Title

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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 45(45)

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Publication Date

2023

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Abstract

Memory retrieval is influenced by both prior and current experiences. The various factors (e.g., frequency, recency, or similarity) may interfere during retrieval due to prior experiences, while the context-dependent memory effect may enhance based on present experiences. Most memory research has been limited to controlled laboratory settings, but this study aims to examine memory retrieval in a more natural setting by using a GPS application (e.g., Traccar Client) to track participants' daily GPS locations every 60 seconds for 5 weeks. Participants were then asked to recall their locations at a specific time, choosing from all locations visited in the previous 4 weeks. Results demonstrated the existence of the context-dependent memory effect in real-world settings, with more frequent or recent visits leading to increased correct responses. This study is the first to use the current methodology to study the context-dependent memory effect and to measure an individual's genuine memories in a more ecologically valid way.

Keywords: context dependent memory; memory interference; recall; frequency effect; recency effect; experience sampling methods/ecological momentary assessment (ESM/EMA)

Introduction

The process of retrieving memories of a specific event is affected by current and prior experiences. With regard to the current experiences, there may be a context-dependent memory effect to facilitate memory retrieval. Context-dependent memory refers to the improved recall when the individuals is in the same context where the original memory was formed. For example, if someone loses their car keys in their room, they are more likely to remember where they placed them if they search in the same room, rather than a different room. This is due to episodic memory, which deals with daily life events, stores not only the misplaced item but also the location in which it was lost. Thus, people tend to use temporal or spatial context information when trying to remember a specific event. This effect has been extensively validated using various types of external and internal contexts.

A notable study that demonstrated the greatest effect of context-dependent memory was conducted by Godden and Baddeley (1975). In the study, one group of divers learned a list of words on land while the other group did the same underwater. The participants were then asked to recall the learned words in either the environment where they originally learned the words or in a different environment. The results showed that the participants who learned the words underwater recalled best when retrieving the words in the same context and vice versa. Godden and Baddeley (1975) demonstrated that context encoding, in which contextual information is automatically stored when an item is encoded, is crucial. This contextual information serves as a retrieval cue, enhancing memory performance. Therefore, this classic experiment shows that when recalling a past event, people not only retrieve the item but also the contextual information that was associated with the item.

A growing body of research exploring the context-dependent memory effect has developed from the classic study by Godden and Baddeley (1975). Subsequent research has been primarily conducted in a laboratory setting, using various manipulations of contexts, such as background colors (Isarida & Isarida, 2007), physical locations (Canas & Nelson, 1986; Coveney et al., 2013; Eich, 1985; Fernández & Glenberg, 1985; Koens et al., 2003), physical activities (e.g., chewing gums; Miles & Johnson, 2007), background music (Balch, Bowman, & Mohler, 1992; Smith, 1985), video features (Smith & Manzano, 2010), odors (Schab, 1990), or mood (Eich, 1995).

In M. Goldwater, F. K. Anggoro, B. K. Hayes, & D. C. Ong (Eds.), *Proceedings of the 45th Annual Conference of the Cognitive Science Society.*

However, these manipulations within laboratory settings have not always produced significant memory effect (Convey et al., 2013; Eich, 1985; Fernández & Alonso, 2001; Fernández & Glenberg, 1985; Koens et al., 2003; Miles & Johnson, 2007; Saufley, Otaka, & Baresco, 1985). The failures to find evidence for a context dependent memory effect have led to increased questions about the existence of such an effect in the real world. However, due to the limitations of the technology and the complexity of experimental design, there has been limited memory research conducted in nature settings. Thus, a new approach is needed to develop memory research in daily life.

In the realm of psychological research, advancements in technology have paved the way for innovative methods of investigation. A recent study by Shin et al. (2021) utilized virtual environments to examine the context-reinstatement effect, wherein participants demonstrated enhanced recall of items learned either underwater or on Mars when they were tested in the same virtual environment. Although previous studies, including this VR study, have made strides in exploring the context-dependent memory effect, limitations in experimental methods still exist in understanding this effect in complex environments, such as our daily lives. To address these limitations, this study introduces a smartphone-based method that captures individual experiences and memory performance, providing a more ecologically valid investigation of the context-dependent memory effect.

Memory retrieval in daily life can be impacted by various factors, beyond the context-dependent memory effect. One such factor is the frequency effect, where the frequency of a memory trace affects memory retrieval. This can lead to the word frequency paradox in recognition memory, where low-frequency words are more easily recognized, while high-frequency words are better remembered in recall.

