Effects of Location and Fade-In Time of (Audio-)Visual Cues on Response Times and Success-Rates in a Dual-Task Experiment

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ABSTRACT

While performing multiple competing tasks at the same time, e.g., when driving, assistant systems can be used to create cues to direct attention towards required information. However, poorly designed cues will interrupt or annoy users and affect their performance. Therefore, we aim to identify cues that are not missed and trigger a quick reaction without changing the primary task performance. We conducted a dual-task experiment in an anechoic chamber with LED-based stimuli that faded in or turned on abruptly and were placed in the periphery or front of a subject. Additionally, a white noise sound was triggered in a third of the trials. The primary task was to react to visual stimuli placed on a screen in front. We observed significant effects on the response times in the screen task when adding sound. Further, participants responded faster to LED stimuli when they faded in.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; *Laboratory experiments*; *Interaction devices*;

KEYWORDS

Audio-Visual Stimuli; Peripheral Display; Dual Task Experiment; Reaction Time; Error Rate; LED; Fade-In Time; Spatial Location; Linear Mixed Models.

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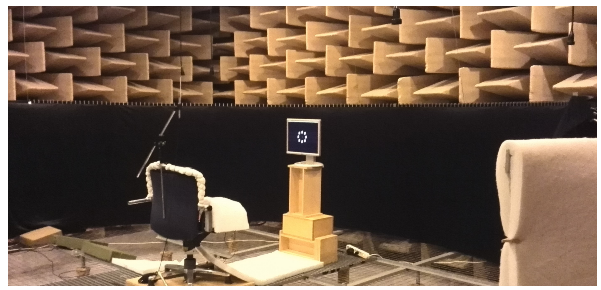

Figure 1: The anechoic chamber and experimental setup: a half spherical loudspeaker array with LEDs placed above and a 15" monitor in front. During the experiment, the ambient light was reduced to 15 Lux.

1 MOTIVATION

Whenever a person is focused on a primary task, it is important to not distract her to not negatively impact the performance. However, depending on the urgency of an information, cues may also need to attract the attention and must not be missed. Example situations range from notifications about status updates in social networks while writing a paper to blind-spot warnings while driving.

According to [Matthews et al. 2004], peripheral displays can be used to inform users with varying levels of urgency. However, there is no clear definition of which cue parameters contribute to perceiving it as urgent. Related works are either specific for a domain or a modality. For example, in [Politis et al. 2013] the authors investigated how combinations of auditory, visual, or haptic cues affect the perceived urgency and annoyance. In [Matviienko et al. 2015] ambient light patterns were analyzed and design guidelines for various situations were derived. Best practices can be derived from works using peripheral displays, such as works using auditory [Kerdegari et al. 2016], tactile [Kaul and Rohs 2017], visual [Gutwin et al. 2017] or multi-modal cues [Ebrahimi et al. 2016]. These kinds of displays can also be used to shift attention. In [Booth et al. 2013] projected visual cues were used to shift the attention towards them. In [Tscharn et al. 2016] it was found that participants' gaze was drawn towards the side that was more illuminated by the ambient light, even though they did not notice it. Visual cues were also tested as pop-out effects in [Gutwin et al. 2017]. Motion was found to strongly contribute to this effect and that a higher visual angle impacted the localization accuracy negatively. In [Bailey et al. 2009], Subtle Gaze Directions (SGD) was presented. The attention was shifted to an area in a digital image by image-space modulation. The saccadic velocity was monitored and the modulation was stopped before it entered the observer's foveal vision. In [Bailey et al. 2012] Bailey et al. investigated the impact of SGD on short-term spatial information recall. Using SGD significantly improved the accuracy of target count and spatial location recall. High-frequency flicker to guide the user's attention in an image was explored in [Waldin et al. 2017]. The flicker was easy to locate, when it was in the peripheral field of vision, but was distracting when the focus was on another region. Additionally, it was hardly noticeable when looking at it.

