in Sections 4–6.

3.1 Visual Stimuli

The goal is to examine whether the perceived waiting time of a progress bar displayed at the center of the screen can be influenced by presenting motion-based visual stimuli in the user's peripheral vision. Previous research has shown that peripheral visual information is processed unconsciously, allowing users to detect motion without actively attending to it [42]. Leveraging this characteristic, we aim to reduce perceived waiting time by introducing peripheral motion cues.

Fig. 1. Screen layout illustrating the central progress bar and peripheral motion patterns.

This method is designed for use during waiting or loading times in PC or smartphone interactions. As shown in Fig. 1, the central region of the screen displays the progress bar, while moving patterns are presented in peripheral areas. The intent is to subtly influence users' perception of time through peripheral visual motion.

3.2 Task and Procedure

Each trial proceeded as follows. First, a start screen was presented with a central circle (Fig. 2a). When the participant clicked on it, the display transitioned to the progress bar screen (Fig. 2b), during which peripheral motion patterns were shown depending on the condition. After the progress bar completed, the screen switched to a response screen (Fig. 2c), where participants reported their perceived waiting time using a slider ranging from 0 to 15 seconds in 0.1-second increments.

To prevent motion aftereffects [55], each trial ended with an interstitial video of about 10 seconds (Fig. 2d), selected randomly from a preset list. After the video, the system returned to the initial start screen for the next trial.

This sequence was repeated for all experimental conditions assigned to each participant. The specific conditions, motion patterns, and device settings varied by experiment and are described in detail in the following sections.

4 PILOT STUDY: IDENTIFYING EFFECTIVE PERIPHERAL MOTION PATTERNS

4.1 Objective

The purpose of this preliminary experiment was to identify effective peripheral visual motion patterns that could influence users' perceived waiting time when presented alongside a centrally displayed progress bar.

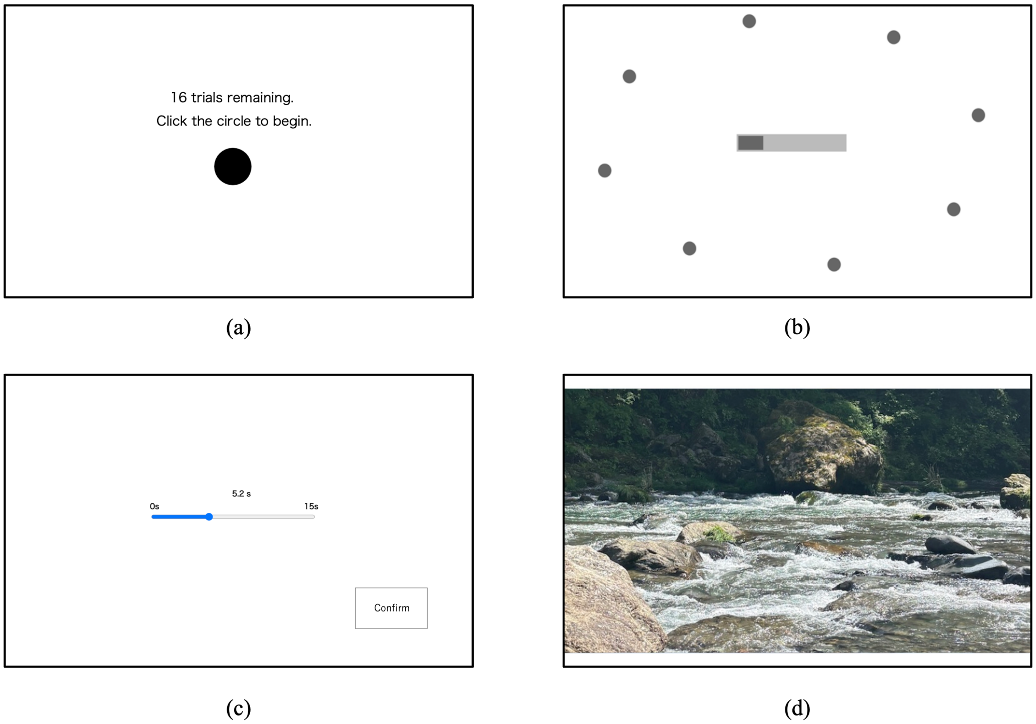


Fig. 2. Trial sequence: (a) Start screen with clickable circle; (b) Progress bar display with peripheral motion; (c) Duration estimation screen with slider; (d) Interstitial video to prevent carryover effects.

Hypothesis. We hypothesized that simple peripheral visual stimuli would reduce perceived waiting time compared to the baseline progress bar condition, and that directional or intermittent motion would be more effective than continuous or non-directional stimuli.

4.2 Conditions

Stimulus Patterns. Five stimulus patterns were prepared(Fig. 3), categorized as follows:

- **No stimulus (Baseline):**
  - A condition in which only a central progress bar was displayed.
- **Rotational motion:**
  - A light dot rotating clockwise along an elliptical path.
- **Horizontal motion:**
  - A light dot moving from left to right and reappearing from the left edge after exiting the right (intermittent).
- **Sinusoidal motion:**
  - A smooth sinusoidal wave moving continuously from left to right.
- **Global luminance change:**
  - A background color transition stimulus that gradually changed from white to black and back.

