DEPARTMENT of PSYCHOLOGY

Episodic memory and scene perception, an eye-tracking experiment with induced cognitive load.

Lejla Fazlic

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Abstract

This study investigates if cognitively induced load via the Sternberg Task influences episodic memory measured through eye metrics data. An eye-tracking experiment was conducted with 34 participants to research if memory will decline when cognitive load increases. The method was a block design, controlled experiment. The analysis consisted repeated measures ANOVAs. The first hypothesis that cognitive load impairs memory encoding was rejected. The second hypothesis that cognitive load will impair recognition of episodic memories was accepted. And the third hypothesis that cognitive load will lead to less similar scan paths was accepted.

Keywords: Episodic memory, Scanpath Similarity, cognitive load, scene perception, eye-tracking.

Foreword

I want to dedicate my warmest thanks to my supervisor Roger Johansson, for the support, and all the constructive feedback, through the becoming of this master thesis. I would also like to thank Mikael Johansson and Inês Bramão for always correcting me when I am wrong and thank you to all my friends who supported me and believed in me along the way.

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Lejla Fazlic, Lund, 2023.

Introduction

Episodic memory is a big part of a person's identity, episodic memory lets us remember who we truly are. Within episodic memory all the events, and life experiences that one person has ever had are stored, alongside the memory of the places where these memories were formed in space and time. Aswell as all the information about one's personality, self, and identity (Nikolaev et al., 2023; Berntsen et al., 2022; Baddeley, 2001; Renoult, et al., 2019; Wheeler, Stuss, & Tulving, 1997). Therefore, any disruption to the episodic memory-system can damage one's cognitive abilities, recognition of places, faces and events, and damage sense of orientation in space and time. Episodic memory damage is a feature of Alzheimer's disease, Parkinsons and other forms of dementia and neurodegenerative brain diseases and less severe forms of cognitive memory decline.

Therefore, research on how to develop proper diagnostical tools for the patients, which are ethical and non-intrusive are of utter importance. The aim of this study is to lay the groundwork for the future development of eye tracking as a diagnostical tool for AD and other types of memory impairment, by investigating simulated memory decline in healthy adults.

In healthy humans our senses, and specifically eye movements govern what is encoded into episodic memory. Thus, eye movements are closely linked to episodic memory, and by investigating gaze patterns and other eye metrics data scientists can reach conclusions about how episodic memory is formed or disrupted and how memories are encoded, recognized, or distorted (Nikolaec et al, 2023; Johansson et al., 2022).

Memory loss and interference can be caused by different things, in the diseased brain it is not only because of cognitive load but also because of brain atrophy. Below, there is a short explanation of the two different forms. In healthy individuals' memory decline is due to cognitive load, in older persons it is due to disease.

Memory loss due to atrophy and disease

In patients with progressive forms of dementia, which is caused by the atrophy of important anatomical structures; loss of not only memories of one's and other's identity but eventually

of oneself and the entire personality, are altogether eventually lost, since episodic memories are made up of unique experiences, a collection of meaningful people, places, spaces, timepoints, and objects (Lars-Christer, 2018). Some procedural memories can remain for some time, but problems with orientation in time and space, the ability to communicate will eventually worsen. Being self-sufficient becomes difficult, remembering how to button one own's shirt, remembering where the bathroom is or how-to put-on shoes is distressful and confusing for the person and such everyday things become impossible. Therefore, early interventions and detections of AD are important to slow down the disease process on time, and for patients to remain a stable, meaningful, and healthy life; for as long as possible. Memory loss due to disease is beyond the scope of this paper but it is important to know the distinction between memory loss in healthy and sick patients, because they are caused by different mechanisms and factors.

Background

Episodic memory

Endel Tulving was the first psychologist to discover and identify episodic memory (also called declarative memory or autobiographical memory) as a neurocognitive memory system and network in the human brain which consists of conscious memory. According to Tulving, this type of memory consists of a person's self-perceived, self's subjective experiences in space and time (Tulving, 2002; Tulving, 1993; Wheeler, Stuss, & Tulving, 1997).

This type of memory allows and enables mental time travel to past memories, where a person can reexperience events, places, and faces; long gone from the present (Wheeler, Stuss, & Tulving, 1997). Autonoetic conscious awareness involves remembering one owns past and traveling in subjective time (Renoult, Irish, Moscovitch, & Rugg, 2019; Tulving, 1993). Even more, episodic memory together with imagination also enables a person to travel into the future by remembering plans of future goals (Healy, & Caudell, 2019). On a neurocognitive psychological level, episodic memory means retrieving memories from long term memory storage and holding it; to be manipulated and processed in working memory, which has a limited spatial and temporal capacity. Furthermore, memory formation and retrieval have different stages, and these are: encoding, storing, consolidation and retrieval. When it comes to memory impairment and cognitive load a problem during any of these

processes (encoding, storing, consolidating, and retrieving) can occur (Das, Hwang & Poston, 2019).

Human beings use episodic memory every day of their life and it makes planning life and reliving everything from our childhood memories to current events possible. Episodic memory is the ability which surrounds storing and retrieving memories about life experiences, which makes up a meaningful and unique world to every person (Benejam et al., 2022, Tulving, 1993; Tulving, 2003). Encoding, retrieval and storing memories are furthermore processed by different parts of the brain and are made up of complex interacting networks, functions, and systems (Benejam et al., 2022; Tulving, 1993).

Episodic memory is thus, the experiences one has of one's life and identity, but episodic memory is also connected with the visual system and with visual imagery. Imagery is simply put; perceiving without actually seeing, seeing with the eye of one's mind. Traveling back in time or mental time travel is only possible in the memory system of episodic memory, otherwise time is an arrow pointing ahead and not one that goes backwards, time is one directional like a river and it can only go backwards inside the mind (Tulving, 2002).

Our eyes are always moving in the temporal order and spatial direction of the topic and motif of our minds. Our minds direct our eyes through top-down control and bottom-up processing (Källa). During encoding, remembering, recognizing and during picturing. Experienced or unexperienced events are processed with the help of our eye-movements. Thus, our eyes are always moving in the temporal and spatial direction of the content in our minds (Janssen et al., 2021).

Our episodic memories consist of several subsystems which operate both through top-down control and bottom-up unconscious processing. These sub-systems are according to previous research made up of vision, attention, searching and retrieving, recollecting, emotion, and self-referential processes (Janssen et al., 2021). Episodic memory thus consists of many sub-systems with their own neural layers and functions which work together to create the perception of coherence and meaning. Cognitive control is associated with the prefrontal cortex, emotion with the amygdala, attention with the dorsal and ventral stream, recollection, and memory binding, and indexing with the hippocampus, and so on, yet all these anatomical structures are just a few parts of a bigger whole that make up what we understand as episodic memory. Other important areas for episodic memory are the prefrontal cortex (seat of cognitive control, attention, and working memory) and posterior parietal cortex (involved in

spatial orientation and planning of route), these areas are involved in the retrieval and selection of relevant memories (Richmond et al., 2022). Subcomponent to episodic memory are two different processes: familiarity and recollection. Familiarity is a detection process ad recollection is a more conscious retrieval process. Furthermore, the prefrontal cortex, the seat of working memory and executive functioning and cognitive control; works together with the hippocampus and medial temporal lobe in retrieving, recollecting, and recognizing episodic memories or places, faces and events (Zeidman, 2016). Remembering an episodic event is thus controlled by a top-down cognitive control process. And recognizing events, places, and faces that one has seen before. Furthermore, familiarity is a feeling that one has seen an object before, but recollection involves a more conscious retrieval of the previously encountered object (Das, Hwang, & Poston, 2019).

Memory decline and loss due to cognitive load

In 1998 John Sweller developed cognitive load theory (Mavilidi, & Zhong, 2019; Sweller, 2020). The cognitive load theory states that the capacity of working memory is limited and is affected negatively by cognitive load, thus encoding will suffer if there is too much cognitive load. Encoded and learned information is transferred to long term memory because the limited capacity of working memory. A human can remember and hold 7 items of new information in working memory and process about 4 items, processing capacity is around 20 seconds before forgetting occurs (Sweller, 2022). When cognitive load increases the resources of working memory become strained and some information will not be encoded properly and will fail to be transferred to long term memory, memory performance in the form of encoding and processing novel and incoming information will thus suffer.

Through our eye movements, our memories are integrated and encoded in the correct temporal and sequential order. But in dementia and in memory decline, the temporal and sequential order is deranged, and such memory deficits can be detected through the study of eye movements (Ryan, Wynn, Shen, & Liu, 2022; Whitehead, Li, McQuiggan, Gambino, Binns, & Ryan, 2018).

The aim of this current study is to examine how eye-movements and episodic memory are affected by induced cognitive load. Specifically, the study investigates how induced cognitive load affects gaze behavior during the encoding and recognition of naturalistic scenes, as well as subsequent memory performance for those scenes.

