Abstract

Humans increasingly rely on technological devices to store information they wish to recall at a later date, which has led to a common trend in remembering where information can be accessed instead of what it contains ("Digital Amnesia"). Despite this trend, the human memory is still relied upon for long term recall in situations where technology is absent, such as examinations, presentations and speeches. Techniques (mnemonics) such as the *Mind Palace*, *Pegword* and *Chunking* techniques have existed since the times of Ancient Greece and are regularly practised by memory champions for enhancing recall. This dissertation investigates if and how technology can be used to assist memorisation, with particular focus on lessening the cognitive effort involved in practising the Mind Palace technique.

After a thorough exploration of the state of the art, this dissertation presents "Hold That Thought" (HTT): the first-known mobile-based solution for Mind Palace creation and re-enactment in a physical environment using Bluetooth location-tracking technology to assist the problem of memorising information. A user-centred approach informed its design, before a rigorous usability and experimental evaluation assessed its efficacy. The experiment is the first-known comparison between a system utilising physical spaces, the traditional Mind Palace technique and a control group. Whilst no significant statistical difference was observed in recall accuracy data, the experimental findings support the hypothesis that use of HTT requires less cognitive effort than the traditional Mind Palace technique and a control group. This dissertation is concluded by a critical review of the experimental findings and a reflection on project success before exploring avenues for future work to build on its research.

A video of the application in action can be seen here:
`https://youtu.be/RwE5stBEOIA`.

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Acknowledgements

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Chapter 1
Introduction

"Each day that passes I forget more and remember less" – ***[Bell, 2009]***

To remember and recall a piece of information accurately is a common task, prevalent in many applications including studying for an upcoming examination or delivering a set of speaker notes for a presentation. Tackling these tasks effectively relies on the neurological process of *memorisation.* In a world where ubiquitous devices exist to record and recall data we wish to remember, this project explores the scope for a tool to assist memorisation in preparation for situations when this technology is not available to us.

Have we forgotten how to remember?

Memory has been an active area of research in psychology since its first scientific investigation by the German philosopher Hermann Ebbinghaus in the 1880s [Braisby and Gellatly, 2005]. The science behind how the human brain encodes experiences into memories has inspired books in popular culture such as *"Moonwalking with Einstein"* [Foer, 2011]. Foer claims that in the times of Ancient Greece, the ability to recall information accurately from memory was seen as a concrete sign of intelligence and that as soon as humans started to articulate themselves and record information in literature, there was no longer a need to commit such information to memory. The rise in availability of technology such as search engines as a form of *external cognition* has meant that information is now almost always instantaneously retrievable on demand [Hamilton and Yao, 2018]. This has caused humans to be more selective in what they remember - it has been shown that if people believe they will have future access to information, they generally show lower recall rates for what this information *is* and an enhanced recall rate for *where* to access it [Sparrow et al., 2011]. At times where this external cognition is not available to us (for example, exam study, presentations, memory competitions) and verbatim recall is required, humans do not have the option to offload information to (and retrieve information from) this technology on demand. Instead, they must employ techniques to commit information to memory.

1.1 Mnemonics and Sensory Input

In the classroom, many extensive studies investigating the use of memorisation aids (also known as *mnemonics*) have suggested that these techniques make a significant positive impact on the performance of students in recalling information [Maghy, 2015, Mastropieri et al., 2010, Scruggs et al., 2004, Rummel et al., 2003, Roediger, 1980]. From these studies, it seems that the use of techniques to assist memorisation can have a real scope in improving academic performance.

Experiments have also shown that the efficiency of recall of a given piece of information is improved if kinaesthetic (i.e. spatial or navigational) techniques are exploited compared to passive techniques such as use of desktop computer applications [Tan et al., 2002, Krokos et al., 2018*a*,*b*]. More often than not, a memory is easier to recall if it has some associated sensory information such as a location or emotion to trigger its recall [Kensinger, 2009, Makowski et al., 2017]. Spatial navigation, in particular, is known to enhance a person's ability to remember a piece of information [Brooks et al., 1999]. This is backed up by research using Virtual Reality (VR) headsets. Dinh et al. [1999] discovered that providing additional sensory input to participants produced an increased sense of presence as well as an increased recall of the objects in a virtual environment. Therefore, research seems to indicate that it is easier to remember a piece of information if there is some sensory information to distinguish a memory and relate it back to the piece of information it encodes.

1.2 The "Mind Palace" Technique

The *Mind Palace* technique (known as the *Method of Loci* and abbreviated as MoL) has been adopted, studied and praised for its effectiveness in recalling information since the times of Ancient Greece when rhetoricians would use the technique to remember extended speeches [Yates, 1992]. The method utilises visualizations combined with spatial and navigational memory of a familiar environment to quickly and efficiently recall information. The technique encourages the subject to create a mental image of a piece of information they wish to remember and position it in a *well-known* and familiar environment, creating a path to connect these otherwise potentially unrelated pieces of information. In order to recall the information again, one must simply take a mental journey along the path created in order to visualise the created images and remember what these represented. Several lab studies over the years have shown how effective the Method of Loci is for enhancing memorisation and recall [Wieland et al., 2017, Mccabe, 2015, Perrault et al., 2015, Ikei et al., 2007, Harman, 2001, Kemp et al., 1985, O'Keefe and Nadel, 1978]. The Method of Loci (MoL) is also commonly referred to as the *memory journey* or *memory palace* technique.