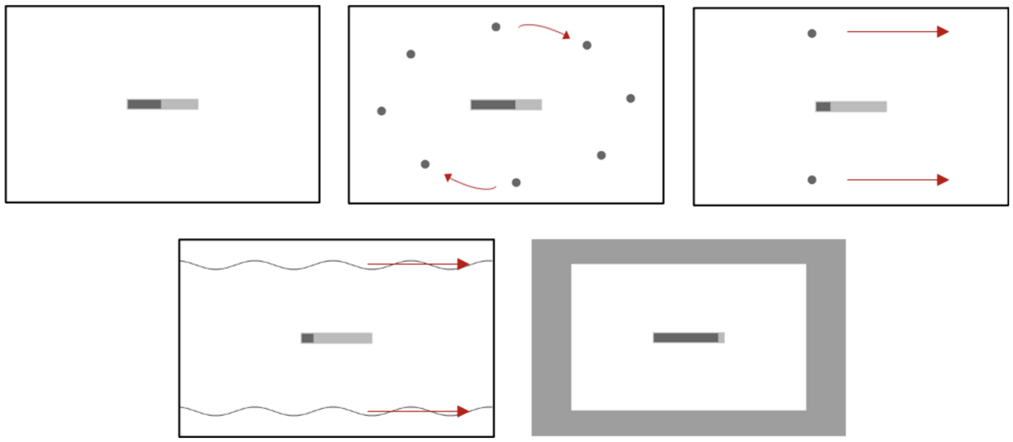


Fig. 3. Stimulus presentation patterns used in the Pilot Study. Arrows indicate direction of motion.

Time Conditions. Eleven time durations were used: 2 through 12 seconds in 1-second increments.

4.3 Response Method

Participants were asked to report the perceived waiting time using buttons labeled in 0.5-second increments from 0 to 15 seconds(Fig. 4). This resolution was chosen to support fine discrimination, especially for short durations.

4.4 Participants

Four participants (two male and two female) completed all stimulus and time conditions.

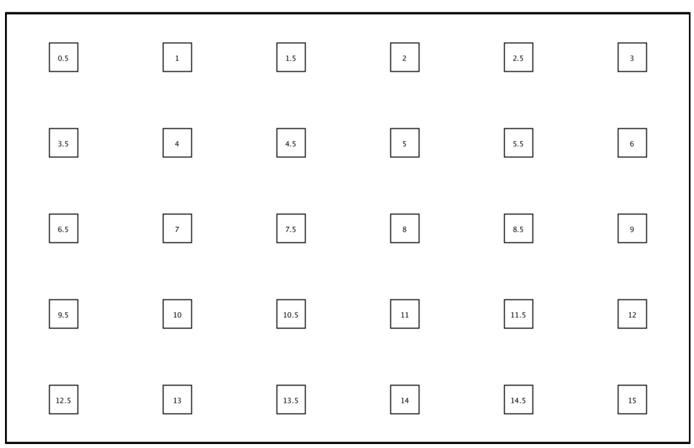


Fig. 4. Duration response interface in the Pilot Study. Participants selected a value in 0.5-second increments.

4.5 Results and Refinement for Main Study

The results showed that the perceived waiting time was the shortest under the condition where a light dot moved horizontally from left to right. This suggests that peripheral motion can indeed influence time perception. In contrast, participants commented that the background color transition condition produced excessive visual stimulation, causing users to shift their focus from the progress bar and leading to increased visual fatigue. Therefore, this stimulation condition was considered inappropriate for reliable evaluation and was excluded from further analysis.

We also evaluated practical considerations for running a large-scale online experiment. A large number of experimental conditions can overwhelm crowd workers and reduce data reliability. The 2–4 second conditions showed only minor differences between stimulus types compared to other duration conditions. Based on both empirical and practical grounds, we excluded the 2–4 second conditions from subsequent studies, as they were deemed less informative and less reliable for evaluation.

Participant feedback further revealed that the original button-based duration input was difficult to use, particularly for short durations. To improve precision and usability, we replaced the 0.5-second increment buttons with a slider interface offering 0.1-second resolution for the main experiments.

5 EXPERIMENT 1: LARGE-SCALE ONLINE EVALUATION OF TIME PERCEPTION

5.1 Objective

The objective of this experiment is to examine, via crowdsourcing, how presenting visual stimuli around a centrally displayed progress bar, either in the same direction or in the opposite direction of the bar's movement, affects users' perceived waiting time during short waits.

Hypothesis. We hypothesize that when visual stimuli move in the opposite direction to the progress bar, users perceive the bar as moving faster. As a result, the overall waiting time is felt to be shorter. This hypothesis is based on the findings of the Pilot Study and is supported by prior research on visual motion and time perception [3, 7, 23, 39].

5.2 Conditions

Stimulus Patterns. Many prior studies on directional visual stimuli have utilized sinusoidal gratings [41, 45, 51], we opted for sinusoidal wave stimuli due to their smoother appearance and reduced visual clutter, which helps prevent gaze shifts from the progress bar. Then, we prepared five stimulus patterns (Fig. 5) categorized as follows:

- **No stimulus (Baseline):**
  - A condition without any peripheral visual animation.
- **Rotational motion:**
  - Clockwise: A light dot rotating clockwise along an elliptical path (rotate_balls).
- **Horizontal motion:**
  - Left to right: A light dot moving horizontally from left to right (slide_balls).
- **Sinusoidal motion:**
  - Left to right: A sinusoidal wave moving from left to right (wave).
  - Right to left: A sinusoidal wave moving from right to left (wave_reverse). This was added based on findings from the Pilot Study to evaluate the influence of motion direction.