Memory decline and divided attention

Episodic memory becomes slower and less effective with for example aging, with time episodic memory will decline and memory becomes impaired (Howe et al., 2020).

Recalling, recollecting, and recognizing previously encoded spatial and temporal episodic memory-events becomes more and more difficult due to for example interference, poor and weak encoding due to the hippocampus inability to bind items together properly. Thus, the weakly encoded memory is easily distorted and more prone to errors and interference (Howe et al., 2020). Several things can disrupt or distort episodic memory encoding, storage, or recognition, these can be cognitive load or for example anything which divides attention. Since working memory is limited, divided attention between one main memory related task and a secondary task will disrupt parts of episodic memory, such as encoding, storage, consolidation, or recognition (Greene, Martin, & Naveh-Benjamin, 2021). If the divided attention occurs during the encoding of the first memory task, then a disruption of memory capacity at encoding or recognition is expected to occur. When limited cognitive resources are divided processing incoming information becomes more difficult and memory encoding will become compromised since all of attention is not focused on one task but on two tasks which need to be processed by the memory system. Thus, information which is not fully attended to during encoding will not be further processed properly into long term memory. Furthermore, familiarity (recognizing an item, scene, or face) and recollecting (effortfully retrieving information) are both top-down processes. Thus, binding contextual and spatial features of a scene during encoding is thus not only a bottom up automatic process but requires allocating attentional resources via top down decisions. Lastly the authors conclude that divided attention interferes with memory if it occurs at encoding but does not interfere with memory processing if divided attention occurs at retrieval (Greene, Martin, & Naveh-Benjamin, 2021).

In this study we study how a cognitive load task interferes with episodic memory by dividing the attention during encoding,

Furthermore, encoding and retrieval of memories are two distinct cognitive processes. Encoding involves deciding on and choosing relevant information, putting information in a

specific order, and storing information while recognition and retrieval demands matching incoming information with stored information (Risius, et al., 2019).

The scanpath theory

This study is grounded in the scanpath theory of vision. This theory states that internal cognitive models via top-down control, oversee looking behavior, perception, and active gaze behavior through top-down control (Stark, & Choi, 1996). So, what is a scanpath you might wonder, a scanpath is a spontaneously generated eye pattern, which consists of repetitive and changing saccades and fixations, these saccades and fixations repeat themselves when a person is looking at a scene or for example a picture (Stark, & Choi, 1996). According to the authors the theory states that the scanpaths are controlled by a top-down process, the actual looking/ viewing but also the perceptual process itself. Simply put people perceive with their mind, and that means that the visual perception is mainly a top-down process. The scanpath theory stands in opposition to the view that eye movements are influenced by the outer world and that scanpaths for example are ruled by a bottom-up process that send signals to the brain via the retina. The scanpath theory in contrast states that inner cognitive models and top-down control and perceptions control active looking and viewing and that it is not just an implicit bottom-up reaction to shapes, motions, colors, and other features of the outer world.

Previous research has shown that investigating memory processes through eye movements and eye metrics data has been beneficial to study the mind's eye, or what is going on in the mind, when we perceive. By following and looking at eye movements scientists can study how memories are encoded, retrieved, stored and how they can become disrupted or distorted (Stark, & Choi, 1996). Internal cognitive models control what we look at and not the external world in itself (Stark, & Choi, 1996). According to the authors the visual perception is thus driven by cognitive models which direct the repetitive scanpath which serves as a modification process of the inner cognitive models. What we see is just a reflection of our perceptions and inner cognitive models and not only sensory input from the outer world.

If we follow this theory than an induced cognitive load that mimics memory decline should disrupt top-down controlled visual perceptual, episodic memory processes, such as encoding and recognition, due to the load interfering with working memory capacity. This in turn will be reflected in the scanpath similarity or dissimilarity.

By looking at scanpaths during no load conditions and cognitive load conditions and compare them with each other we can see if the memory has become affected by the induced cognitive load, which in this study mimics actual cognitive decline.

Previous research describes the importance of scanpath analysis as it enables an understanding of eye movements through space and within a given time, therefore causation of memory can be examined (Dewhurst et al., 2012). Scanpath analysis is thus the most appropriate analysis for studying memory encoding because it gives us the direct path the visual system takes and directs when encoding memories, in time and in space, and thus the original memory without the cognitive load or induced memory decline can be compared to the memory where there was an intrusion to the attention of the visual system. By making such a comparison the difference between the healthy and "damaged" memory can be compared, through a scanpath. Previous research has shown that scanpath analysis can be used as a tool to study neurological disorders (Dewhurst et al., 2012).

Relevant structures and functions of episodic memory

In this section, a short summary of important anatomical structures is presented, which are relevant to episodic memory. This part of the paper serves an informative role, to really understand episodic memory, and potential deficits, one needs to be aware of the anatomical structures of the brain and their functions and roles in formation, retrieval and consolidation of episodic memories.

Medial temporal lobe and episodic memory

Our episodic memory is in parts made up of connected networks in the medial temporal cortex (Sawczak et al., 2022). Without the integrity of these structures and networks, we would not know who we are, and much less where in time and space we are. Our self and identity reside in this complex anatomical seat of the medial temporal cortex. This is because crucial subcortical structures for memory encoding and retrieval, recollection, and recognition

are seated within the medial temporal lobe. The medial temporal lobe is the home base of many crucial structures like the hippocampus, amygdala, and entorhinal cortex. A recent study found that within the entorhinal cortex and hippocampus, there are memory-sensitive neurons, these were found through implanted electrodes. These memory sensitive neurons had a specific type of firing rate that could predict episodic memory encoding and these firing patterns were proved to be reinstated during the time of retrieval (Yoo, Umbach, & Lega, 2021).

Hippocampus and episodic memory

The Hippocampus is a subcortical structure, situated deep inside the medial temporal lobe, covered by the folded cortex which consists of gyri and sulci, and it is a crucial structure for cognition and memory (Zeidman, & Maguire, 2016). The hippocampus is also responsible for making sense of internal maps of spatial scenes and events in time and place, hippocampus is also involved in the current perception of the world by making sense of the experienced environment (Zeidman, & Maguire, 2016).

The hippocampus is linked to the frontal eye fields which are responsible for eye movements related to cognitive control and in that way this connectivity promotes the recollection of memories (Armson et al., 2021). In age-related deterioration, hippocampal volume is lower, and connectivity is lost, and the loss of matter leads to cognitive memory decline (Richmond et al., 2022). Another interesting finding that concerns the hippocampus is that rhythmical theta oscillation which are neuronal firings that are associated with the recall of episodic memories and spatial navigation, any damage to the hippocampus is detrimental to spatial navigation and orientation, and if any loss of the hippocampus occurs the consequences will be temporal lobe amnesia (Aggleton, & O'Mara, 2022). Thus, the hippocampus is involved in both encoding and retrieval of episodic memories, both in perception and in remembering (Zheng et al., 2022). When an event is experienced the episodic memory of that event is simply a byproduct of the brains processing of that event. The cortical activity of that event is encoded in the hippocampus as a cortical pattern representing a memory and the hippocampus further binds the cortical activity of that memory into representation. This representation is reactivated during recollection by the hippocampus via pattern completion; reactivation of an episodic memory is an encoded pattern of cortical activity which represents the episodic memory of a specific event (Renoult et al., 2019). Theories of episodic memory state that the

retrieval of memories depend on the hippocampus which interacts with the neocortex and works as an index to pinpoint where the memories are stored, thus the neocortex and the hippocampus work in coordination to find and reinstate memories into conscious awareness (Estefan et al., 2019).

When the hippocampus is damaged as in for example Alzheimer's disease the hippocampus fails at pattern separation processing, and pattern completion processes and similar memories of scenes might become confused (Damiano, & Walther, 2019). The dentate Gyrus is responsible for the pattern separation mechanism (Grande et al., 2021). Furthermore there are also pattern completion mechanisms which control incoming information via the CA3, the completed information then travels to the CA1 where the information is compared to incoming memory information, thus in the CA1 it is either reinstated if it has previously occurred in memory but if the information is novel it will be stored as new information that is marked as a new representation (Grande et al., 2021). Episodic memory simply cannot exist without the hippocampus and the size of the anatomical structure itself is also an indication of memory capacity, with atrophy being a clear indicator of serious memory decline, such as impairments in recollection and impairments in reinstating the original cortical activity which occurred during encoding (Madan, 2020).Hippocampus is crucial to episodic memory because it tells us where, when, what and how, events in time and space occurred; hippocampus points us in the right direction of episodic memories their contexts and enables mental time traveling (Maden, 2020).

Eye movements and memory

For many people, the eyes are a way to explore the environment, faces, places, and objects and to receive input into our brain which is stored for future orientation, planning, and proper action, our eyes are in a way a window to the outside world but also to the inside of the mind and brain where our memories exist.