What is missing are guidelines for multi-modal displays which show information at different levels of urgency while multitasking. Towards this goal, we explored how a person's performance in a dual-task experiment is affected by location, fade-in time, and noise. Our analysis may help to design cues for a dual-task environment. Further, our experimental setup can be applied in future research.

2 EXPERIMENT

A variety of modalities can be used to design cues in a multitasking setup, like observing the traffic while following navigation instructions. We decided to use ambient light and sound as a starting point for our research. While the impact of auditory and visual cues on response times (RTs) are well researched in general, not much research has been done to investigate the effect of different parameters of light on RTs in a dual-task setup. Furthermore, these modalities are interesting because they are commonly used in assistant systems to assist in multitasking situations. We varied the dimensions location and fade-in time of the light cues and if a noise is activated along with it. We did informal pretests to decide which parameters to use per dimension and will use the results of this experiment to decide which parameters to explore in the future. For this experiment, our expectations are that:

(1) Screen RTs and error-rates will increase when a noise is played.
(2) LED RTs will decrease with noise because multi-modal cues trigger faster responses than unimodal (e.g. [Politis et al. 2013]).
(3) Peripheral LED stimuli will be missed more often and their RTs will increase because the participant's focus will be on the screen in the center and thus stimuli will be harder to perceive.
(4) LED RTs will decrease with fade-in because the stimulus is first noticed when it has a sufficiently high brightness.

2.1 Experimental Setup

The experiment took place in an anechoic chamber (see Fig. 1). The setup consists of a 180° semi-circular arrangement of LEDs and speakers at a distance of 265cm to a participant. In our experiment, the ambient light was dimmed to 15 Lux on average. A 15" monitor was placed in front of the subject with a viewing distance of 126cm. A numeric keypad with labeled keys served as an input device.

2.2 Presented Stimuli

In [Lavie and Fockert 2003], the effects of perceptual load and target-stimulus degradation on distractor processing were analyzed. In three experiments, different stimuli were presented as high-perceptual-load tasks and low-perceptual-load tasks. We decided to adapt the high-perceptual-load tasks for our *screen task (ScrT)* to mimic a high-load situation as given for example in driving. The

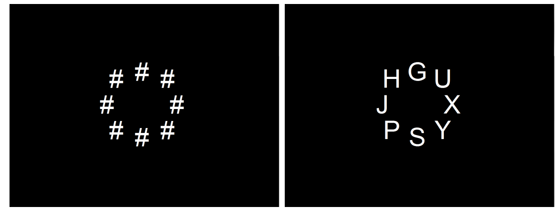

Figure 2: Left: The fixation display with hashes, shown for 1000ms. Right: The display with a target ('X') and distractors, shown for 200ms.

stimuli were presented on the monitor. As shown in Fig. 2, each display consists of eight circularly arranged letters with a diameter of 17 cm. Seven letters are distractors and one letter is the target letter. All letters are placed randomly at one of the eight locations.

The LED display was used to present light cues in the *LED task (LedT)*. The light cues were presented in dark blue (RGB (0,0,32)). We chose to use a linear fade-in time of 0ms, i.e. along with the onset of the letters on the screen, or 800ms. The 800ms were chosen because we wanted to have a very quick fade-in which is still recognized as such and not as an abrupt change. The lights were located at three possible locations: close to the center, or in the mid-peripheral field of view at 45° towards the left or right. This area was chosen because it is outside of the area that is scanned to perform the *ScrT*. Also, it is still perceivable with both eyes and a common location for assistant systems using light, such as blind-spot warning systems. The lights stayed activated until the end of a trial.

In 33% of the trials, and only if the lights were off or turned on abruptly, an additive Gaussian white noise with 200ms length was played on the speaker in front along with the *ScrT*. It was also played in a third of the trials without lights to check if participants regularly react to the noise instead of the light cue. We decided for this sound because the pretests showed that it would be hard to ignore but not annoy participants during the experiment.