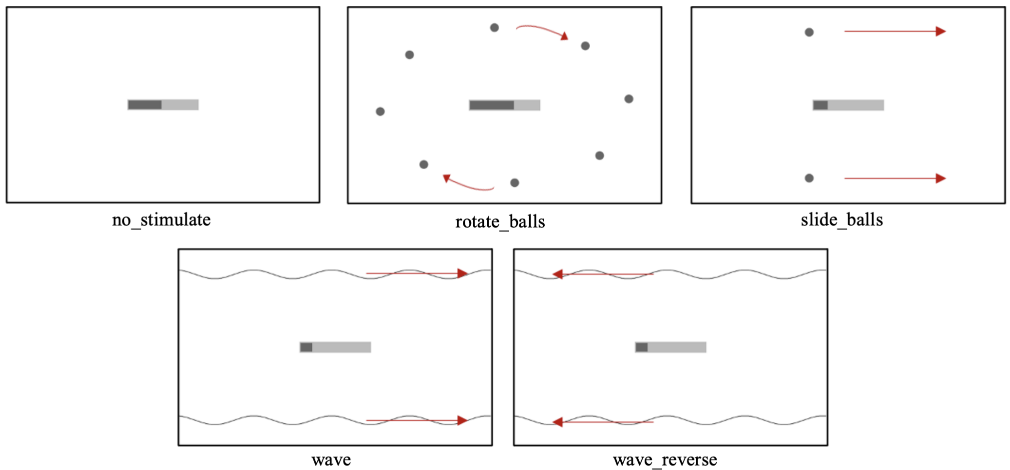


Fig. 5. List of stimulus presentation patterns used in the stimulus direction comparative experiment. Arrows indicate motion direction.

Stimulus Speed. The rotational speed of the elliptical stimulus was set to 2 radians per second, and the slide_balls stimulus was matched to this speed. For the wave and wave_reverse stimuli, the speed was aligned with the progress bar under the 8-second condition to avoid excessive visual intensity observed when matching the rotating dot's speed.

Time Conditions. We initially considered 11 time durations ranging from 2 to 12 seconds in 1-second increments, based on previous findings indicating that users are generally willing to wait about 2 seconds for web content to load and that visual feedback is recommended when the wait exceeds 1 second [29, 34, 35, 48].However, for the actual experiment, we selected eight durations—5 to 12 seconds in 1-second increments—based on the results of the Pilot Study, which showed limited discrimination in the 2–4 second range.

Assignment of Conditions. Each participant was randomly assigned two stimulus conditions: one being the baseline (progress bar only) and the other one of the four stimulus patterns. All participants completed 16 trials (2 conditions × 8 durations).

5.3 Crowdsourcing Implementation Strategies

In crowdsourced experiments, there is no experiment supervisor present, making it impossible to monitor participants directly. As a result, data collected through online platforms, including those using crowdsourcing, can be affected by inattentive or insincere responses [8, 12, 53]. To address these issues and improve data quality, various strategies have been proposed [4, 11, 31, 40].

Participant Screening. We rejected 901 workers based on their response patterns in previous crowdsourcing tasks we conducted on the same platform.

Instructions and Verification. Before starting the experiment, participants were shown a screen outlining procedures and precautions (Fig. 6). Proceeding to the experiment required checking all acknowledgment boxes. After the trials, they were directed to a follow-up questionnaire via Yahoo! Crowdsourcing, where they entered both their user ID and

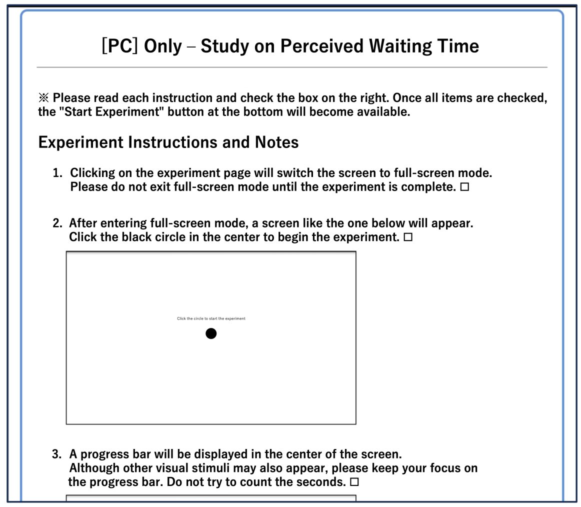


Fig. 6. Explanation screen listing procedures and precautions shown before the experiment.

the correct answer to a six-choice question shown at the end of the experiment. This step helped filter out users who did not complete the task properly.

Response Filtering. We also tracked the response time on the duration input screen and initialized the slider to 0 seconds. Submissions without moving the slider or with excessively long response times were flagged as inattentive and excluded from analysis.

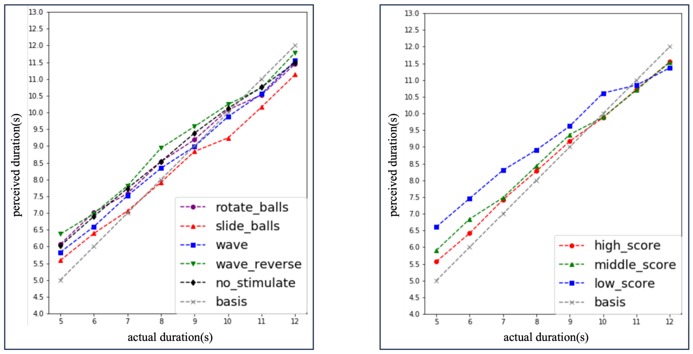
5.4 Results

We conducted an online experiment using Yahoo! Crowdsourcing, targeting 300 male and 300 female participants who accessed the system via PC. Prior to analysis, we excluded participants who submitted inappropriate responses. Specifically, the following criteria were used for exclusion:

- 18 participants who entered invalid user IDs,
- 49 participants who answered "0 seconds" as the perceived waiting time,
- 28 participants whose responses in the progress-bar-only condition deviated beyond the mean plus or minus two standard deviations,
- 107 participants whose response times on the duration input screen fell outside the mean plus or minus two standard deviations.