Another factor is the recency effect, which is explained by the hypothesis that memory strength decreases over time (Friedman & Wilkins, 1985). Therefore, making items less accurately remembered the longer they have been encountered or remembered. In addition, memory interference may occur when an item to be remembered is similar to other distractors. In the study of Kinnell & Dennis (2012), the false alarm rates for fractals were higher than other distinctive stimuli (e.g., faces or words). Since fractal images have higher similarities and complexities compared to other stimuli, participants find it hard to distinguish each other.

In the current study, we propose a more ecologically valid way to examine how prior (e.g., frequency effect) and current (e.g., context-dependent memory effect) experiences affect memory performance by recording every moment in the participants' daily life with a GPS tracking application. Experience Sampling Methods/Ecological Momentary Assessment (ESM/EMA) is then used to understand whether contextual information significantly affects the memory retrieval of daily events, when participants are present in either the same or different contexts. Based on our knowledge, there has been no substantive research on examining the context-dependent memory effect outside of the laboratory. The present study examines the human memory process in a real world setting with a new approach and lays the groundwork for research methods for effects on memory retrieval.

Experiment

Methods

Participants Eight undergraduate students (six females, *M* = 20.4 years, *SD* = 0.80) participated in the study. There was one Android smartphone user, and the others were iPhone users. Participants received up to 120,000 won (approximately 100 USD) for their participation. The compensation was based on the number of questions that they answered during the memory test phase. The experiment was approved by the Institutional Review Board at Hanyang University.

Procedure and Design The experiment was conducted over seven weeks (see Figure 1A). The experiment always started on a Monday and ended on a Sunday. The experimental procedure was divided into three parts: data collection (five weeks), memory test (two weeks), and post-survey (one day). The post-survey included three sub-tasks: location identification, psychological similarity measurement, and frequency and recency survey.

Before the Experiment Participants visited the laboratory and were guided to install two smartphone applications on their personal devices: Traccar Client (a GPS tracking application; https://www.traccar.org/) and Telegram. Traccar was able to track the participant's GPS, and the Telegram app was used to communicate with the experimenter as well as receive links to the test page during the memory test phase of the experiment. Participants were instructed to keep the Traccar app running for the entire seven weeks, where their GPS information was recorded with a sampling rate of 60 seconds. The data was uploaded to the server as soon as network connection was available, and the experimenter monitored whether the data was being continuously collected every day. External batteries were also provided to the participants when requested.

Data Collection For the first five weeks, participants collected their GPS location through their smartphones application. Participants were not provided with any specific instructions for the duration.

Memory Test After the 5-week data collection period, participants were administered with an online memory test during the sixth and seventh weeks. The test trials were generated based on the first four weeks of the data collection phase, and the last week of data (the 5th week of data) were excluded in order to have a retention interval of one week before the test. The participants were asked about their memories each day from 10 a.m. to 10 p.m. A link to a test page was sent to the participant's Telegram app during each hour slot (e.g., 10:00~10:59) at a random minute. For each trial, participants were asked where they were at a certain time (e.g., “Click the marker for the location that you were at 3 p.m. on September 24, 2022”, as shown in Figure 1B). Participants had to select a marker on a map, where they were able to zoom in and out of the map. Thereafter, participants were asked to rate their confidence on a scale ranging from 1 *(not at all confident)* to 5 *(very confident)*. Over a period of two weeks, participants were cued with a total of 168 trials, with 12 trials per day. The trial page was designed to be easily accessible on their smartphones.

All the memory trials were generated from stationary points that were detected from the raw GPS data. We defined the stationary points as the participant staying within a 50m radius for 15 minutes or longer. Since one of the goals of this study is to verify context-dependent memory in real-life, the memory trials were sent as following this process:

(1) It was checked whether the current participant's stationary point was one of the location points they had stayed at during the previous four weeks.

(2) If it was one of the location points from the previous four weeks, there was a 50% chance of sending a memory trial about that location point to measure memory when the context matched, and a 50% chance of sending a memory trial for random location point other than the current location point to measure the memory when the context did not match.

(3) If the participant’s stationary point was not one of the four-week location points, a memory trial was sent about the random location points.

Participants were time-limited to submit their responses within five minutes of receiving the test link.