Previous research has shown that eye movements support memory recollection, and the retrieval of details in episodic memories (Armson et al., 2021). When personal remembered events are retrieved or recalled it has been shown that this can be detected through the number of saccadic eye movements. Through eye movements, spatial and temporal orders are reintroduced into conscious memory and thus reexperienced (Armson et al, 2021). The oculomotor system is connected structurally and functionally with the medial temporal lobe;

When attention is turned inward, imaging and eye movements together recollect the memory and thus the memory is reexperienced. On the other hand, when objects and places are recognized, they are connected to gaze fixations, recognition occurs when you look at something previously encountered. Thus, when an object, face, or place is recognized a person will fixate their gaze on that particular area of interest to process the information in working memory (Armson et al,2021). Thus, gaze fixations and saccadic eye movements are a part of explorative behavioral movements which aid in encoding and recognizing memories.

Furthermore, a previous study has demonstrated that episodic memory is linked with several eye metrics (Janssen et al., 2021), and found that when participants accessed memories they showed more fixations, shorter fixations, more blinks, and smaller pupils. The larger number of fixations was interpreted as an indicator of memory search similar to a real visual search, which happens during the encoding of ongoing events (Janssen et al., 2021). The visual search shows that participants focus on internal memories and look for that or those specific memories. Longer fixations and larger pupils are an indicator of cognitive load and a display of greater cognitive effort in searching for a memory, the fixations indicate processing demanding information. In sum, the visual system is highly involved in memory encoding, recognition and retrieval (Haj et al., 2022).

A study by (Damiano, & Walther, 2019), showed that when participants viewed remembered pictures, they spent less time fixating their eyes on those same images, as opposed to when they viewed novel or forgotten images which were characterized by more fixations. Better memory was linked with longer fixation duration to the scene and more fixations, and longer fixation duration indicates information processing (Foulsham et al., 2012).

 Therefore, encoding and retrieval can effectively be studied with eye tracking, which is not as intrusive and distressing as actual interviews that assess memory impairments.

The study successfully predicted from eye movements whether stimuli in the form of pictures would be remembered, thus the accuracy of memory can be investigated through eye tracking. Furthermore, the study found that existing memories guide eye movement repetitions in retrieval through what is referred to as the scanpath hypothesis, this means that repeating the eye movements which were done during encoding improves memory retrieval (Damiano, & Walther, 2019).

Another interesting finding in the study by (Damiano & Walther, 2019) was that forgotten images were treated as never-before-seen images by the participants. Furthermore, to further

build support for the hypothesis that eye movements have a causal role in memory encoding and retrieval the study concluded that memory was impaired when a divided attention task was introduced simultaneously as encoding the image via eye movements (Damiano, & Walther, 2019). Most importantly the study found that not only do eye movements affect memory but memory itself affects eye movements.

Gaze behavior and memory decline

Recent findings show that there is a close connection between the oculomotor system and the memory system (Liu, Shen, Olsen, & Ryan, 2018). Eye movements are crucial for memory representations, for example because visual exploration is connected to the functional integrity of the hippocampus, and that the more gaze fixations a person makes to a stimulus, the better the memory for that stimulus will be. Thus, if the gaze fixations in any way are restricted the memory for that specific stimulus which was attended to during the restriction will be impaired. Visual exploration is thus closely connected to the hippocampus ability to bind and form memory representations while the person is encoding and exploring a scene. Typical eye gaze fixations last around 250 to 400 milliseconds (Ryan, Wynn, Shen, & Liu, 2022). By using eye-tracking as a method researchers have been able to investigate how the eyes tend information in high temporal and spatial resolution in real time while viewing what the eyes of that person is attending to, how they encode and retrieve memories, therefore, eye-tracking has been used previously to study changes in memory-functioning due to for example aging milliseconds (Ryan, Wynn, Shen, & Liu, 2022). Thus, with eye tracking memory related cognitive changes can be studied through eye metrics data. Individuals with cognitive decline show changes in eye movements which mirrors the changes which occur in the underlying structures and functions of anatomical memory seats like the hippocampus, medial temporal lobe, and entorhinal cortex. Deficits in memory due to disconnections between the information sent between the oculomotor system and the medial temporal lobe can be seen for example when older adults with cognitive decline do not show any preference for new pictures of scenes over previously viewed ones. By examining free viewing and scene exploration with eye tracking memory encoding and retrieval can be studied from moment to moment in real time as it occurs. Thus, there is a close relationship between the oculomotor system and the hippocampus (Ryan, Wynn, Shen, & Liu, 2022). Eye movements have been used as an alternative to classical diagnostical tools to screen for cognitive memory decline, since eye tracking paradigms are more appropriate to use for patients with language

impairment (Whitehead et al., 2018). Thus eye-tracking has been used to both diagnose and to study memory decline and impairments. Other studies have also used eye-tracking as a diagnostical tool to assess memory decline/impairment in older adults, by detecting abnormal eye-movements, slower reaction times and other abnormal eye-related behaviors which indicate memory decline, impairment, or other problems in the older population (Tokushige et al., 2023).

The present study

Aim

The aim of this study is to investigate how eye-movements relate to memory encoding and recognition; during induced cognitive load which is supposed to mimic memory decline. The study contains an experiment with healthy individuals. The experiment will consist of an encoding phase and a recognition phase, a cognitive load will be induced during a short time interval that will mimic the negative effects of aging on memory. Another aim of this study is thus to lay the groundwork for future development of diagnostical tools with eye-tracking for detecting the early onset of Alzheimer's disease or other diseases which are characterized by memory decline.

In summary this study aims to investigate how eye movements encode and recognize episodic memories during cognitive load (Wynn et al., 2022). Specifically, the study will simulate memory deterioration in healthy adults to investigate whether eye-tracking could potentially be used as a diagnostic tool in the future assessment of Alzheimer's disease.

Hypotheses

The first hypothesis is that increased cognitive load will make it more difficult to encode a picture. Thus, memory for a picture will be more distorted in a condition with higher cognitive load when compared to a condition with lower cognitive load. This distortion will be expressed as poorer memory performance in a subsequent memory test.

The second hypothesis is that increased cognitive load will impair the capability to recognize previously seen pictures and thus impact/influence the visual processing of such pictures. It is expected that poorer recognition will be expressed in more fixations, i.e., a visual sampling behavior that is more like viewing a novel picture.

The third hypothesis is that the overlap in scanpaths between the first and second time a picture is inspected, will decrease as a function of increased cognitive load. Thus, more cognitive load will lead to less scanpath similarity.

Method

Design

The study consists of a block design with controlled conditions, with different difficulty levels. These levels were: baseline, easy and hard. The baseline level was the control condition, and there was no cognitive load in this condition. The different conditions consisted of a Sternberg Task which induced cognitive load. See Figure 0.

The Sternberg task consisted of figures in the form of consonants which were displayed for a few seconds between every picture of outdoor scenery. The combination of consonants in the easy and hard conditions is thus referred to as the Sternberg Task, and the participants were instructed to keep the combination of consonants in memory while evaluating the pictures of outdoor scenes. The participants had to remember the exact order in which the consonants appeared, and the Sternberg task is meant to induce cognitive load in the participant and impair memory encoding and recall. See Figure 0.

The task which the participants face is to encode information (outdoor scenes) while maintaining another type of information in the mind simultaneously, (consonants in a particular order). The participants were instructed to evaluate the outdoor pictures by rating if they liked the picture, disliked the picture or if they were neutral towards it. Right key was pressed for liking, left for disliking and the arrow pointing down was pressed if they were neutral. In the control condition which consisted of 30 trails there was no Sternberg Task to keep in mind. The other 2 conditions consisted of one level with 3 consonants which were easy to remember, and one level which was difficult to remember consisted of 7 consonants, both levels consisted of 30 trails. See Figure 0.

Participants

The data sample consists of students from Lund's University. 34 (19 females, 1 identified as other and 14 males). Students from different departments were recruited. The mean age was 27, and the standard deviation was 6, (Mean = 27, SD = 6).

The inclusion criteria were cognitively healthy, normal, or normal-to-corrected vision, and that they were well rested before the experiment. All participants fulfilled the inclusion criteria.

One participant's data was lost due to the computer updating and shutting down in the middle of the experiment. 4 more participants were lost due to the lab being booked the last days of the experiment, thus 34 remained.

Ethical considerations

All participating subjects were anonymous and were informed that they could withdraw their consent at any given time if they for any reason changed their mind, no needed explanation needed to be given. All participants were informed about their rights, to remain anonymous to give and withdraw consent freely and that no harmful psychological or physiological influence would be applied to them during the experiment. All participants signed an informed consent form. The study was conducted in line with the ethical declaration of Helsinki.