2.3 Procedure

The experiment was structured into a training block and four test blocks. The training block consisted of a few trials to make sure that the tasks were understood. Participants were asked to place their fingers above the keypad and respond as quickly as possible. Additionally, they were instructed to ignore the noise and to respond to the *LedT* first, to reduce variance in the measures that were caused by variations in the response order. Each block contained 72 trials of which a third (24) included LED stimuli. Also, across both groups, one-third (24) of the trials included noise. All trials were randomized per block and participant. A trial began with the presentation of a black screen for 2-3s. Subsequently, eight hashes (see Fig. 2) were shown for 1s. The letters for the *ScrT* were then presented for 200ms. Participants had then 4 seconds to indicate which one of the target letters 'N' or 'X' they saw by pressing the corresponding key. Only one of the letters was shown per trial. To perform the *LED task*, participants had to press the corresponding key when they detected an LED stimulus. The blocks took about 10 minutes each with breaks of 5 minutes. Overall, each participant conducted 288 trials of which 96 included LED stimuli in about 60 minutes. The number of valid trials is given as 'N' in Table 1.

Table 1: Response times in seconds, the ratio of correct responses in percent ('C') and the ratio of perceived LED cues in percent ('R'). 'Mdn' is the median RT, 'IQR' its interquartile range and 'N' the number of measures.

	Screen Task (ScrT)				LED Task (LedT)			
Noise, Fading, Angle	*Mdn*	*IQR*	*C*	*N*	*Mdn*	*IQR*	*R*	*N*
off, abrupt, center	1.139	.657	72.9	280	.838	.428	99.7	287
off, abrupt, left	**1.098**	.675	69.7	142	.831	.427	100	144
off, abrupt, right	1.113	.555	**81.9**	144	**.781**	.445	100	144
off, 800ms, center	1.116	.590	69.4	278	.807	.391	**97.6**	281
off, 800ms, left	1.107	.704	**66.2**	142	.806	.335	99.3	143
off, 800ms, right	1.125	.651	77.1	144	.800	.457	100	144
on, abrupt, center	1.159	.667	7.9	282	.848	.432	100	288
on, abrupt, left	**1.236**	.763	71.6	141	**.859**	.438	100	144
on, abrupt, right	1.170	.714	67.4	141	.807	.363	100	144
All without lights	**.886**	.468	**79.3**	3329	-	-	-	-
All with lights	1.128	.662	71.7	1694	.822	.417	99.5	1719

2.4 Participants

20 healthy volunteers with normal or corrected vision and hearing abilities participated in the experiment. We excluded two datasets because of faulty recordings. The final sample consisted of 18 participants (10 female) with an age of 23-30 years ($M = 26.16$, $SD = 2.50$).

3 RESULTS

We removed the responses for the *ScrT*, if participants answered before the cue. Responses were removed for both tasks if a participant pressed the key for the *LedT* when there was no light cue. 161 measures (3.1%) for the *ScrT* were removed, because of these filters. Nine times (.2%) participants did not respond in the *LedT*.

We analyzed the effects with generalized linear mixed models (GLMMs) using R, version 3.3.3, and the lme4 package, version 1.3-13. We considered four fixed effects: (1) "horizontal angle" with the levels "center", "left" and "right", (2) "fade-in" with "abrupt" and "800ms", (3) "noise" with "off" and "on" and (4) "trial-number" which increases for every trial per participant and ranges from .003 (first trial) to 1 (288th trial). "Subject" was defined a random effect in all models. We fitted all possible variations of a model with maximum likelihood and selected the one with the lowest Akaike Information Criterion (AIC). The differences between the AIC of compared models are reported as $AIC_\Delta = abs(AIC_a - AIC_b)$. We removed factors of the best model and compared this reduced model to it using likelihood ratio tests to check if the factors had a significant impact. The model was then compared against the baseline model without fixed effects and "subject" as random effect to test if the included factors had a significant impact.

