
# Prospective memory in a virtual environment: beneficial effects of cue saliency

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| Journal: | *Journal of Cognitive Psychology* |
| Manuscript ID: | JCP-BA 13-21.R1 |
| Manuscript Type: | Brief Article |
| Date Submitted by the Author: | 20-Sep-2013 |
| Complete List of Authors: | Trawley, Steven; Edinburgh University, Psychology<br>Law, Anna; Liverpool John Moores University, School of Natural Sciences and Psychology<br>Brown, Louise; Nottingham Trent University, Psychology<br>Niven, Elaine; University of Edinburgh, Psychology<br>Logie, Robert; Edinburgh University, Psychology |
| Keywords: | prospective memory, delayed intentions, cue saliency, virtual environment, EVET, naturalistic task |
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Title Page

# Prospective memory in a virtual environment: beneficial effects of cue saliency

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**ABSTRACT**

Prospective Memory (PM) research focuses on how the cognitive system successfully encodes and retains an intention, before retrieving it at a particular future time or in response to a particular future event. Previous work using 2D text stimuli has shown that increasing the saliency of the retrieval cue can improve performance. In the present work, we investigated the effect of increased cue saliency in a more ecologically valid 3D virtual environment. The findings indicate that increased perceptual saliency of the cue does benefit PM in a dynamic and visually rich environment, but that the impact of cue saliency does not interact with attentional load.

Keywords: prospective memory; delayed intentions; cue saliency; virtual environment; EVET; naturalistic task

Word count: 3999.

Reference count: 20

## INTRODUCTION

When an individual encounters a situation that is conducive to completing a previously established goal, the anticipated prospect is that they will remember and complete the task. An example would be remembering an earlier intention to buy milk while driving towards a supermarket. However, a successful outcome is not guaranteed and many factors could contribute to failure. In recent years, researchers have reported a variety of situations that can influence an individual's ability to correctly retrieve such prospective memories (PM). A number of these findings are incorporated into an influential theory known as the multiprocess framework (MPF) that attempts to incorporate the results into a coherent model with distinct predictions about PM performance (Einstein & McDaniel, 2005). This framework distinguishes between two retrieval processes; a strategic process that actively monitors for the appropriate situation to retrieve the intention whilst concurrently performing any ongoing task, and an automatic process that spontaneously retrieves the intention in response to cue presentation. The visual distinctiveness or saliency of the PM cue is one of these parameters that determines the automaticity (or failure) of PM retrieval, and is the focus of the present study. The suggestion is that a perceptually salient PM cue, which attracts attention automatically by standing out in relation to non-cue stimuli, would cue retrieval of a delayed intention without the need for any conscious monitoring. In the example of purchasing milk on the drive home, according to the MPF, there is greater chance of success if the driver encountered a prominent colourful roadside advertisement for milk that was adjacent to the supermarket. Such a cue, by nature of its visual saliency, would result in increased evaluation and, thus, would increase the likelihood that the driver would remember its significance in time to respond.

In order to explore what factors influence PM, researchers typically use a dual-task paradigm (Einstein & McDaniel, 1990). This consists of an ongoing task (e.g., lexical decision) and PM task (e.g., press spacebar if you see the word "orange"). Using this approach, there is evidence for the benefits of increased visual cue saliency. For example, Brandimonte and Passolunghi (1994) found that PM was improved when the PM cue was presented in uppercase, in contrast to the other items involved in the ongoing task being in lowercase.

A natural extension of the above work is to explore whether the performance benefits of increased visual saliency can be observed in more ecologically valid scenes. The typical laboratory dual-task paradigm provides precise experimental control and measurement of ongoing task performance but in this type of task, two-dimensional stimuli are passively presented to participants who have no influence over cue presentation rate or order. The specific question this paper addresses is whether the benefits of PM cue saliency are replicable in a more ecologically valid, yet complex and cluttered visual environment (i.e., navigating around a large building). Furthermore, in everyday life we have a significant influence over what stimuli we are presented with and when, by virtue of our movements in a navigable environment. Trawley, Law and Logie (2011) have addressed both of these issues by providing participants with full autonomy to navigate a 3D virtual building. This task, known as the Edinburgh Virtual Errands Task or EVET (Law, Trawley, Brown, Stephens, &