After filtering, data from 398 participants (203 male, 195 female) were included in the analysis.

To understand the general tendency of erceived waiting time across different stimulus conditions, we first conducted a holistic comparison across all presentation durations. Fig. 7a presents the average perceived waiting time (vertical axis) for each actual waiting time (horizontal axis), separated by stimulus condition. When focusing on the wave and wave_reverse conditions, we found that the left-to-right wave reduced perceived waiting time compared to the progress-bar-only condition. In contrast, the right-to-left wave increased perceived waiting time. Moreover, the slide_balls condition, in which the stimulus was presented intermittently, had a greater effect in shortening perceived waiting time



(a) (b)

Fig. 7. (a) Classification based on stimulus patterns across all trials. (b) Classification based on perceived waiting time in the absence of visual stimuli.

than the continuously presented rotate_balls and wave stimuli. Among the stimuli that moved in the same direction as the progress bar (slide_balls and wave), both showed stronger effects than rotate_balls. A one-way ANOVA revealed a significant difference in perceived waiting time among the stimulus patterns ($F(4, 6363) = 18.686$, $p < .001$, $\eta^2 \leq .008$). Pairwise comparisons with Tukey's p-value adjustment showed that the slide_balls stimulus resulted in significantly ($\alpha = 0.05$) shorter perceived waiting times than the no_stimulate, rotate_balls, wave, and wave_reverse conditions. Additionally, the wave_reverse condition was perceived as significantly longer than the rotate_balls condition. No other pairwise comparisons showed significant differences.

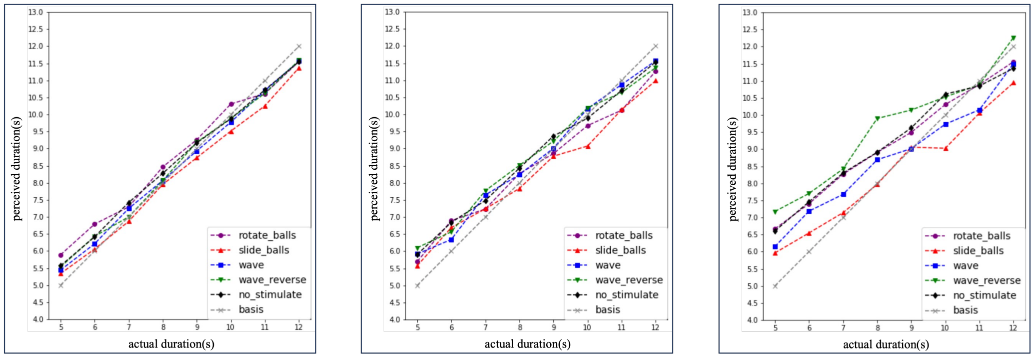
To account for individual differences in time perception, participants were grouped based on the accuracy of their duration estimation in the progress-bar-only condition. They were classified into three groups: high_score (highly accurate), middle_score (moderately accurate), and low_score (less accurate).

Fig. 7b shows the perceived waiting times under the no-stimulus condition for each group. The low_score group displayed particularly large deviations from actual waiting times in the shorter duration range (5 to 10 seconds). Contrary to our expectation that longer durations would lead to greater errors, shorter durations showed more pronounced deviations. The middle_score and high_score groups exhibited only minor differences for 10 to 12 seconds, though both showed some divergence in the 5 to 10 second range, similar to the low_score group.

Fig. 8a to c display results by stimulus condition for each accuracy group. The horizontal axis represents actual waiting time, while the vertical axis shows the average perceived waiting time.

In Fig. 8a, the high_score group appeared relatively unaffected by visual stimuli. While there was little difference between wave and wave_reverse, the slide_balls condition notably reduced perceived waiting time. In the middle_score group (Fig. 8b), slide_balls again consistently shortened perceived waiting time, except at the 6-second mark. The low_score group (Fig. 8c) showed a clearer contrast between wave and wave_reverse than the high_score group. Overall, the data suggest that participants with less accurate baseline time perception were more affected by the presence of visual stimuli.

Interestingly, these results contradict our original hypothesis, which predicted that stimuli moving in the opposite direction of the progress bar would shorten perceived waiting time. Instead, the opposite pattern was observed: stimuli moving in the same direction, particularly the slide_balls condition, led to shorter perceived waiting times. This suggests



(a) (b) (c)

Fig. 8. Classification results based on perceived waiting time across all data. (a) High-score group. (b) Middle-score group. (c) Low-score group.

that visual congruency between central and peripheral motion may play a more important role than directional conflict in shaping users' time perception.

5.5 Discussion

From the results in Fig. 7a, we infer that visual stimuli moving in the same direction as the progress bar tend to shorten perceived waiting time, whereas stimuli moving in the opposite direction tend to increase it. These results contradict our initial hypothesis, indicating the need to further investigate the relationship between perceived speed and time perception. One possible explanation is that the impression of the visual stimulus alone had a stronger influence on perceived duration than the discrepancy between the progress bar and the stimulus speed. Alternatively, as suggested in previous studies[56], the increased perceived speed of the progress bar may have led to a longer perceived duration. Furthermore, intermittent stimuli had a stronger effect than continuous ones. The fact that the slide_balls condition significantly reduced perceived waiting time compared to other conditions supports these results. However, because certain combinations, such as intermittent stimuli presented in the opposite direction of the progress bar, have not been tested, further investigation is necessary.Future studies could optimize the speed and intensity of these visual stimuli to achieve greater reductions in perceived waiting time.