Equipment and materials

The experiment was programmed and presented in PsychoPy (Pierce, 2007). Eye metrics data and eye movements were recorded with a Tobii Pro Spectrum eye tracker (Tobii, Stockholm, Sweden). Data from both eyes was recorded with a sampling frequency of 600 Hz. Participants had their heads stabilized with a chin and forehead rest. Stimuli were presented at a viewing distance of 62 cm on an EIZO FlexScan EV2451 monitor with a resolution of 1920 × 1080 pixels and a refresh rate 60 Hz, which was part of the Tobii Pro Spectrum eye tracker. 9-point calibration and validation routines were conducted before the first block and was repeated until the deviation scores were below an error of 0.5° both horizontally and vertically. Eye movement recording a calibration was controlled by the open-source toolbox Titta (Niehorster et al., 2020).

Stimuli and design

130 pictures were chosen as the stimuli material, some pictures were found on a free platform called Tumblr and other parts of the stimuli pictures were taken with a Samsung 51A phone camera. We also included a Sternberg Task, consisting of different combinations of consonants, which was randomly generated. The instructions were in English, and the experiment was programmed in PsychoPy. The cognitive load task was the Sternberg task, and its point was to induce cognitive load.

Figure 0

Study design
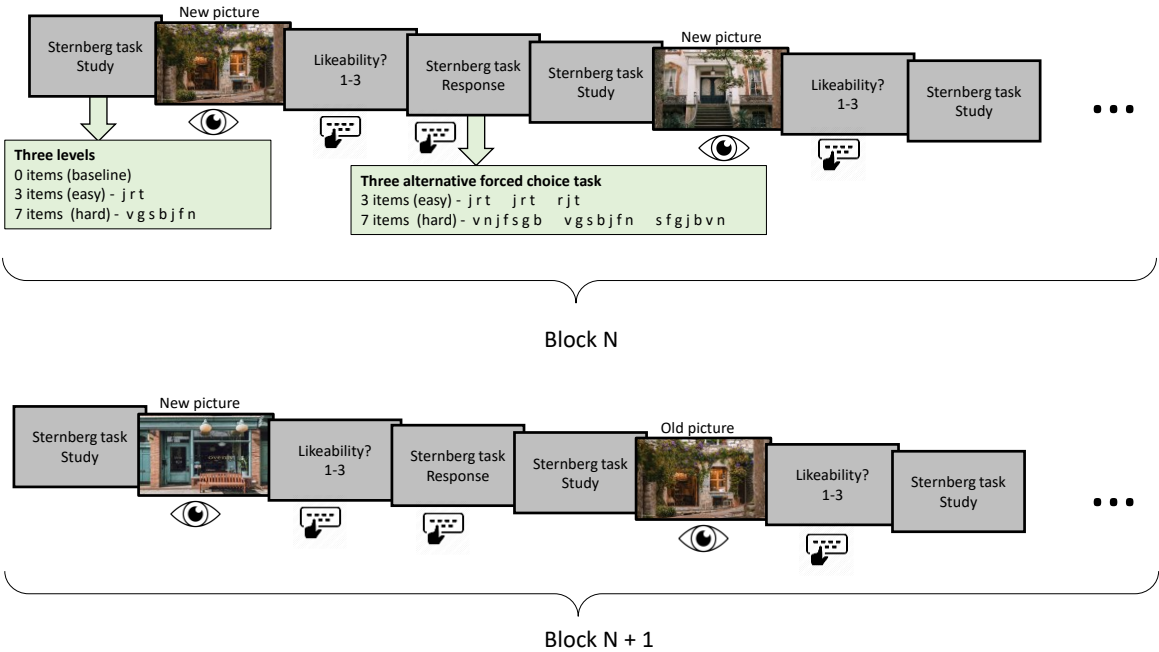
Procedure

When the participants entered the laboratory, they filled in two consent forms, one of the consent forms was a copy for them to keep. The chin-and forehead rest were cleaned with alcohol wipes before and after every participant contribution and participation.

After being seated comfortably they were instructed that the experiment would approximately take 60 minutes to complete and that the first part of the experiment is a practice round. After the practice round calibration was done, the calibration that we aimed for was below 0.5 degrees accuracy. The participants were instructed to look at the center of the calibration circle, and to follow it with their eyes. The experiment lasted for around 50- 60 minutes,

depending on how quickly the participants finished it, some were faster, others took more time. The experiment had 5 blocks and 12 pictures in every block. Each block included 3 parts (Baseline, Sternberg easy and Sternberg hard). Each part consisted of 12 pictures, 6 of these were old pictures and the other 6 were new pictures, never previously seen. This goes for all blocks except for the first block. 36 pictures were shown in each block, these were: 12 baseline, 12 Sternberg easy and 12 Sternberg hard. 36 x 5 = 180 trials in total.

In some conditions the participants got to view the pictures freely without a cognitive load Sternberg task, this condition was called baseline. And in some conditions the participants had to view the pictures after viewing the cognitive control task; these were the easy Sternberg level consisting of 3 letters and the hard Sternberg level, consisting of 7 letters. See Figure 0.

The last 10 minutes of the experiment were dedicated to a surprise memory test which consisted of the original pictures and an identitcal mirror image. The participants had to choose between the correct image and an identical mirror image. In this last surprise memory test, all the previously studied images were shown again, this was shown and done to measure how well the participants remembered the images. Participants were not aware of this last surprise memory test.

Analysis

In this chapter all the different analyses are explained.

Measurements were made to investigate whether the Sternberg task worked, and if it really did induce cognitive load. The cognitive load was consequentially measured through reaction time/response time and memory accuracy and performance; of the Sternberg task itself.

Furthermore, measurements of how the Sternberg task influenced memory of the images and through the gaze parameters/ eye metrics data were made. The eye metrics data that was investigated was the number of gaze fixations for the new and old pictures and gaze duration, that is how long the participants looked at the pictures. And the scanpath similarity for the different pictures were analyzed.

There was some background data which measured if the Sternberg task worked, this would mean that the participants exhibited less accuracy and longer response times, for the hard condition rather than the easy condition. The last surprise mirror memory test also examined if the induced cognitive load/Sternberg task influenced memory for the images.

All the repeated measures ANOVAs were done in JAMOVI, and two scanpath similarity analysis were done with repeated measures ANOVA.

The first analysis was done to test if the Sternberg task had an influenced the likeability interacted with the outdoor scenes.

The first hypothesis is that increased cognitive load will make it more difficult to encode a picture. Thus, memory for a picture will be more distorted in a condition with higher cognitive load when compared to a condition with lower cognitive load. This distortion will be expressed as poorer memory performance in a subsequent memory test.

The second hypothesis is that increased cognitive load will impair the capability to recognize previously seen pictures and thus impact/influence the visual processing of such pictures. It is expected that poorer recognition will be expressed in more fixations, i.e., a visual sampling behavior that is more similar to viewing a novel picture. Tests were also done to analyze how fixation duration and the number of fixations, were affected by participants viewing the old pictures and the new pictures during the different levels of the induced cognitive load which is the Sternberg task, and memory for the scenes.

Third hypothesis is that the overlap in scanpaths between the first and second time a picture is inspected, will decrease as a function of increased cognitive load.

Thus, more cognitive load will lead to less scanpath similarity. The position dimensions in the multi match were the most reasonable dimension to use as a proximity measure for the scanpath similarity. The scanpath similarity analysis means that the similarity is a comparison of the order of fixations between two scan paths analysis was done to test if the Sternberg task/ the induced cognitive load worked. We expected less accuracy for the hard conditions, than for the easy conditions and longer response times.

The scanpath similarity analyses

Lastly, a scanpath similarity analysis was done to check if the scanpath similarity for the new and old pictures, (first time the participants saw the pictures versus the second time they saw the images) were similar to each other, and if the exposure of the images was influenced by the different Sternberg levels and the memory of the scenes. Thus, the scanpath similarity measures position of fixations and the difference in the shape of the saccadic vectors and calculates similarity between the first time a specific image was observed and the second time a specific image was observed (Foulsham et al., 2012). This comparison is done to calculate how similar the scanpaths or motoric eye-sequences of memory are to each other.

Lastly, a repeated measures ANOVA was done for the scanpaths between the different cognitive load/Sternberg levels and randomly chosen pictures of the outdoor scenes. This was done to check for the influence of chance over memory recognition reflected through similar scanpaths. The Random similarity measures were calculated by testing the average similarity for the old images in relation to all other images in the same Sternberg condition. The average similarity was calculated for the difference between the second (old pictures) time a specific image was viewed and between all other images which were observed the first time, within the same Sternberg level. The expectation was that; if there is similarity in the scanpaths between the first and second time an image is viewed and observed, the similarity should be higher than when it is compared against chance: a random condition.

Results

In this chapter the results from the experiment are presented in text, and in figures.