Logie, 2013; Logie, Trawley & Law, 2011) requires participants to perform a series of errands (e.g., collect a newspaper) in specific locations in a large virtual building. The EVET was considered the most appropriate technique for exploring the role of planning in PM, as it afforded participants the opportunity to choose their own path through a virtual building. Trawley et al. (2011) found that participants whose decisions deviated from their original plans exhibited more PM omission errors. One potential limitation of this study, however, is that it did not involve a traditional ongoing task as prescribed by the typical dual-task PM paradigm. Nevertheless, results from Trawley et al., (2011) and other studies with EVET (Law et al., 2013; Logie et al., 2011) suggested that the navigational requirement was sufficiently attentionally demanding to function as an ongoing task. Thus, the ongoing (i.e., navigating to errand location) and PM (i.e., remembering to perform errand at location) tasks were combined (for a similar approach, see Titov and Knight, 2000). Although this approach was suitable for the issues addressed previously, there are distinct advantages of separating the ongoing task from the PM task. First, studies have used ongoing task performance as a measure of PM cost (e.g., Marsh, Hicks, Cook, Hansen, & Pallos, 2003; Smith, 2003), which can help to answer the question of whether PM retrieval is strategic or automatic in a particular experimental situation. Second, the PM cue can be separated geographically and conceptually from the locations that the participant is required to visit to complete the EVET.

With this new approach we examined the benefit of increased visual cue saliency on PM performance. In the adapted version reported here, participants were given two types of errands; location specified (e.g., deliver newspaper to room T4) and location unspecified (e.g., if you see picture press the button). The location specified tasks would function as the ongoing task, mirroring its role in traditional PM tests, while the location unspecified tasks function as the PM retrieval cue. We compared PM and ongoing task performance with high and low PM cue saliency as a between-subjects manipulation. Furthermore, to examine the importance of attention in the effect of cue saliency on PM performance we asked participants to perform the EVET twice; once concurrently with a verbal task and once without. The verbal task we used was random generation, which previous work by our lab has shown causes a reliable disruption of EVET performance (Law et al., 2013).

Based on the reported attentional consequences of manipulating perceptual saliency, our predictions were that salient PM cues would improve PM performance and that this beneficial effect would be greater in conditions of increased attentional demand (dual task conditions). This interaction is predicted by the MPF, in which the beneficial effects of saliency should be most apparent when attentional resources are limited. At this point it is important to consider a contrasting view put forward by Smith (2003) who propose the preparatory attentional and memory processes (PAM) theory, which in contrast to the MPF, argues that successful PM retrieval always requires cognitive capacity. This position is based upon the observation that average ongoing task response times for non-cue trials were significantly slower when participants were given a PM task to perform. Smith (2003) argues that slower ongoing task response times indicate monitoring or other preparatory processes. Smith, Reed, Hunt, McVay and McConnell (2007) have shown evidence for strategic retrieval even with salient PM cues. Due to these obligatory processes, PAM theory would not predict a greater benefit from cue saliency when participants perform the random generation task. .

As far as the authors are aware, this is the first reported test of the PM saliency hypothesis in such a setting, in which the participants have complete navigational freedom.

## METHOD

### Participants

Forty participants (20 female) were recruited from the undergraduate psychology course at the University of Edinburgh. The mean age was 21.5 years (*SD* = 2.3). All participants were compensated with course credit.

### Materials

*The Edinburgh Virtual Errands Task (EVET).* The EVET is a desktop virtual environment that requires the performance of eight errands within eight minutes. The errands are located throughout a large office building with four storeys that participants navigate via keyboard and mouse. Further details of the virtual building and its construction are given in Logie et al., (2011). The EVET has building rules that require participants to use the left stairs for travelling down and the right stairs for travelling up, to avoid entering any non-task rooms, and to avoid picking up any non-task objects.

Prior to completing the EVET for the first time all participants completed a practice session followed by a skill test. The former involved following a series of onscreen errand commands, which were similar to, but not the same as, those used in the main testing session (onscreen commands were only present for initial training). The latter was similar to the EVET practice but only half as long, and designed to provide an index of how effectively they could perform a series of errands.