The results in Fig. 7b show that users with greater deviations in time estimation tend to have difficulty evaluating waiting durations in the range of 5 to 10 seconds. Therefore, by focusing on shorter durations in future investigations, it may be possible to effectively reduce users' perceived waiting time.

As illustrated in Fig. 8a through 8c, the slide_balls stimulus consistently reduced perceived waiting time across all user groups. Notably, participants in the low_score group exhibited the greatest reduction compared to other visual stimuli, suggesting a strong effect. These findings imply that the slide_balls condition was the most effective in creating a subjective shortening of waiting time.

Moreover, a comparison of the group-level trends indicates that the lower a user's accuracy in the progress-bar-only condition, the more susceptible they were to visual manipulation. In particular, participants in the low_score group showed large shifts in perceived waiting time depending on the presence or absence of visual stimuli. This suggests that such stimuli may not only help mitigate stress during waiting periods but could also be applied to extend perceived waiting time in enjoyable experiences, thereby enhancing overall user satisfaction.

6 EXPERIMENT 2: DEVICE-BASED COMPARISON BETWEEN PC AND SMARTPHONE

6.1 Objective

This experiment compares how peripheral visual stimuli presented alongside a centrally located progress bar affect perceived waiting time on PC and smartphone devices.

Unlike the previous large-scale crowdsourcing experiment, this study was conducted in a controlled, face-to-face setting, ensuring a uniform presentation environment across both devices. To ensure fair comparisons, all stimulus pattern properties were standardized before testing their effects.

Hypotheses. We hypothesized that users would experience more stress during waiting on smartphones due to the smaller screen size, and that the effectiveness of peripheral stimuli in reducing perceived waiting time would be greater on PCs than on smartphones. We also hypothesized that horizontally moving visual stimuli would be more effective on PCs with landscape orientation, while vertically moving stimuli would be more effective on smartphones with portrait orientation.

6.2 Conditions

Stimulus Patterns. Six stimulus patterns were prepared: two horizontal, two vertical, and two rotational types, in addition to a baseline condition with no stimulus. These patterns are illustrated in Fig. 9. For all conditions except the baseline, eight light points were displayed to maintain uniform stimulus intensity across conditions. Each pattern included three conditions: a positive direction, a negative direction, and a no-stimulus control. Specifically, rightward, downward, and clockwise motions were categorized as positive; leftward, upward, and counterclockwise motions as negative.

Time Conditions. Waiting durations were set from 5 to 12 seconds in 1-second increments, resulting in eight time conditions: 5, 6, 7, 8, 9, 10, 11, and 12 seconds.

Assignment of Conditions. Each participant was randomly assigned to one of the three stimulus pattern types (horizontal, vertical, rotational) and completed 24 trials (3 stimulus directions × 8 durations) for each device type. All participants experienced both the PC and smartphone conditions, with the order of device usage counterbalanced. A five-minute break was provided between the two sessions.

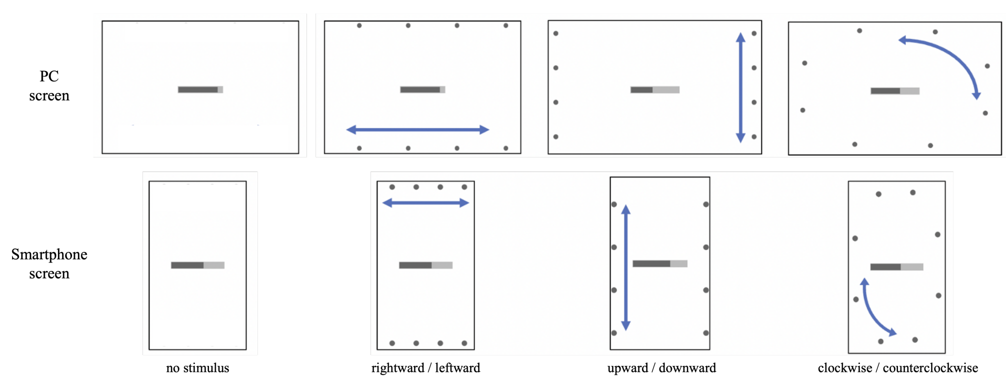


Fig. 9. List of stimulus presentation patterns in cross-device comparative experiment.

6.3 Design of Visual Stimuli

Device Setup. A MacBook Pro with a 14-inch screen was used for the PC condition, and an iPhone 11 with a 6.1-inch screen was used for the smartphone condition.

Stimulus Patterns. To examine the influence of motion direction on perceived waiting time, we designed three categories of peripheral visual stimuli: horizontal, vertical, and rotational motion. Each category included a condition where the motion direction was positive, another where it was negative, and a baseline condition with no peripheral stimulus. All stimulus pattern conditions included eight moving light dots to ensure a consistent level of visual intensity. The details of each stimulus category are as follows:

- **Horizontal motion:** In this condition, light dots moved along the horizontal axis across the screen.
  - **Positive direction (rightward):** Dots entered from the left side of the screen and moved toward the right, which is consistent with the direction in which progress bars usually advance.
  - **Negative direction (leftward):** Dots entered from the right and moved toward the left, creating a motion opposite to the progress bar's perceived movement.
  - **Baseline:** Only the progress bar was presented, with no peripheral motion.
- **Vertical motion:** In this condition, dots moved vertically across the screen.
  - **Positive direction (downward):** Dots appeared at the top and moved downward, resembling natural gravitational movement.
  - **Negative direction (upward):** Dots rose from the bottom of the screen toward the top.
  - **Baseline:** No peripheral stimulus pattern was presented.
- **Rotational motion:** Light dots moved along an elliptical path centered around the progress bar.
  - **Positive direction (clockwise):** Dots rotated clockwise along the elliptical trajectory.
  - **Negative direction (counterclockwise):** Dots rotated counterclockwise.
  - **Baseline:** The progress bar was presented by itself.