Post Survey Participants visited the laboratory within a week of completing the memory test to take part in the post-survey. The survey was constructed with the locations that the participants visited over the past seven weeks. The purpose of the three sub-tasks was to measure the participants' psychological similarity between each visited locations and to examine the frequency and recency of the location points.

[Experiment – "Where were you?"]
Hello, 100003?
[Q-164]
1. Where were you at the time specified below?
September 8th, 2022 at 6:28 PM

- Try to answer by remembering the provided date and time, instead of relying on your regular activities.
- Please do not refer to any calendars or diaries.
- To provide your response, click on a marker on the map.
  - To pinpoint the precise location, zoom in on the map and select a marker.
  - When you click on a marker, it will turn red.

[Experiment – "Where were you?"]
Hello, 100003?
[Q-164]
2. How confident are you in your answer (memory)?

Not at all confident	Not confident	Moderately confident	Confident	Very confident

Ok

Figure 1. Experimental Design and examples of the tasks (a) Design of the Experiment. The experiment was conducted over seven weeks. The procedure was divided into three parts: data collection (five weeks), memory test (two weeks), and post-survey (one day). The post-survey included three sub-tasks: location identification, psychological similarity measurement, (b) Test pages containing a memory trial and confidence rating of the response, (c) Identification task in the post survey: to identify each location points by labeling them and choosing a map with appropriate zoom level for the subsequent tasks. Participants also had an option to indicate they do not remember the location, (d) Psychological similarity measurement: to place location points close to each other if they felt that the locations were similar to each other, and otherwise far away.

In the first task, participants were presented with location points that were pinned on a map one at a time. Then they were asked to identify each location points by labeling them (see Figure 1C). There were two versions of location with different zoom levels, and they also had an option to indicate that they do not remember the location. The locations that the participants did not remember were not used in the subsequent tasks.

In the second task, participants were presented with tiles of maps, which included the locations that they have visited for the last seven weeks (see Figure 1D). Each map tile included one location which was pinned on the map. The map tiles were presented in the middle of the screen. Participants were then asked to place the maps on the gray square, which was placed on the right side of the screen. They were also instructed to place location points close to each other if they felt that the locations were similar to each other, and otherwise far away (Goldstone, 1994). When the participants clicked the tile map, a zoomed-in version of the map appeared on the right side of the screen.

The final task involved answering three questions related to the locations (see Figure 1E): (1) the date that they visited the location for the first time, (2) how often they visit the location, and (3) whether they visit the location regularly. For each location, a pin on the map was presented and the above three questions were asked.

Results

Analyses were performed on the pooled participant data, which consisted of 905 trials, excluding non-response (22.5% and RT outliers (6.6%). Outliers were defined as RTs exceeding 60,000ms for response and 7,000ms for confidence rating. The average accuracy rate (proportion of correct responses) across participants was .54. The mean of RT was 19152.2ms (*SD* = 11551.9), and the average confidence rating was 3.7. The average RT for confidence ratings was 1824.1ms (*SD* = 894.3).

To investigate the impact of context-dependent memory on recall, we looked at the relationship between the context congruency and response accuracy. A correct response (recalling a location point correctly) was coded as 1, while incorrect responses were coded as 0. Context congruency was coded as 1 and 0, with 1 indicating congruent context where encoding and retrieval contexts match, and 0 indicating incongruent context where the context at retrieval and encoding is different. Results from the logistic regression indicated that there was a significant association between the context congruency and accuracy (β =.642, *p* < .001; see Figure 2), suggesting that recall was easier when the retrieval environment matches the encoding environment. Further analysis of the relationship between confidence rating and accuracy revealed that higher confidence ratings were predictive of better memory performance (β =.642, *p* < .001; see Figure 3).

We also examined the interference stemming from other locations during retrieval, assuming that similar locations would generate more interference. Similarity was defined as the density of GPS points – a denser location (i.e., a location that has more neighboring locations) would have more interference. We hypothesized that memory performance would improve as the density of location decreases. We calculated the median GPS distance between each location point (e.g., target) and the remaining locations (e.g., distractors) – see Figure 4 as an example. Our findings showed no significant relationship between response accuracy and the median GPS distance, (β =.006, *p* >.05), suggesting that the physical density such as GPS is not likely to affect memory retrieval. However, interestingly, contrary to physical distance, memory performance improved as the median of psychological distance increased (β =1.182, *p* < .001). This implies that the spatial representation in one's psychological space, which is more useful for recall in daily life, is more likely to cause confusion as the psychological distance decreases.