The standard list of eight errands given to participants (e.g., "Pick up brown package in T4 and take to G6") constituted the location specified errands described earlier. For the prospective memory task (i.e., the location non-specified errand) participants were instructed that if they saw any wall pictures in the building they were to press the large button underneath the picture. They were told to do this only once per picture and that this task was equally as important as the other errands. This PM information was also printed at the bottom of the errands list. The pictures (five in total) were placed in locations found to have high dwell time for participants performing the EVET in our previous studies. As participants performed the EVET twice, two different errand lists were used (referred to as List A and B; see Logie et al., 2011 for details). These lists contained the same type of errands but used different rooms and initial start point. For list A, each floor had one picture with the exception of the third floor that had two. List B was the opposite, with two pictures located in the ground floor. Saliency maps were generated, using Itti and Koch's (2000) model with standard parameters, to objectively assess each of the five PM cues in their high and low saliency between group conditions (see Figure 1).

<insert Figure 1 about here>

*Random Generation Task.*

Participants were required to speak aloud random months of the year at the rate of once per second. In addition to performing this concurrently with the EVET in the dual task condition, they performed this by itself for two minutes to establish baseline performance. All verbal responses were recorded on audiotape for later transcription. Random Number Generation (RNG) score was calculated using RGCalc (Towse & Neil, 1998). This RNG measure is based on the frequency with which particular response pairings occur in the data and varies between 0 and 1, with lower scores indicating greater equality of possible response pairings.

*Gaming experience.* Two questions were asked of each participant following Moffat, Hampson, and Hatzipantelis (1998); a general self-assessment of gaming experience and a more specific self-assessment of 3D gaming experience. Each question was rated on a seven-point scale. The mean of both scores was taken as a measure of gaming experience. However, there was no significant relationship between game experience (or EVET skill) and the PM performance measure, therefore these data are not discussed further.

**Procedure and Design**

All testing was conducted over a one-hour session with each participant tested individually. Half of the participants received the high PM cue saliency version of the EVET and half received the low saliency version. The combination of task list, and order of testing (i.e., whether participants started with single or dual task conditions) were fully counterbalanced. At the start of the test session participants rated their gaming experience. Next, participants completed the EVET practice and skill test.

Participants were then given their errand list to study along with a schematic map of the building. The procedure was as follows: an initial two minute period of study; immediate free recall of the errands; a further study period of five minutes; cued recall of the errands. At the end of this period participants were asked to verbally recall the errand list and building rules. Any mistakes were corrected, and this process was repeated until recall of the list was at 100% (typically, this required a further two minutes of study time). Thus, including the initial learning phase and final checking, each participant spent approximately twelve minutes working with the errand list before starting the EVET. This minimised the risk that participants would fail to complete errands simply because they could not recall them. The delay between PM encoding and PM retrieval was approximately 2-3 minutes due to the lag in starting the EVET and depending on when the participant's movements brought them into contact with the first PM cue. The EVET lasted for eight minutes, and neither the task list nor building map were present during the test. Performance was scored with a weighted scoring procedure (see Logie, et al, 2011). With the exception of the skill and practice sections, participants performed this sequence once with EVET alone (half with list A, half with list B) and once with the alternative list while they performed the random generation task.

## RESULTS

Descriptive statistics and correlations between the variables are shown in Table 1. In the following sets of results, the effects of cue type and attentional demand on performance were analysed (see Table 2 for summary data). Unless otherwise stated the results were analysed using a two-way mixed design ANOVA with attentional load (single or dual; within participants) and cue saliency (high or low; between participants) as the main factors.

<Insert Table 1 about here>

<Insert Table 2 about here>

*PM EVET performance:* The PM performance index comprised a ratio between the number of times a participant navigated within the proximity of a PM cue and the number of times they correctly pressed the button. This ratio represented successful performance for participants whilst controlling for cue exposure as a consequence of their movements around the EVET building. Failure to press a button, that had not been pressed before, was considered an error of omission. Errors of commission (see Scullin, Bugg, & McDaniel, 2012; Scullin & Bugg, 2013) were recorded but frequency was so low that no meaningful results concerning these types of PM errors could be obtained. All participants successfully recalled the PM task instructions at the end of the test session. There was no effect of counterbalancing for dual/single start order, so for this analysis the reported results are collapsed across this variable.

There was a significant main effect of load, $F\ (1,38) = 12.15$, $MSE = .038$, $p < .001$, $\eta^2_\rho = .242$; single EVET PM omission errors $M = .43$, $SD = .35$; dual EVET PM omission errors $M = .27$, $SD = .29$ and for cue type, $F\ (1,38) = 10.49$, $MSE = .132$, $p = .002$, $\eta^2_\rho = .216$; Low saliency $M = .22$ $SD = .21$; High saliency $M = .48$ $SD = .35$.