This structure allowed us to systematically compare the effects of motion direction across different stimulus patterns and device environments, while keeping the visual load consistent across conditions.

Stimulus Density Control. Perceptual psychology studies on the filled-duration illusion suggest that higher stimulus pattern density tends to increase perceived waiting time [30, 54, 59, 60]. To equalize the stimulus pattern load across devices with different screen sizes and resolutions, we did not match pixel speeds. Instead, we adjusted the number of stimuli passing through the screen per second. In both the horizontal and vertical stimulus conditions, 28 light dots passed through each side of the screen over a 12-second period, resulting in a total of 56 dots. In the elliptical motion condition, 28 light dots passed through a specific angular position during the same duration. These settings correspond to a speed of 7d/12 cm/s in the horizontal and vertical conditions (assuming the stimulus travels a distance d), and approximately 1.8 radians per second in the elliptical motion condition.

6.4 Participants

A face-to-face experiment was conducted with 30 participants (22 males, 8 females). Participants were evenly assigned to one of the three stimulus categories: horizontal, vertical, and rotational motion, with each category having 10 participants. Within each category, five participants started the experiment on a PC and five on a smartphone. To reduce individual differences in baseline time perception, the data were normalized so that the average perceived waiting time for each participant matched the actual waiting time.

6.5 Results

Fig. 10 presents the average perceived waiting times for each stimulus condition, comparing PC and smartphone environments. The horizontal axis represents the actual waiting time, while the vertical axis indicates the perceived waiting time. A gray reference line shows where the perceived waiting time equals the actual waiting time. Fig. 10a shows results under the no-stimulus condition. Across both devices, there was no significant difference in perceived waiting time. In shorter durations from 5 to 9 seconds, participants tended to overestimate the wait. In contrast, for durations from 10 to 12 seconds, their perception closely matched the actual duration. On average, perceived waiting time was 0.15 seconds longer on the PC and 0.19 seconds longer on the smartphone compared to the actual waiting time. Fig. 10b and 10c display results under horizontal motion conditions. perceived waiting times were similar between devices, with both showing a slight underestimation of duration for 10 to 12 second trials. Fig. 10d and 10e focus on vertical motion stimuli. On smartphones, perceived waiting time was consistently shorter than actual time for both upward and downward motions. On PCs, downward motion also reduced perceived waiting time, but upward motion had little effect. Fig.s 10f and 10g show the results for rotational stimuli. In the 10 to 12 second range, perceived waiting time was shorter than the actual duration regardless of device or rotation direction. For clockwise motion, this effect was more pronounced on the PC. For counterclockwise motion, it was stronger on the smartphone. Separate two-way repeated-measures ANOVAs were conducted for each motion condition (horizontal, vertical, and rotational), with stimulus pattern (stimulus A, stimulus B, no stimulation) and device type (PC vs. smartphone) as within-subjects factors. Across all motion conditions, no significant main effects of stimulus pattern were found (all $F(2,474) \leq 1.26$, all $p \geq .29$, all $\eta^2 \leq .005$), nor were there significant main effects of device type (all $F(1,474) \leq 0.71$, all $p \geq .40$, all $\eta^2 \leq .001$).

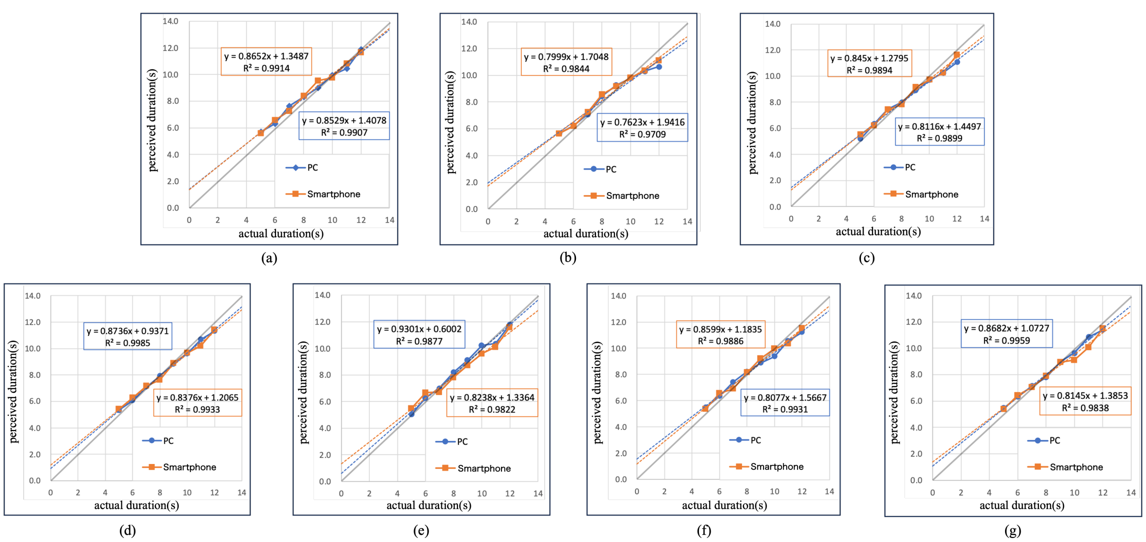


Fig. 10. Classification results based on device type across seven stimulus patterns. (a) no stimulus group. (b) rightward group. (c) leftward group. (d) upward group.(e) downward group. (f) clockwise group. (g) counterclockwise group.