Descriptive data

For analyzing how the cognitive load effected the participants evaluation of the pictures: if they liked or disliked the pictures, a repeated measures Anova was performed. The factors Scene type (old pictures and new pictures) and the factor Sternberg levels (Baseline level, easy level, and hard level) were compared to each other. There were two main effects on both scene type and on Sternberg level. There was no interaction effect between scene type and Sternberg level. A statistically significant difference was found for the factor scene type:

$F(1, 33) = 14.207, p = .001, \eta^2 p = 0.301.$

There was also a statistically significant effect for Sternberg level difficulty:

$F(2, 66) = 4.072, p = 0.021, \eta^2p = 0.110.$

There was no interaction effect between the two: $F(2, 66) = 0.295, p = 0.746, \eta^2p = 0.009.$ New pictures were rated as more likeable than the old ones. During the difficult Sternberg level, the pictures were rated as less likable. Figure 1 depicts the plot for these results.

Figure 1

Descriptive data – Induced cognitive load and likability for scene types.
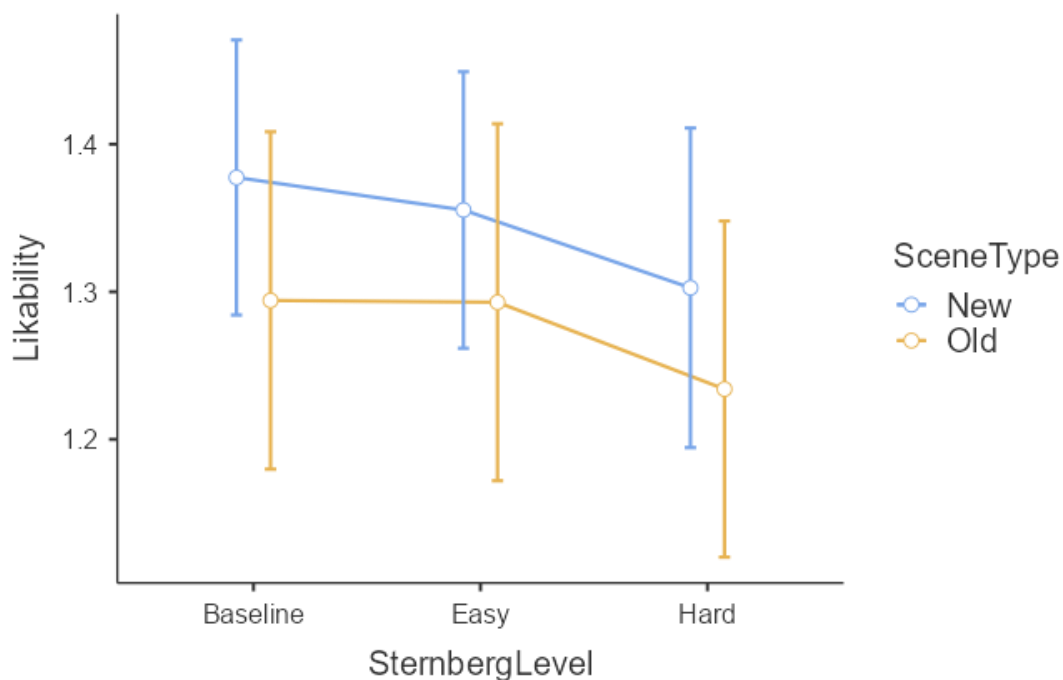
Memory test

In this section results for cognitive load and memory accuracy for old and new pictures is presented. For the memory test there were two significant main effects, but no interaction effect. The Anova investigated the difference between the factor scene type (old and new pictures) and the factor Sternberg levels, which in this analysis consisted of only two levels: easy and hard.

There was a statistically significant effect for Sternberg level difficulty between easy and hard, $F(1, 33) = 10.929$, $p = 0.002$, $\eta^2 p = 0.249$.

The Sternberg hard task was indeed more difficult for the participants than the easy and baseline conditions, and performance was better for old pictures or the previously seen pictures. A statistically significant main effect was found for the factor scene type:

$F(1, 33) = 6.131$, $p = 0.019$, $\eta^2 p = 0.157$. The performance was better for the old pictures. There was no interaction effect between the factors Scene type and the factor Sternberg levels: $F(1, 33) = 0.325$, $p = 0.573$, $\eta^2 p = 0.010$. Figure 2 depicts the plot for these results.

Figure 2

Cognitive load and memory accuracy for old and new pictures.
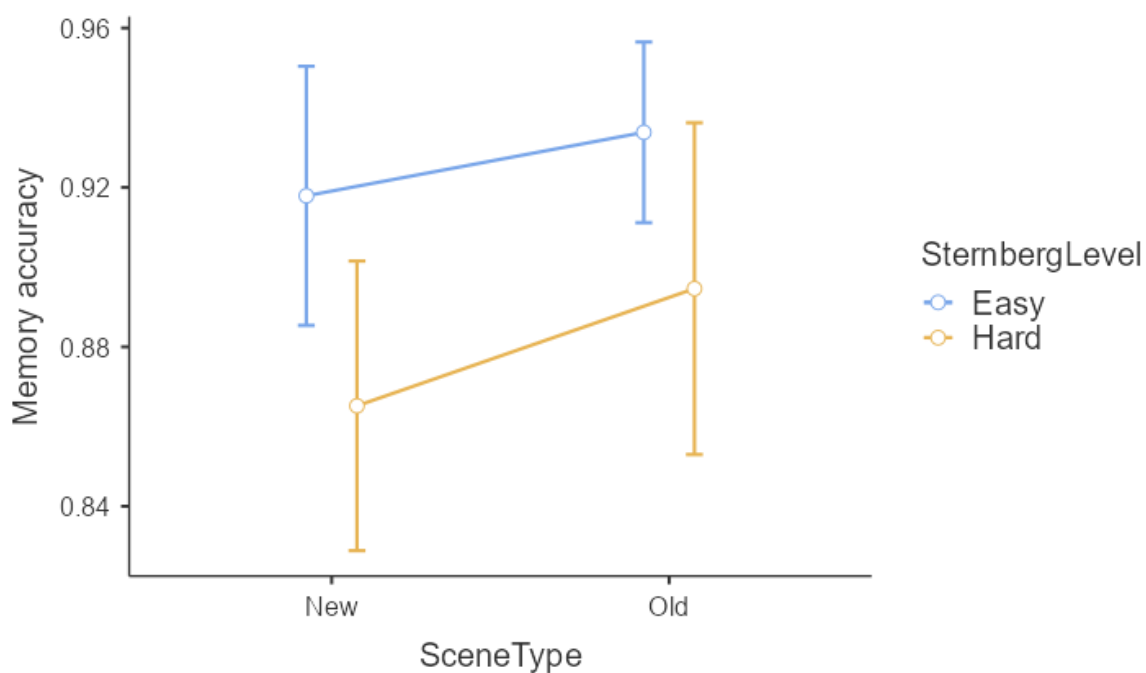
Cognitive load, response times and the Sternberg levels.

Response times were also analyzed for the Sternberg tasks when participants looked at the old, previously seen pictures versus the new, never before seen pictures. There were two main effects here and one interaction effect. The first main effect was for the different Sternberg levels: $F(1, 33) = 93.83$, $p = .001$, $\eta^2 p = 0.740$.

The hard Sternberg level was more difficult for the participants.

The second main effect was for Scene type, old and new pictures: $F(1, 33) = 7.62$, $p = 0.009$, $\eta^2 p = 0.188$. The performance was better for the previously (old) seen pictures.
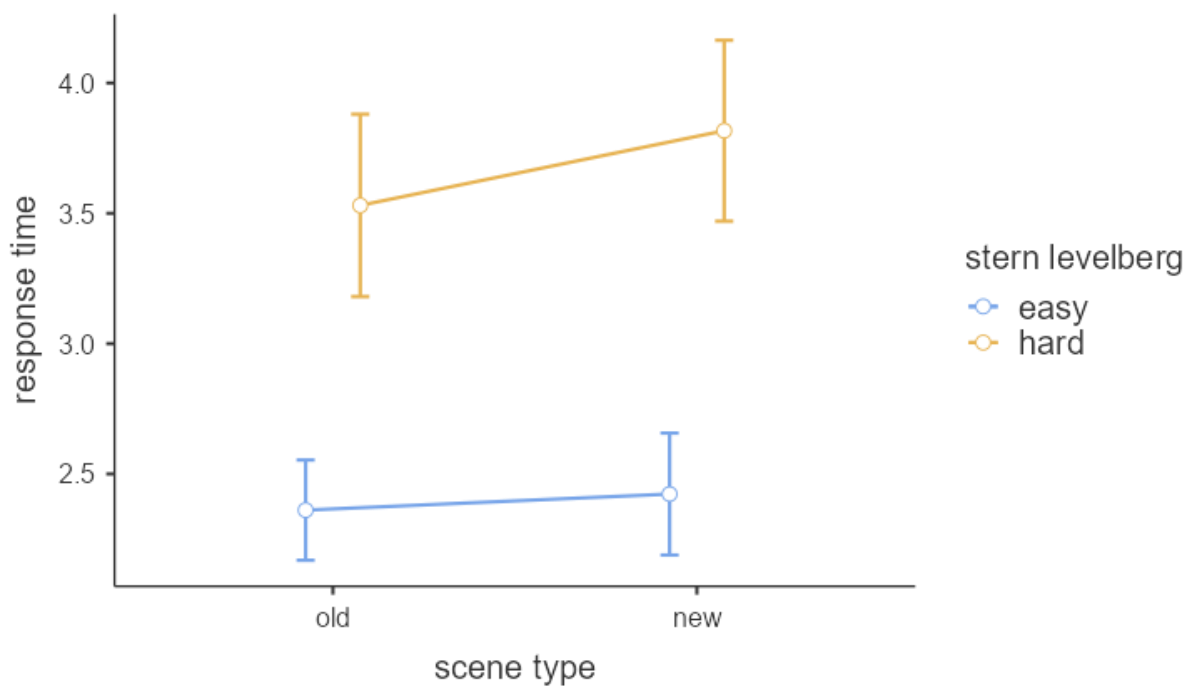
And the interaction effects were between scene type and Sternberg levels:

$F(1, 33) = 7.11$, $p = 0.012$, $\eta^2 p = 0.177$.