There was no significant interaction between the two factors, $F$ (1,38) = 0.25, $p$ = .62, $\eta^2_\rho$ = .006.

The failure to obtain an interaction effect here was surprising as it was predicted by the MPF and creates a difficult situation with regard to the interpretation of a null effect. An alternative approach is to reconsider this interaction from a Bayesian perspective. The R package *BayesFactor* (Rouder, Morey, Speckman, and Provinve, 2012) provides a Bayes factor for each combination of our factors, which allows us to directly contrast competing models. Our model of main effects only (load and cue type) produced the greater Bayes factor ($BF$ = 11.8 × $10^6$, ±2.1%), compared with the model that included the interaction ($BF$ = 3.70 × $10^6$, ±2.5%). The main effect only model was preferred by a factor of nearly 4 (3.97, ±1.29%).

*EVET score:* This measure was based on the same scoring procedure as that reported in previous studies (Logie et al., 2011; Law, et al., 2013) and is designed to index efficient errand completion. Points were allocated for performing errands and were removed for rule breaks, such as breaking the stair rule. This measure did not include any PM responses. There was a significant main effect of load, $F$ (1,38) = 4.67, $MSE$ = 18.42, $p$ = .037, $\eta^2_\rho$ = .11; single EVET score $M$ = 10.53, $SD$ = 6.34; dual EVET score $M$ = 8.45, $SD$ = 6.16. There was no main effect of cue type, $F$ (1,38) = 0.06, $p$ = .81, $\eta^2_\rho$ = .002, or interaction between the two factors, $F$ (1,38) = 0.83, $p$ = .37, $\eta^2_\rho$ = .021.

*EVET travel time:* This indicated the total amount of time each participant spent travelling around the EVET building. Time spent within a room was excluded (i.e., the time spent completing a specific errand), therefore it was predicted that this measure would directly index each participant's ability to navigate effectively within the virtual building. There was no effect of counterbalancing for dual/single start order, so the reported results are collapsed across this variable. The main effect of load was significant, $F$ (1,38) = 4.41, $MSE$ = 1121.33, $p$ =.042, $\eta^2_\rho$ = .104); single EVET travel time $M$ = 321.68 seconds, $SD$ = 36.27; dual EVET travel time $M$ = 337.40 seconds, $SD$ = 36.99. There was no main effect of cue type, $F$ (1,38) = .001, $MSE$ = 1629.19, $p$ =.97, $\eta^2_\rho$ = .000, and no interaction, $F$ (1,38) = 0.11, $p$ =.74, $\eta^2_\rho$ = .003.

*Randomness of secondary task responses:* Baseline performance was compared to dual-task performance using mixed ANOVA (the between- participants factor being cue type). There was a significant main effect of load, $F$ (1,38) = 52.81, $MSE$ = 0.007, $p$ < 0.001, with participants producing significantly less random responses in the dual-task condition (*M* = .27, SD = .10) than during baseline random generation performance (*M* = .41, *SD* = .10). There was no main effect of cue type or interaction.

Graphical representation of participant movement patterns collapsed across all floors can be seen in Figure 2. High/low cue type groups and single/dual attentional load conditions are each represented as a 3D plot derived from kernel-density estimation (Cao, 2008). Each plot represents the probability of that location being occupied by participants from that group. In short, a high peak indicates an area in which participants from that group dwelled, whereas flatter troughs represent areas of travel with no stops. In line with the main effect of load on travel time, the left lower plot highlights the additional time participants in the dual task condition spent navigating from errand to errand along the corridors. In contrast, participants in the single task condition appeared to focus their time in the folder sorting room (left upper plot). The plots on the right, however, are closer in appearance. This suggests that the salience of the PM cue did not have a discernable effect on their movement through the building. This is in line with the non-significant effect of cue type on the EVET travel time measure.

<insert figure 2 about here>

**DISCUSSION**

The results support the cue saliency hypothesis in a more dynamic situation than used previously. The benefit of cue saliency and the detrimental effect of increased attentional load on PM performance are in line with the MPF. However, the absence of an interaction contrasts with the MPF prediction that increased salience would be most beneficial when attentional resources are limited (for a similar MPF saliency/attention prediction see Rendell et al, 2012). The interaction effect size was small, suggesting that sample size was not an issue here. Furthermore, a Bayesian analysis gave no reason to believe that an interaction was present. These findings may be more consistent with the PAM theory than with the MPF. Smith et al. (2007) argued that salient cues do not lead to automatic retrieval of the intention, but rather recruit extra resources to the PM task which can be utilised in preparatory processing, leading to enhanced PM performance. Therefore, if resources were scarce due to the presence of a competing random generation task, one might then expect cue saliency to have *less* benefit in the dual-task condition than it did in the single-task condition.