Table 1. Proportion of perceived waiting time relative to the actual waiting time for short and long durations on each device.

	rightward	leftward	upward	downward	clockwise	counterclockwise	average
PC (short durations)	1.059	1.039	1.021	1.021	1.058	1.035	1.039
PC (long durations)	0.957	0.951	0.964	0.990	0.954	0.974	0.965
Smartphone (short durations)	1.063	1.044	1.025	1.037	1.041	1.037	1.041
Smartphone (long durations)	0.964	0.972	0.958	0.953	0.979	0.946	0.962

Table 2. Proportion relative to the perceived waiting time under the no-stimulus condition for each device.

	rightward	leftward	downward	upward	clockwise	counterclockwise	average
PC	0.966	0.953	0.971	0.983	0.977	0.975	0.971
Smartphone	0.991	0.986	0.943	0.947	0.978	0.959	0.968

Table 3. Proportion relative to the perceived waiting time under the no-stimulus condition for the first and second trials.

	rightward	leftward	downward	upward	clockwise	counterclockwise	average
PC (1st trial)	0.948	0.941	1.001	1.026	0.983	0.982	0.980
PC (2nd trial)	0.994	0.972	0.951	0.955	0.970	0.968	0.969
Smartphone (1st trial)	0.992	0.988	0.960	0.942	0.997	0.991	0.978
Smartphone (2nd trial)	0.991	0.984	0.972	0.985	0.959	0.929	0.970

Interaction effects between stimulus pattern and device type were also non-significant in all cases (all $F(2, 474) \leq 0.26$, all $p \geq .77$, all $\eta^2 \leq .001$).

Table 1 summarizes the ratio of perceived waiting time to actual waiting time, separated into short durations (5 to 8 seconds) and long durations (9 to 12 seconds). These results indicate that short waits are typically overestimated and long waits underestimated. While short-duration perception was consistent across devices, longer durations showed device-dependent differences: the PC yielded shorter perceived waiting times for leftward and clockwise motions, while the smartphone showed stronger effects for upward and counterclockwise motions.

Table 2 compares the perceived waiting times under each stimulus condition to those under the no-stimulus condition. In all cases, perceived waiting times were shorter than the baseline. Specifically, horizontal motion reduced perceived waiting time by 2.5 to 3.3 percent more on PCs. Vertical motion was more effective on smartphones, reducing duration by 2.8 to 3.6 percent compared to PCs. These results support the hypothesis that horizontal motion is more effective on PCs and vertical motion more effective on smartphones. Paired-sample t-tests were conducted to compare the difference scores (stimulus − *no_stimulate*) between PC and smartphone conditions for each stimulus pattern. However, no significant differences were observed in any condition (all $t(9) \leq 1.30$, all $p \geq .23$, all $d \leq .44$).

In the case of rotational stimuli, no difference was found between devices for clockwise motion. However, counterclockwise motion was 1.6 percent more effective in reducing perceived waiting time on the smartphone.

To examine the effect of trial order, participants were grouped by whether they used a PC or smartphone first. Table 3 shows the ratios of perceived to actual duration for each group. For participants who used the PC first, horizontal stimuli had a stronger time-reducing effect. For those who used the smartphone first, vertical stimuli were more effective.

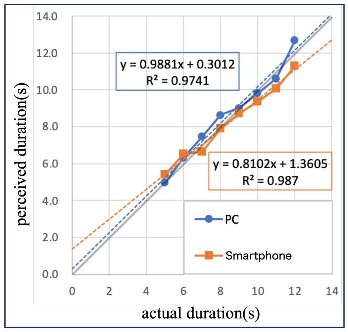


Fig. 11. perceived waiting times on the first trial of the upward stimulus pattern condition, shown separately for PC and smartphone devices.

Fig. 11 shows that, in the upward motion condition, perceived waiting time was shorter on smartphones in the first trial, but this effect weakened in the second trial. In contrast, other stimulus patterns gained effectiveness in the second trial.

6.6 Discussion

Fig. 10a shows that the perceived waiting times across time conditions were similar between the PC and smartphone. On average, perceived waiting time was 0.15 seconds longer than the actual time on the PC and 0.19 seconds longer on the smartphone. These results indicate that, in the absence of visual stimuli, the device type alone does not substantially affect users' perception of waiting time.

Furthermore, as illustrated in Fig. 10 and summarized in Table 1, a consistent pattern emerged across all stimulus conditions. For shorter waiting times between 5 and 8 seconds, participants tended to overestimate the duration, while for longer waiting times between 9 and 12 seconds, they generally underestimated it. This suggests that breaking down time conditions into finer increments enables a more detailed investigation of perceived waiting time.

Table 2 indicates that all stimulus pattern conditions resulted in shorter perceived waiting times than the no-stimulus baseline. This supports the conclusion that peripheral visual stimuli around a central progress bar can effectively reduce perceived waiting time on both PCs and smartphones, regardless of the specific stimulus pattern. When comparing devices, horizontal motion stimuli such as rightward and leftward movement were particularly effective on PCs, reducing perceived waiting time by approximately 2.5 to 3.3 percent relative to the no-stimulus condition. This corresponds to a reduction of about 0.21 to 0.28 seconds. On smartphones, vertical motion stimuli such as downward and upward movement produced stronger effects, reducing perceived waiting time by approximately 2.8 to 3.6 percent, or roughly 0.23 to 0.30 seconds. These results support the hypothesis that horizontal stimuli are more effective on PCs, while vertical stimuli are more effective on smartphones. However, since Tukey's post-hoc multiple comparisons revealed no significant differences between any of the stimulus patterns, caution is needed in interpreting these results. In addition, Table 2 reveals that the direction of motion, such as left versus right or up versus down, had only a small impact on the effectiveness of the stimulus. The differences in perceived waiting time between positive and negative directions were relatively minor, ranging from 0.03 to 0.16 seconds. This suggests that the orientation of motion, rather than its polarity, plays a more critical role in modulating perceived waiting time.