Response time is mostly related to cognitive load and the response times were slower for the hard Sternberg conditions. Figure 3 depicts the plot for the results.

Figure 3

Cognitive load, response times and the Sternberg levels.

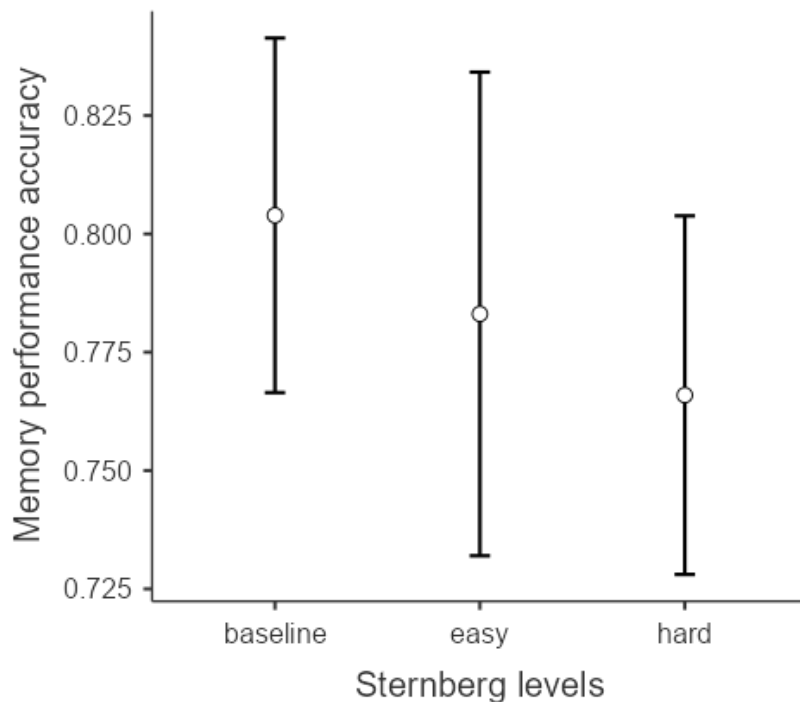**Cognitive load and memory performance**

These results are for the investigation of the cognitive load, which is the Sternberg levels, and how the levels affect the memory performance.

The results were not significant: $F(2, 66) = 2.24, p = 0.115, \eta^2p = 0.063$.

Figure 4 depicts the plot for these memory performance results.

Figure 4

*Cognitive load and memory performance*

Response times during memory test

This Repeated measures Anova analyzes hypothesis 1, it measures memory performance and reaction times, during the different Sternberg levels, no difficulty which was baseline, easy difficulty, and hard difficulty. There were no significant results: $F(2, 66) = 0.710, p = 0.495, \eta^2p = 0.021$. Figure 5 depicts the plot for these results.

Figure 5

Response times during memory test
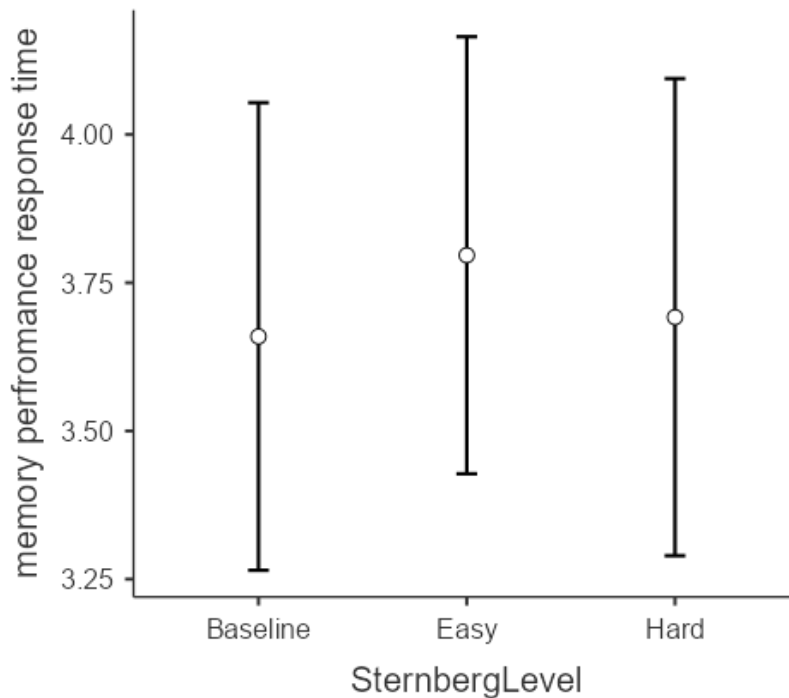
**Analysis for hypothesis 2**

Number of fixations

For hypothesis 2, the number of fixations that occurred during the cognitive load levels was investigated. Scene type, (which were old pictures and new pictures), the factor Sternberg level, and the number of fixations that the participants made for the new versus old pictures during the different Sternberg levels was measured with a repeated measures Anova. There were two main effects and one interaction effect. There was a main effect for the scene type, $F(1, 33) = 34.45$, $p = .001$), $\eta^2 p = 0.511$. The main effect means that it mattered if the participants looked at new or old pictures. There was also a main effect for the Sternberg levels: $F(2, 66) = 7.31$, $p = .001$, $\eta^2 p = 0.181$. which means that it made a difference whether the participants were viewing the pictures after the different Sternberg levels which were baseline, easy and hard. There was also an interaction effect between the scene type and the Sternberg levels: $F(2, 66) = 6.24$, $p = .003$, $\eta^2 p = 0.159$. This means that there was a difference in the number of fixations during the different cognitive load/Sternberg levels while the

participants viewed the old and new pictures. There were more fixations for the new pictures during the easy Sternberg level. Figure 6 depicts the plot for the number of fixations.

Figure 6

Number of fixations during cognitive load
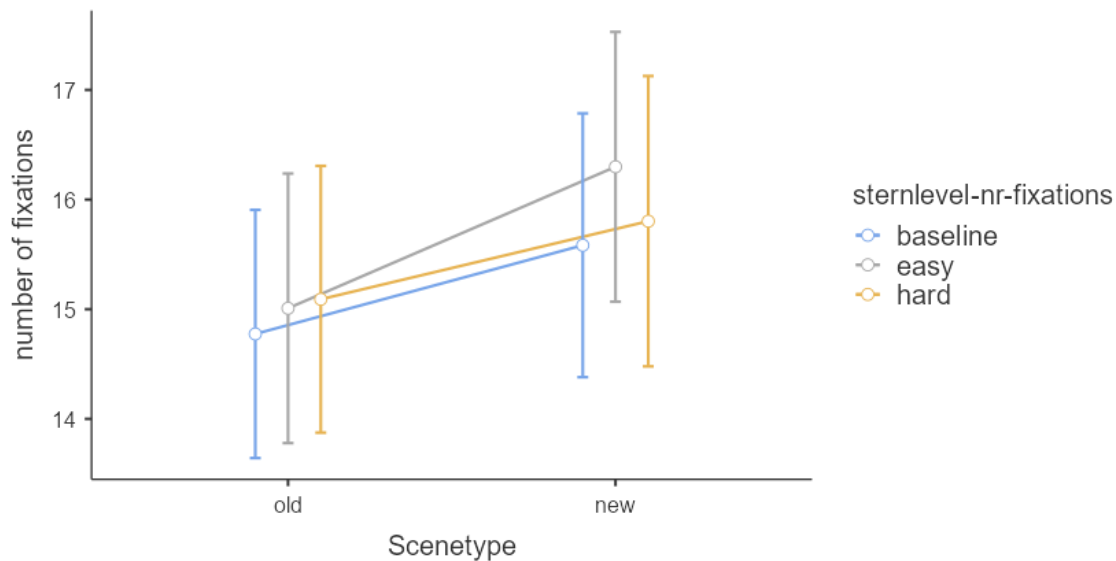

Fixation duration

The second investigation for hypothesis 2 was the comparison of the factor Scene type (old and new pictures), and the cognitive load/Sternberg levels and the duration of eye fixations. There were no significant main effects, but there was a significant interaction effect. There was no main effect for Scene type, $F(1, 33) = 0.712$, $p = 0.405$, $\eta^2 p = 0.021$.