3.1 Responses Without LED Stimuli

RTs in the *ScrT* increased by 242ms when lights were active. This indicates that participants responded first to the *LedT*, following the instructions they received. The ratio of correct responses decreased from 79.3% to 71.7%, indicating that the *LedT* is distracting. We did not further analyze these differences, because the measures without *LedT* serve as a baseline and were added to check for participants who would randomly press buttons without reacting to the cues.

Table 2: The best fitted models for RTs of *ScrT* and *LedT* as well as the correct answer in *ScrT*. They were tested against reduced models without a given factor and the baseline model. Intercepts and coefficients are displayed in italic. Differences in AIC are given as AIC_Δ. Results of likelihood tests are given with χ^2 and p.

ScrT RT: $.178 - .077t + .043n_{\text{on}}$	
without trial-number (t)	$AIC_\Delta = 7$, $\chi^2(1) = 9.015$, $p < .01^{**}$
without noise (n)	$AIC_\Delta = 6$,$\chi^2(1) = 7.601$, $p < .01^{**}$
baseline	$AIC_\Delta = 12$, $\chi^2(2) = 16.413$, $p < .001^{***}$
LedT RT: $-.162 - .066\text{t} + .042f_{\text{abrupt}} + .022\text{a}_{left} - .034\text{a}_{right}$	
without trial-number (t)	$AIC_\Delta = 4$, $\chi^2(1) = 6.250$, $p = .01^{**}$
without fade-in (f)	$AIC_\Delta =$, $\chi^2(1) = 6.777$, $p < .01^{**}$
without angle (a)	$AIC_\Delta = 5$, $\chi^2(2) = 6.89$, $p = .03^{*}$
baseline	$AIC_\Delta = 11$, $\chi^2(4) = 19.143$, $p < .001^{***}$
Success Rate in ScrT: $.678 + .575\text{t} - .009\text{a}_{left} + .250\text{a}_{right}$	
without trial-number (t)	$AIC_\Delta = 7$, $\chi^2(1) = 8.858$, $p < .01^{**}$
without angle (a)	$AIC_\Delta = 1$, $\chi^2(2) = 4.981$, $p = .08$
Success Rate in ScrT (reduced): $.719 + .570\text{t}$	
baseline	$AIC_\Delta = 7$, $\chi^2(1) = 8.690$, $p < .01^{**}$

3.2 Impact of LED Stimuli on Response Times

RTs for the *ScrT* and the *LedT* were analyzed with GLMMs using a Gaussian distribution and logarithmic link.

3.2.1 *Screen Task.*

The results in Table 1 show that RTs were highest when a light appeared abruptly to the left along with a noise. However, they were lowest with the abrupt left light cue without a noise. The best fitted model, shown in Table 2, suggests that RTs decrease over time and increase with noise. Higher RTs in the first block (*Mdn*: 1.194, *IQR*: .822) compared to the fourth block (*Mdn*: 1.087, *IQR*: .575) as well as higher RTs with noise (*Mdn*: 1.170, *IQR*: .706) compared to without (*Mdn*: 1.121, *IQR*: .632) support this.

3.2.2 *LED Task.*

As shown in Table 1, RTs increased most when the light turned on abruptly to the left along with the noise. RTs decreased most with the abrupt right light cue without noise. The best fitted model, shown in Table 2, suggests that RTs decrease over time or with fade-in. Further, they increase slightly for left cues, while RTs to right cues decrease slightly. This is supported by the higher RTs for the first block (*Mdn*: .892, *IQR*: .463) compared to the fourth block (*Mdn*: .818, *IQR*: .384), the higher RTs with abrupt activation of the LED (*Mdn*: .832, *IQR*: .433) compared to the 800ms activation (*Mdn*: .806, *IQR*: .400), and the faster RTs for the right side (*Mdn*: .797, *IQR*: .423) compared to center (*Mdn*: .830, $IQR = .417$) and the left side (*Mdn*: .833, *IQR*: .421).