Next, we examined memory performance in relation to frequency and duration. To analyze these effects, we calculated the frequency of previous visits to each location at the time of responding to each memory trial during the five-week data collection period. For the frequency effect, memory performance improved as the frequency of visits to each location increased during the data collection period (β =.008, *p* < .001). This result was also replicated for the location frequency reported in the post-survey (β =.004, *p* < .001; see Figure 5). For the mean duration of each location, a longer duration predicted better memory performance (β =.000 *p* < .001; see Figure 6).

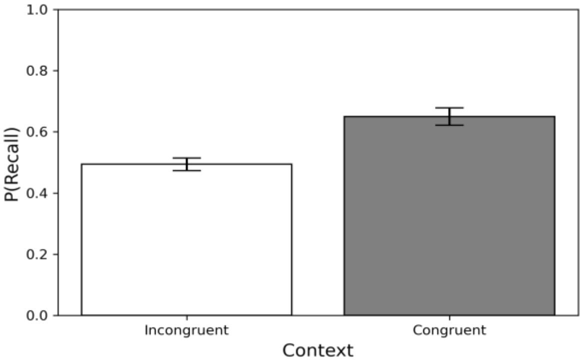

Figure 2 Accuracy rate and Context

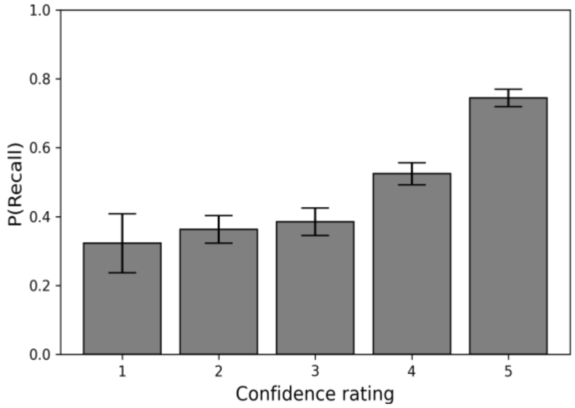

Figure 3 Accuracy rate and Confidence rating

We further analyzed the relationship between recency and response accuracy. To analyze the recency effect, we searched the latest GPS points to each location at the time of responding to each memory trial. Results showed that accuracy improved when participants visited each location more recently (β = -.050 p < .001). To examine how memory of the location changes over time, we calculated the time elapsed between the first visit to a location and the time it was presented in the memory trial. Interestingly, accuracy improved as the elapsed time increased (β =.000 p < .001), indicating that the longer a location remains in memory, the more distinctive it becomes and thus easier to distinguish from other locations.

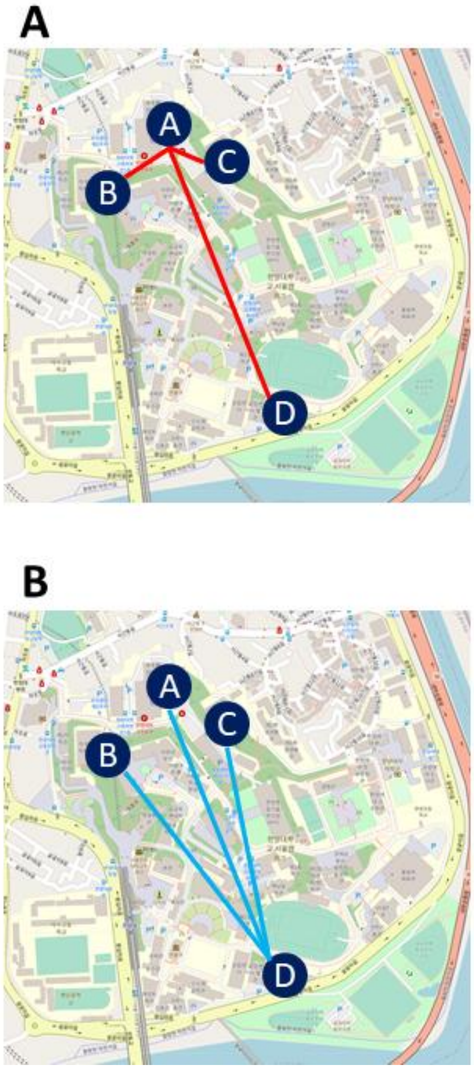

Figure 4 Examples of different location density (A: High Density, B: Low Density)

Discussion

In the present study, we investigated the context-dependent memory effect on memory recall in people's everyday life. Participants collected data for five weeks and recalled where they were on a particular day at a particular time on the sixth and seventh week of the experiment. Results showed that memory performance improved when recalled in the same context as the encoding context, suggesting that the context-dependent memory effect exists in the real world. However, the effect size (Cohen's *d*) for our finding was .3, which is relatively small compared to earlier works that we used from the meta-analysis conducted by Smith & Vela (2010) (see Figure 7). To further explore this effect, we aim to increase the sample size by recruiting more participants.