This means that there was no statistically significant difference in fixation duration when participants looked at new versus old pictures. For Sternberg level there was no statistically significant main effect, $F(2, 66) = 1.661$, $p = 0.198$, $\eta^2 p = 0.048$. There was no statistically significant difference in fixation duration during the different cognitive load levels, which were baseline, easy and hard. There was an interaction effect between the scene type and the Sternberg levels, $F(2, 66) = 3.305$, $p = 0.043$, $\eta^2 p = 0.091$. The different Sternberg levels mattered for fixation durations for the old and new pictures, and the participants exhibited

longer fixation durations for the ne pictures in the easy cognitive load level. Figure 7 depicts the plot for these results.

Figure 7

Fixation duration during cognitive load while viewing different scene types.
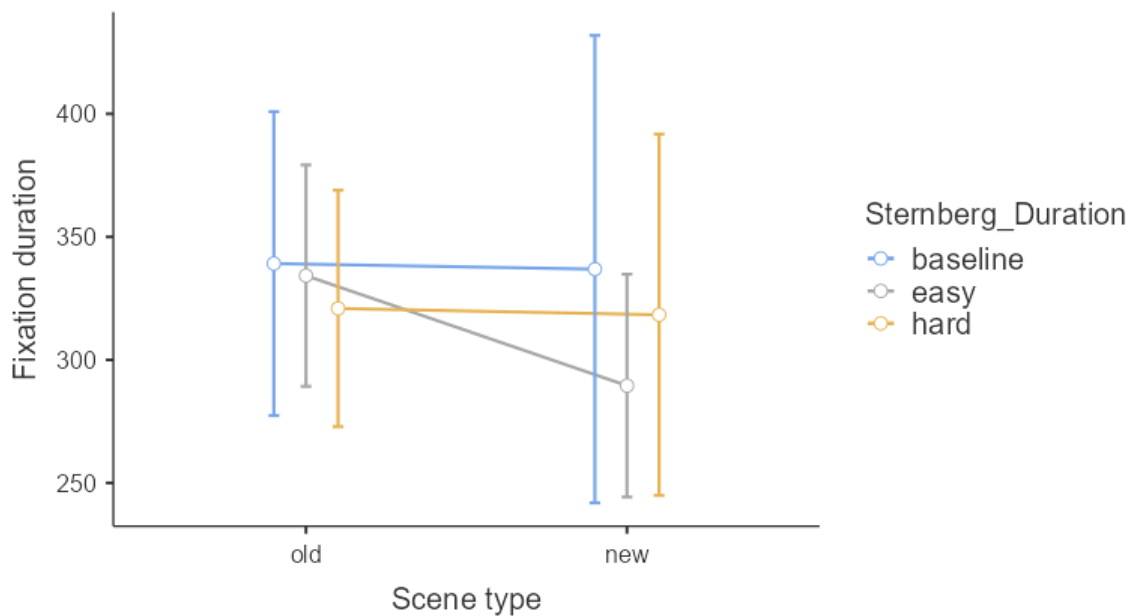
Hypothesis 3

The scanpath similarity measures how similar the order of fixations are between two scanpaths, this was tested with a repeated measures ANOVA. Figure 8 refers to the plot of these results. The first scanpath similarity was based on the position if fixations.
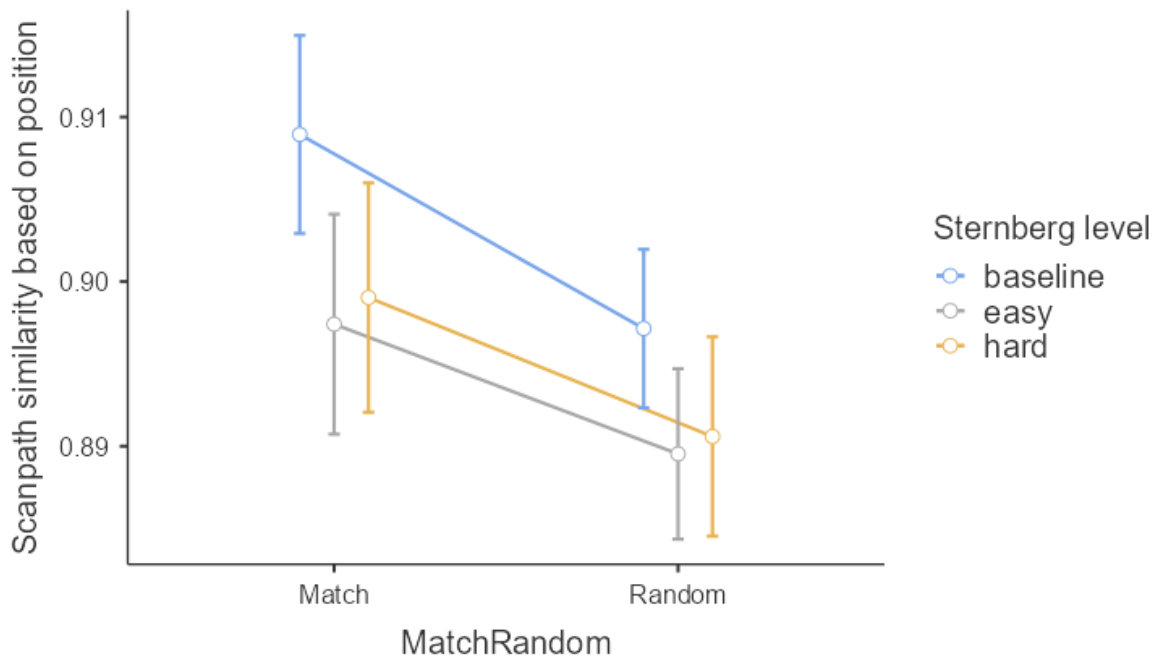
The results show the scanpath similarity between the different cognitive load/Sternberg levels and the position of fixations. There were two main effects but no significant interaction effect.

The main effect was for the Sternberg levels and the scanpath similarity: $F(2, 66) = 13.17$, $p = .001$, $\eta^2 p = 0.285$. The second main effect was for the randomly matched pictures: $F(1, 33) = 74.07$, $p = .001$, $\eta^2 p = 0.692$. No interaction effect was found between randomly matched pictures and the cognitive load/Sternberg levels, $F(2, 66) = 2.04$, $p = 0.139$, $\eta^2 p = 0.058$. Figure 8 shows the plotted results for the scanpath similarity based on position.

Figure 8

Scanpath similarity based on position.

A scanpath similarity analysis was also done based on the shape of the scanpath.

The different cognitive load levels/ Sternberg levels and the shape of the scanpath similarity was compared against randomly matched pictures, there were two significant main effects but no significant interaction effect.

For the Sternberg levels the main effect was significant:

$F(2, 66) = 9.46$, $p = .001$, $\eta^2 p = 0.223$. For the Random match there was also a significant statistical effect: $F(1, 33) = 179.19$, $p = .001$, $\eta^2 p = 0.844$. There was no significant interaction effect between Sternberg levels and randomly matched pictures: $F(2, 66) = 2.58$, $p = 0.083$, $\eta^2 p = 0.073$.

The plotted results are depicted in figure 9.