However, there was no evidence of a significant modulation of the effect in either direction.

One possible explanation is that the PM cues were within the focus of attention required for the EVET task. Einstein and McDaniel (2005) argue that processing overlap increases the probability that the cue will automatically prompt retrieval. For example, Einstein and McDaniel (2005; Ex1) used a famous faces task to manipulate whether the ongoing task (categorization) did overlap with the PM cue (word cue) or did not (vowel cue). They found manipulations of attention were only effective with non-focal cues. Similarly, Hicks, Cook and Marsh (2005) showed that manipulations of cue saliency were only effective with non-focal cues. With this in mind, the appearance and position of the PM cues were similar to the number signs outside each room. This similarity to an essential aspect of the building for EVET performance may have brought the PM cues into the focus of attention, and therefore limited the favourable changes in cue detection brought about by cue saliency. The benefit of increased cue saliency was already at a functional ceiling level during the single task condition and could not increase performance any further under dual task conditions. The methodology used here is particularly suitable for manipulating PM cue focus due to the greater number of peripheral stimuli presented to the participant. Another explanation is that the demand exerted by performing the EVET alone was enough for the beneficial effects of increased cue saliency to be demonstrated. Trawley et al. (2011) examined PM performance with only the EVET, assuming the navigational requirement was demanding enough to function as an ongoing task. Future studies with a less demanding EVET (e.g., reduced number of tasks) would address this point. Additionally, in the current design participants have, in effect, one PM task (the standard predetermined location based EVET errands) embedded in another (responding to pictures in an undetermined location). Whether we would find the same effects for cue saliency or attentional load with an ongoing activity that had no PM element (e.g., a simple follow-task) is an interesting issue for future studies.[1]

The significant effect of attentional load on EVET performance is in line with that found previously (Law et al., 2013). Furthermore, travel time between dual and single task groups was significant, demonstrating increased time spent navigating between rooms for participants under dual task conditions. The absence of any discernable difference between EVET performance (score or movement patterns) for the high and low cue saliency groups suggests that participants did not alter task priorities in response to increased or decreased cue perceptual saliency. Rather, as is the aim for any PM study, the PM task was secondary to the demanding ongoing task of completing the EVET. The contrast between the EVET and PM tasks, with regard to one being location specific and the other non-specific may be partly responsible. At the start of both EVET sessions, participants were unaware of PM cue location. In contrast, with a typical PM experiment the eventual physical location of the cue is known to the participant (e.g., within the stream of central presented words during a lexical decision task). PM cues that are location specific may encourage a monitoring approach, whereas this strategy would seem less attractive with location non-specific cues. The relationship between reduced travel time and higher EVET performance supports our previous work (Logie et al, 2011; Trawley et al, 2011). In the latter paper, the issue of plan following and how that is important for successful PM was addressed. However, another suggestion is that with increased execution speed the

[1] We thank an anonymous reviewer for this point.

errands would be less susceptible to forgetting. This would be an interesting area of further research.

This research identifies a practical way to explore the effects of increased perceptual saliency on PM performance in an ecologically valid, yet controlled environment. A variety of applied research topics that extend beyond a simple high/low saliency contrast are relevant for future consideration (e.g., location familiarity). Few studies have addressed the relevance of context familiarity in PM performance (although see Sellen, Louie, Harris and Wilkins, 1997). Furthermore, manipulation of visual saliency has a variety of applied implications. How these applied issues can be considered from a PM perspective is a potentially productive area for further research.

**Acknowledgements**

We are grateful to Matthew Logie for undertaking the programming to create the EVET environment. We acknowledge Leverhulme Trust research grant number F/00 158/W which supported the research that we report here.