When analyzing recall with frequency, participants recalled significantly more location points as the frequency increased compared to the low frequency. This finding supports previous studies on memory recall (Balota & Neely, 1980; Deese, 1960; DeLosh & Mcdaniel, 1996; Ward, Woodward, Stevens, & Stinson, 2003) by demonstrating the recall advantage of high-frequency items. Recency analysis revealed that participants recalled more locations for more recent visits, aligning with the hypothesis that memory strength decreases over time (Friedman & Wilkins, 1985).

The psychological similarity analysis suggested that participants found it harder to recall or distinguish between locations where they were surrounded by many psychologically similar locations in their psychological space. Our findings also provide evidence of individualized frequency, indicating that, because participants have different subjective experiences, the locations that may be confusing can also differ among them. Chalmers et al. (1997)

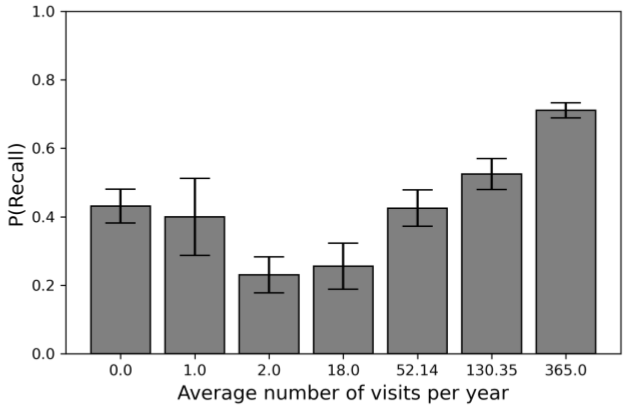

Figure 5 Accuracy rate and Average number of visits per year

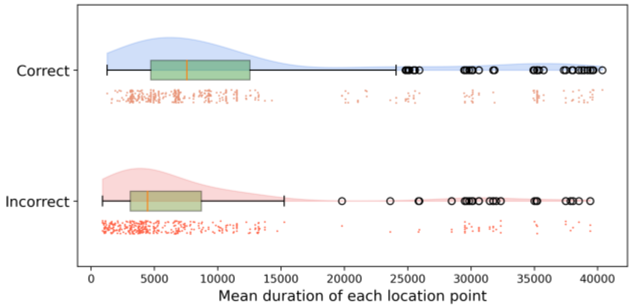

Figure 6 Context and Mean duration of each location point

demonstrated that recognition accuracy could be different based on subjective experience, as items that are frequently encountered may differ for every participant. Results by Yim et al. (2020) also demonstrated that individualized frequency is a better predictor to measure one's memory performance.

Finally, the methodology used in the current study contributes to memory research in real-life settings. Experience sampling methods allowed us to gain a more holistic view of an individual's experiences and also examine these experiences in more detail. In addition, assessing individualized frequency or similarities in memory could be a more ecologically valid measurement of one's genuine memory performance.

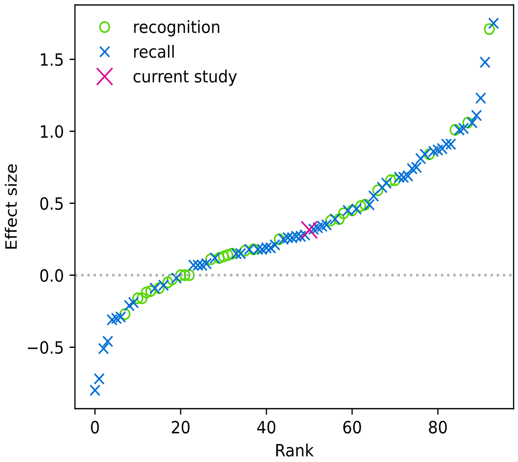

Figure 7 Effect size of the context-dependent memory effect

Acknowledgments

This work has supported by the National Research Foundation of Korea funded by the Ministry of Science and ICT (No.2018R1A5A7059549) by JHC, and HY.

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