3.3 Impact of Stimuli on the Success Rate

The effects on the *ScrT* success rate was analyzed using GLMMs with binomial distribution and logit link.

3.3.1 *Success Rate in ScrT.*

As shown in Table 1, the rate was lowest with a fading-in light to the left without noise. The best rate was observed with the abrupt light to the right without noise. Overall, the success rates are lower than the observed 91% in the high-load condition in [Lavie and Fockert 2003]. As shown in Table 2, the best fitted model has *trial-number* and *angle* as factors.

However, removing *angle* did not decrease the model's quality. The reduced model suggests that the ratio of correct answers increases over time. The lower ratio of the first block (67.5%), compared to the fourth (74.6%) support this.

3.3.2 Ratio of Reactions to an LED Stimulus. The light was missed in nine trials, every time without noise: seven times for "fade-in in front" and once for "fade-in in on the left" or "abrupt activation in front". We did not fit models for these small differences.

3.4 Discussion

All measures show that participants responded quicker and made fewer errors over time. Adding noise increased RTs for the *ScrT*, supporting our first expectation. However, we did not observe the expected effect on the success rate. Still, another noise could be more distracting and thus affect it too. Our second expectation, regarding decreasing RTs when lights and sounds are activated at the same time, is not supported. This could indicate that the light cue and noise sound are not perceived as one multi-modal cue, but rather as a cue and a distraction. As only .5% of all LED cues were missed and most of those were in the center, our third expectation is not supported. Also, RTs to left cues seem to be higher, while RTs to right cues seem to be lower. This is especially interesting, because the results are not similar for both sides. We need to analyze related works on left or right visual field attentional advantages, such as [Matthews and Welch 2015], and conduct additional studies with varying visual angles to further investigate this. Contradicting our fourth expectation, the fade-in time of 800ms decreased the response time for the *LedT*. This could be due to an immediate orientation reflex triggered by a changing light in the environment [Bradley 2009], but further studies with more variations of fade-in time need to be conducted to support this claim.

4 FUTURE APPLICATIONS

This experiment is a step towards a better understanding of light cues combined with other modalities in a dual-task environment. Due to the limitations given by our setup, its results cannot be applied directly to cue design and need to be validated first. Still, based on our results, we give the following preliminary considerations. First, adding a second modality to decrease RTs may not be beneficial for the primary task, because the second cue could be perceived as distracting. Second, the location needs to be chosen carefully as it may affect RTs differently for the left and right side. Third, a linear 800ms fade-in could be used to trigger faster RTs.

In general, visual stimuli, as explored in this work, are useful for spatial attention guidance systems in various application areas. One example is the automotive domain, where cues could help directing the driver's attention towards critical information such as a fast rear vehicle when preparing for a lane change. Another application area is the maritime domain, where information sources are often spatially spread over several systems on a ship's bridge.

5 CONCLUSION & FUTURE WORK

In this work, we presented an experiment in a dual-task setup. One task was responding to a demanding visual task on a screen in front of a subject, while the other task was to react to LED stimuli that were triggered at the same time. The stimuli were varied by their fade-in times, angles to the subject, and if a white noise sound was played along with them. We found that participants performed better over time. Further, the noise increased the response times for the screen task, but not for the LED task. The response times for the LED task were decreased when lights were activated to the right or with a linear 800ms fade-in. We suggest considering these results when developing future applications in a dual-task setup.

As the screen task in our setup was very demanding, the targets may be displayed in bigger size or longer to vary the level of workload and check if the observed effects remain the same in future experiments. Our experimental setup can be used to further explore the design space of multi-modal and especially LED-based cues. Future work should also explore further dimensions of a light cue, such color, size of the light source, fade-in functions, or onset times. These variations can be analyzed to test if our effects can be generalized and to derive design guidelines for spatial attention guidance systems.

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