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Table 1.Descriptive statistics and correlations between measures.

| | Mean | Standard Deviation | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 1 EVET skill test | 174.5 | 37.8 | -.39$^{*}$ | -.27 | -.27 | -.54$^{**}$ | -.36$^{*}$ | .433$^{**}$ | .22 |
| 2 Previous game experience | 6.8 | 3.1 | | .19 | .18 | .30 | .29 | -.03 | -.26 |
| 3 PM Performance (single) | .43 | .35 | | | .64$^{**}$ | .25 | .17 | -.25 | .00 |
| 4 PM Performance (dual) | .27 | .29 | | | | .15 | .29 | -.25 | -.13 |
| 5 EVET Score (single) | 10.5 (.53) | 6.3 (.32) | | | | | .53$^{**}$ | -.51$^{*}$ | -.15 |
| 6 EVET Score (dual) | 8.5 (.43) | 6.2 (.31) | | | | | | -.44$^{**}$ | -.50$^{**}$ |
| 7 EVET travel time (single) in seconds | 321.7 (.67) | 36.3 (.07) | | | | | | | .18 |
| 8 EVET travel time (dual) in seconds | 337.4 (.70) | 37.0 (.08) | | | | | | | |

Note: The EVET travel time and weighted performance score is reported as normal alongside a proportion of maximum (in brackets). Maximum EVET score is 20; maximum travel time is 480 seconds. $^{*}$ $p$ <0.05, $^{**}$ $p$ <0.001

Table 2. Performance measures as a function of cue type and load conditions.

| | Single Task | | Dual Task | | |
|---|---|---|---|---|---|
| | Mean | Standard Deviation | Mean | Standard Deviation | Cohen's *d* |
| PM Performance (low cue saliency) | .30 (6.8) | .28 (1.5) | .13 (7.0) | .14 (1.7) | 0.70 |
| PM Performance (high cue saliency) | .55 (6.1) | .36 (1.4) | .42 (6.2) | .33 (1.2) | 0.38 |
| EVET Score (low cue saliency) | 10.8 (.54) | 6.5 (.33) | 7.8 (.39) | 6.9 (.35) | 0.45 |
| EVET Score (high cue saliency) | 10.3 (.52) | 6.3 (.32) | 9.1 (.46) | 5.4 (.27) | 0.20 |
| EVET travel time (low cue saliency) | 322.8 (.67) | 42.3 (.08) | 336.0 (.70) | 37.2 (.07) | 0.33 |
| EVET travel time (high cue saliency) | 320.6 (.67) | 30.2 (.06) | 338.8 (.71) | 37.6 (.08) | 0.53 |

Note: Average number of proximate opportunities for PM performance is reported (in brackets). The EVET travel time and weighted performance score is reported as normal alongside a proportion of maximum (in brackets). Maximum EVET score is 20; maximum travel time is 480 seconds.

Figure Captions.

Figure 1. Example saliency maps showing contrast between high and low saliency cues towards the left of each image.

Figure 2. Graphical representation of participant movement patterns collapsed across all four floors and for all participants as a function of condition (high peaks represent areas of the most frequent dwelling).