Analysis of trial order effects in Table 3 indicates that the effectiveness of visual stimuli was influenced by whether the PC or smartphone was used first. On PCs, the horizontal motion condition led to the largest reduction in perceived waiting time during the first session, but this effect weakened in the second session, where other stimulus conditions had a stronger impact. On smartphones, vertical motion was the most effective in the first session, with a similar trend of reduced effect in the second session. These results suggest that exposure to the first set of conditions may influence participants' perception in the second session, possibly due to the formation of duration expectations.

To mitigate such carryover effects in future experiments, it may be beneficial to conduct both sessions on the same device or to assign different sets of waiting time conditions to the first and second sessions. This would help control for memory-based bias and isolate the true impact of stimulus direction and device type on perceived waiting time.

7 GENERAL DISCUSSION

This section discusses how peripheral visual motion influences users' perception of waiting time, based on three experiments that examined motion type, direction, and device context. Building on these findings, we consider their theoretical implications, practical applications, and limitations, and propose directions for future research.

7.1 Interpretation and Integration

Together, the three experiments indicate that peripheral visual motion can serve as a subtle but effective means of modulating perceived wait time. While the effectiveness of such stimuli may depend on the alignment of motion direction and display format (e.g., screen aspect ratio or orientation), the presence of motion alone—regardless of its direction—generally contributes to a reduction in perceived waiting time compared to no-stimulus conditions.

Moreover, the results from Experiment 2 suggest that users' perception adapts over repeated exposure, as the effects of certain stimuli diminished during the second trial. This finding implies a potential habituation effect, where the novelty of the stimulus wears off, thus reducing its influence on perceived time. Designers should therefore consider introducing variability or adaptive features in visual feedback to maintain its effectiveness over time.

7.2 Implications for Design

Our findings offer several practical implications for interface and UX designers. First, incorporating peripheral visual motion can improve user experience during short waiting periods by making time feel shorter. Second, designers should consider aligning the direction of motion with the orientation of the device, such as using horizontal motion for PCs and vertical motion for smartphones. Lastly, the diminishing effect observed in repeated exposures highlights the need for dynamic or varied feedback mechanisms in longer-term or multi-step interactions.

7.3 Limitations

Although we employed both controlled laboratory settings and large-scale crowdsourcing, several limitations should be acknowledged.

First, gaze direction was not verified despite instructions to fixate on the central progress bar. Since visual attention plays a critical role in time perception, it remains unclear whether participants truly processed the peripheral stimuli as intended. Future experiments should integrate eye-tracking to confirm whether participants are maintaining central fixation or being drawn toward peripheral motion.

Second, while outlier responses were excluded, the reliability of the high_score and low_score groups remains uncertain. The middle_score group, less likely to include extreme behaviors, may offer the most stable data. In addition, our participant samples may have been subject to demographic or behavioral biases. For example, the lab-based experiments involved a relatively small and homogeneous group, while the crowdsourced sample was limited to users of a specific platform. These factors may affect the generalizability of the findings. Future studies should consider recruiting more diverse populations and accounting for individual traits such as age, visual sensitivity, or cultural background.

Third, stimulus speed was designed based on the filled-duration illusion, but actual perceived motion intensity may have varied across devices due to differences in resolution and display size. Refining stimulus design to equalize perceived speed across platforms remains a challenge.

Finally, device affordances may have influenced attentional focus. On PCs, multitasking is common, whereas smartphones typically constrain user attention. To improve ecological validity, future experiments should simulate concurrent activities that reflect real-world usage.

7.4 Future Directions

Future studies should explore multimodal stimuli by combining visual motion with auditory or haptic feedback. It is also important to investigate stimulus habituation over time, perhaps through longitudinal designs. Moreover, the integration of peripheral motion with changes in the progress bar itself, including modifications to its speed, shape, or path, could reveal novel ways of modulating perceived wait time. Cultural and demographic factors may also play a role and merit further exploration.

8 CONCLUSION

This study investigated how peripheral visual stimuli presented alongside centrally displayed progress bars influence users' perceived waiting time. Through a series of experiments conducted in both online and controlled environments, we explored the effects of stimulus pattern, motion direction, and device type on temporal perception.

In the Pilot Study, we found that intermittent motion stimuli—such as discrete moving light dots—were more effective in reducing perceived waiting time than continuous motion stimuli, such as rotating or wave-based motion.

Experiment 1, conducted as a large-scale online study, demonstrated that the direction of motion plays an important role in shaping perceived time. Visual stimuli moving in the same direction as the progress bar had a greater impact in shortening perceived waiting time. This experiment also confirmed that intermittent motion stimuli were effective in reducing perceived waiting time.

In Experiment 2, we compared the effects of identical visual stimuli across two device types: PCs and smartphones. Results indicated that the effectiveness of peripheral visual stimuli varies depending on screen orientation and form factor. Horizontal motion was more effective on PCs, while vertical motion was more effective on smartphones. Furthermore, repeated exposure to the stimuli diminished their effects, suggesting that adaptation or expectation may influence user perception over time.

Taken together, our findings highlight the potential of combining peripheral visual motion with progress indicators to modulate users' perception of time during waiting periods. These insights can inform the design of user interfaces aimed at reducing perceived delays and enhancing overall user experience.

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