Figure 9

Scanpath similarity based on shape.
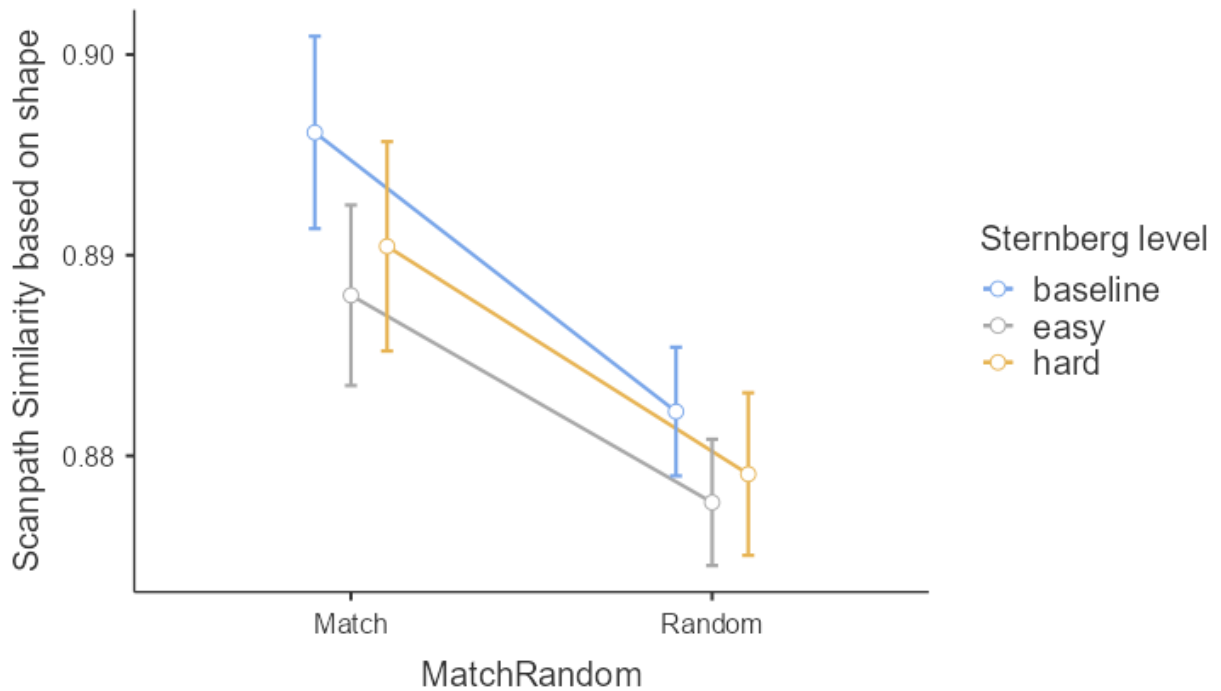
Discussion

For the first analysis which concerned the descriptive data the interpretation would be that new pictures were more stimulating and interesting and therefore they were considered to be more likable, as for the difficult Sternberg level, the cognitive load took up too much processing power and this interfered with memory capacity, in line with the cognitive load theory and therefore the pictures were deemed as less likable. Because there were less resources to explore the pictures fully with the eyes since working memory was occupied with holding the difficult Sternberg task in memory, eye movements that could be made were limited. This is an interpretation of why the pictures were judged as less likable

because the top-down cognitive control was divided between two tasks, remembering the correct order of the letters, and exploring, the picture.

The conclusion drawn from the first analysis is that cognitive load does affect memory capacity, as predicted according to the cognitive load theory (Sweller, 2022; Sweller, 2020).

Regarding the memory accuracy during the different Sternberg levels, no significant effects were found here, this could be because our sample of participants was very small.

Another problem which might have interfered is that the task to correctly choose between a mirror image and the original image is that this task was not very cognitively demanding, and the participants had already seen the original pictures several times during the experiment, thus the picture probably has been encoded; but the participants only saw the mirror image one time during the whole experiment, therefore making a correct choice was not altogether that difficult since the correct image was seen many times and the mirror image only ones.

If the surprise memory test at the end of the experiment had been more complex and cognitively demanding, there might have been significant effects. Thus, memory accuracy was not impaired by the induced cognitive load in this part of the experiment.

However, there was a trend in this analysis of memory accuracy and cognitive load, and the trend was that memory performance does tend to decline with increased cognitive load. This is what was predicted and expected with the hypothesis. This hypothesis (that increased cognitive load would interfere with memory encoding) had to be rejected. More research is needed, because the sample was too small to make any final conclusions regarding the matter. Alternatively, a more complex surprise memory test with more choices with mirror images should be conducted to retest the hypothesis. The performance for the memory tests did not suffer as predicted by the first hypothesis, and the first hypothesis is thus rejected.

According to the previous literature, memory capacity is limited and suffers when attention is divided (Sweller, 2022; Sweller, 2020). Since the participants were exposed to the pictures many times during the experiment hour, encoding might have happened through a different unconscious process. Another interpretation could be that the pictures were encoded unconsciously through bottom-up processing, this interpretation is in opposition to the scanpath theory (Stark, & Choi, 1996).

Hypothesis 1

The cognitive load affected the number of fixations and increased cognitive load meant less exploration /fixations for pictures. Fixation duration was also investigated during the viewing of the old and new pictures during the different cognitive load levels, significant results were found here, with longer duration fixations in the no cognitive load condition.

Hypothesis 2

The second hypothesis is that the increased cognitive load will impact/influence the processing and visual sampling of the pictures during the second time that the pictures are observed. The increased cognitive load will impair the capability to recognize previously seen pictures and thus impact/influence the visual processing of such pictures. It is expected that poorer recognition will be expressed in more fixations, i.e., a visual sampling behavior that is more similar to viewing a novel picture. This hypothesis was accepted.

More fixations were made for new pictures, because this type of stimuli was never seen before and thus more interesting to explore. The fixation duration was also higher for new pictures in the no cognitive load (baseline) condition. Which means that the cognitive load did affect the time of processing of scenes, because longer fixation durations indicate better processing and thus better encoding (Foulsham et al., 2012). Thus, the cognitive load impaired how long the participants looked at a picture and impaired fixation duration for new and previously seen pictures.

Fewer fixations were expected for the previously seen pictures during the second viewing of the pictures. Less fixations are predicted to occur because the pictures have already been seen before and thus processed and encoded. We could accept this hypothesis because there were more fixations for new pictures and less fixations when the cognitive load increased in the difficult condition level of the Sternberg task. This finding is in accordance with previous research that states that memories for a scene or object will be better, the more fixations are made to that object or scene (Liu, Shen, Olsen, & Ryan, 2018; Watkins, & Tulving, 1975). Since gaze fixations were impaired due to the induced cognitive load, the fixations in turn turned out to be fewer and the encoding was therefore impaired. Furthermore, changes in memory encoding can successfully be studied through eye tracking due to its high temporal and spatial resolution in real time while memories are encoded, this finding is also in

accordance with previous research which has successfully investigated memory encoding through eye tracking (Ryan, Wynn, Shen, & Liu, 2022; Haj et al, 2022). This finding is also in line with both the scanpath theory and the cognitive load theory (Sweller, 2022; Sweller, 2020; Stark, & Choi, 1996). Fixation duration was also impaired for the conditions with higher cognitive load as compared to the baseline condition with no cognitive load. And participants spent more time viewing pictures without cognitive load. This implies that cognitive load impairs fixation duration or information processing and memory encoding, resulting in poorer memory for conditions where the cognitive load was high.

Hypothesis 3

In the third hypothesis the overlap in scanpaths between the first and second time that the participants view the pictures was tested. The expectations were that the increased load led to a less similar scanpaths between the first and second time.

This hypothesis was accepted, which means that cognitive load did interfere with top-down memory processes like encoding, at least for the difficult and easy conditions. But that was not the case for the baseline condition.

Since there was no cognitive load in the baseline condition; encoding without cognitive load might thus have been a combination between top down and bottom-up processing, off course no such conclusions can be drawn without further research. According to the scanpath theory, it should be either top-down processing or the opposing theory that encoding was bottom up (Stark, & Choi, 1996). One interpretation of the results found in this study would be that there might be a combination of our inner cognitive models and impressions from the outer world when we conduct encoding without load (a combination between top down and bottom-up memory encoding). And for the cognitive load conditions, a load must interfere with encoding and thus with recognition, therefore the scanpaths must be a bit dissimilar or different because the recognition is not a perfect recognition of a memory, because proper encoding has not occurred due to limited resources of working memory, and the divided attention which occurs between processing the task that is inducing the cognitive load and the encoding of the scene.

Since the participants of the experiment were never told to encode the pictures, but to encode the letters in the Sternberg task, the encoding of the pictures might have been an unconscious

bottom-up process and not a conscious top-down control encoding process, although this cannot be verified without further testing, and should be included in future research.

Furthermore, since cognitive load usually does impair memory encoding, and because memory encoding according to the scanpath theory is a bottom down process; cognitive load not only interferes with memory encoding but also with our internal cognitive models, our percception and how we view the world. The world around us might become less likable the more cognitive load one experiences, because perception becomes distorted and our memories consequently mispresented, due to impaired processing.

Since according to Tulving, (Tulving, 1993; Tulving, 2002; Wheeler, Stuss, & Tulving, 1997) mental time traveling is a hallmark of episodic memory, these findings could indicate that mental time traveling might become difficult and impaired if there are cognitive loads interfering with episodic memory processes like recognition. Because cognitive load changes and impairs the interaction between the oculomotor system and episodic memory. Thus, recognition becomes impaired. Eye-tracking can be successfully used to study and investigate how cognitive load intereferes with episodic memory processes like encoding and recognition, and this finding was in line with previous research (Whitehead, Li, McQuiggan, Gambino, Binns, & Ryan, 2018).

Limitations

The main limitation of this study was that the sample was very small due to time constraints, to draw any final definite conclusions about how induced load interferes with memory encoding, and a bigger sample would be needed to further investigate these hypotheses.

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