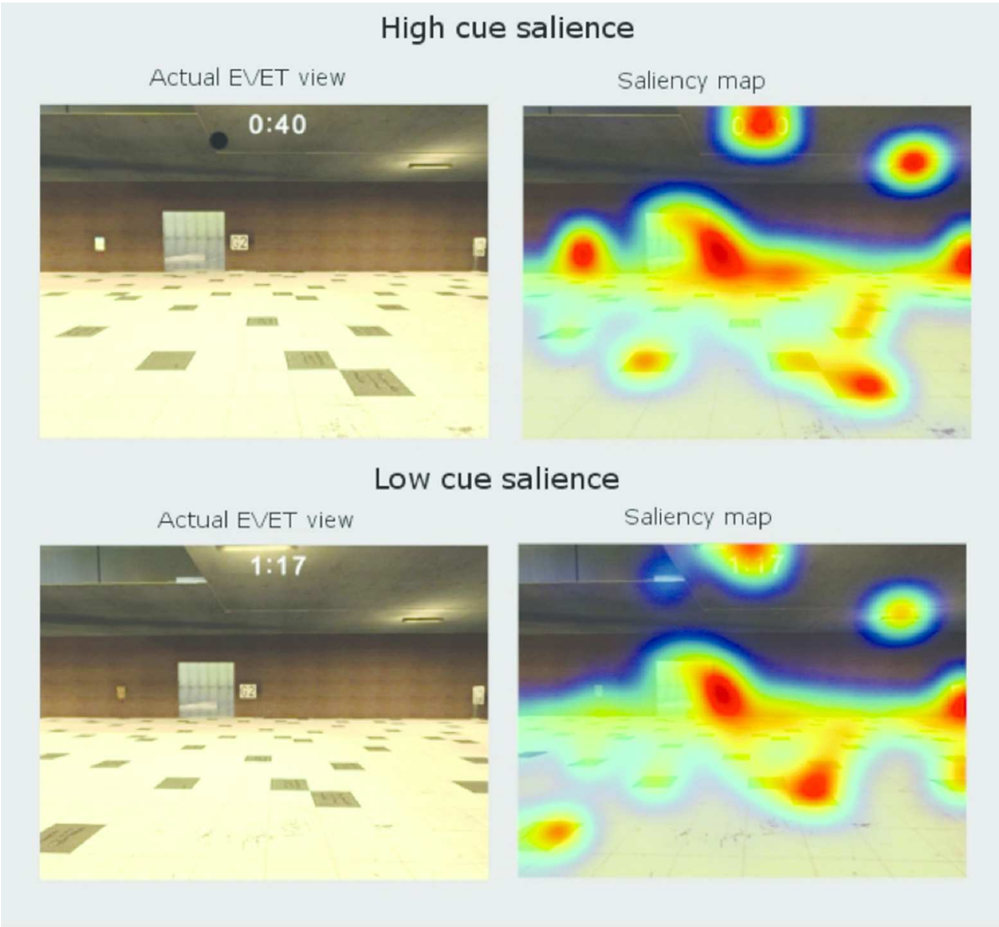
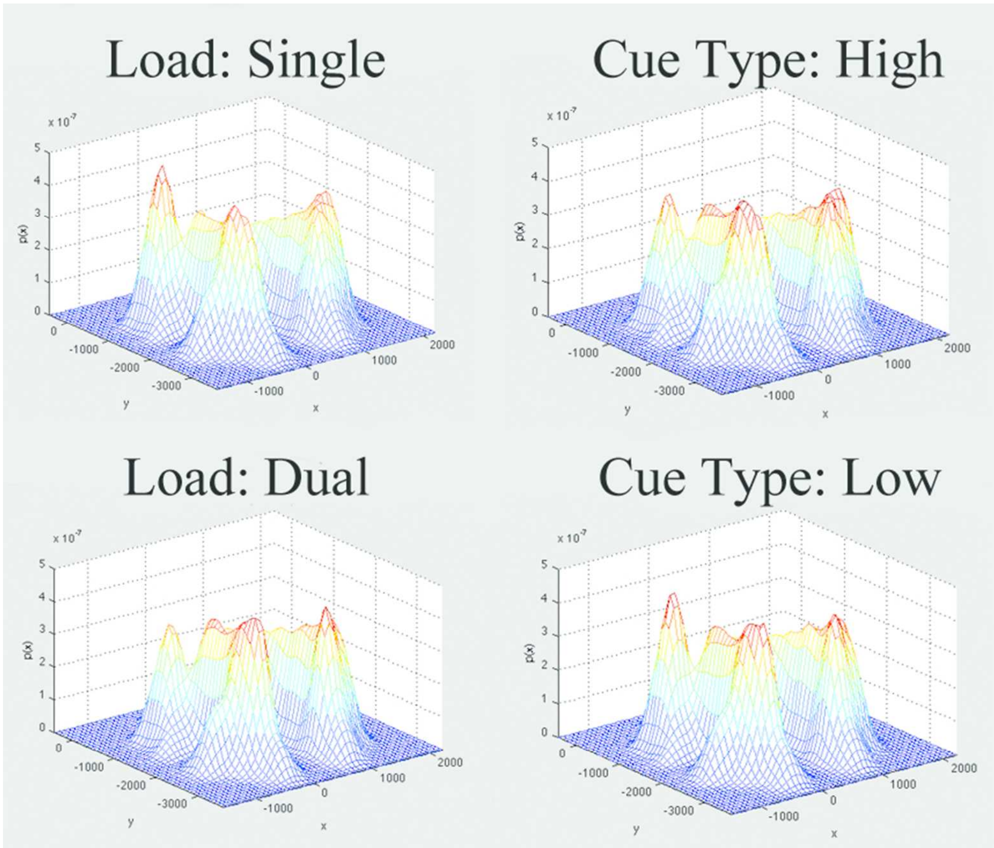



Figure 1. Example saliency maps showing contrast between high and low saliency cues towards the left of each image.
73x67mm (300 x 300 DPI)




73x62mm (300 x 300 DPI)