1.3 Problem Description

Mccabe et al. [2013] observed that knowledge of the MoL technique in undergraduates is low and that the clear modal strategy used by students in their study was the simple *repetition* or rote learning technique. Considering this lack of exposure to, or inexperience with the MoL technique, it is very likely that many students do not approach the task of memorising information in a way that suits their cognitive abilities. As such, this dissertation will focus on the use of the MoL technique in the domain of students' examination revision.

A common issue associated with the practice of the traditional Mind Palace technique is the significant upfront cognitive effort required when creating and navigating palaces [Bower, 1970, Kemp et al., 1985, Bellezza, 1996]. This problem may discourage people from practising the technique despite its proven effectiveness. This dissertation will, therefore, investigate whether this cognitive effort can be lessened with the support of technology whilst retaining the effectiveness of the traditional technique.

1.4 A Foreword on Existing Systems

The use of technology to assist with the Mind Palace technique is not a new concept. Existing systems have made a myriad of different approaches to creating palaces in graphical or physical environments using desktop or mobile-based applications, sometimes integrating Virtual Reality (VR) or Augmented Reality (AR) head-mounted displays to explore the palace environment. Examples of systems using physical spaces in particular include *NeverMind*, *HoloMoL* and *Loci Spheres*, which are discussed in further detail in the Literature Review chapter.

1.5 Project Aims and Contributions

This dissertation aims to assist the problem of memorising information by using technology to augment the practice of the Mind Palace technique and reduce the cognitive effort it requires. As such, we will explore the literature surrounding memory and the effects of spatial navigation on recall before creating a system that helps solve this problem in the domain of students' exam revision. With this system, we aim to carry out a thorough empirical and usability evaluation to evaluate its efficacy. We will eventually show that there are also medical applications of this work.

In order to achieve the above aims, the following objectives have been established:

1. Explore the psychological theories about human memory in order to understand why certain techniques are more effective than others when memorising information.

2. Investigate existing methods for assisting with memorisation and recall, as well as systems that attempt to support this.

3. Extend existing work which supports memorisation of information using the MoL technique such as Rosello et al. [2016] in order to create an effective mobile-based method for practising the technique.

4. Evaluate how users use the system, and whether spatial information helps them recall information more effectively than rote or non-spatial (passive) memorisation methods.
5. Investigate the usability of the system, and its effects on cognitive load, enjoyability and difficulty compared to practising the traditional MoL technique.

1.6 Structure of this Dissertation

An outline of the structure of this dissertation is provided below:

- **Literature Review**: This chapter looks at the current state of literature in the field of memory and information recall. After understanding psychological models and theories, several techniques are analysed to understand their effectiveness, before an assessment of several existing technologies which aim to assist the memorisation of information. The findings in this chapter will help shape the requirements specification.
- **Requirements**: Based on the findings in the Literature Review chapter, we will then move on to present and elicit a formal set of requirements for the proposed system based on lessons learned from experiments and evaluations with current technologies.
- **Design**: Equipped with a set of formal requirements for the system, we shall present a sequence of iterative designs for the mobile application which will be presented to users. Feedback gained from users will be used in the design of the next iteration.
- **Implementation and Testing**: Here we shall put forward all of the implementation details for the system. This includes the hardware and software used, and overall system architecture.
- **Evaluation**: In this chapter we shall be presenting the activities performed in the user study and detailing the data collected during experiments.
- **Results and Discussion**: This chapter assesses the results of the user study and experiments in order to draw meaningful conclusions from results.
- **Conclusions**: We shall use this chapter to reflect upon what has been achieved by the system and make meaningful conclusions. We shall also be making suitable comments for future work, including how to improve the system to make it more usable and effective in the future.

Chapter 2

Literature Review

2.1 Introduction

In order to address the problem of assisting memory recall using the Method of Loci (MoL), it is important to explore the current accepted theories behind memory and information recall, the possible techniques that could be used to train and improve memory and how technology could be used to provide a potential solution to the challenge of memorising information. The findings in this section will help shape the requirements specification.

2.2 The Psychology of Memory

Memory is not only a vital skill necessary for survival but also incredibly important in the way we interact with the world around us [Baddeley, 2009]. Scientific evidence suggests that the brain is constantly able to form new synapses and neurons to accommodate for new information as it needs throughout our lifetimes, not just during developmental years [Gould et al., 1999, 2001]. With the vast amount of information being processed by the brain on a daily basis, it is often a mystery how humans are still able to recall a specific event years after it may have occurred [LePort et al., 2017]. Yet, on the other hand, it is also commonplace for humans to experience illusionary images of childhood experiences that never actually occurred [Newman and Lindsay, 2009, Patihis et al., 2013]. With such an unpredictable number of factors influencing the likelihood for memorisation and the efficiency of recall, it is little wonder that the subject has been studied in a scientific guise for over 120 years.

The first step in understanding how humans can remember certain pieces of information but not others is to study how psychologists have modelled and categorised memory. This will provide a grounding on where currently-accepted theories are derived.

2.2.1 Categorising Memory

Psychologists over the years have conceptualised and subdivided memory into many different categories. The exact number and definitions of these have varied over time - some have referred to as many as 25 distinct categories [Norman and Bernbach, 1970]. In this section, we will assess the commonly-accepted types of memory and how each relates to one another. Figure 2.1 contains a summary of the types to be discussed in more detail; composed as a high-level overview from the variety of sources mentioned below.

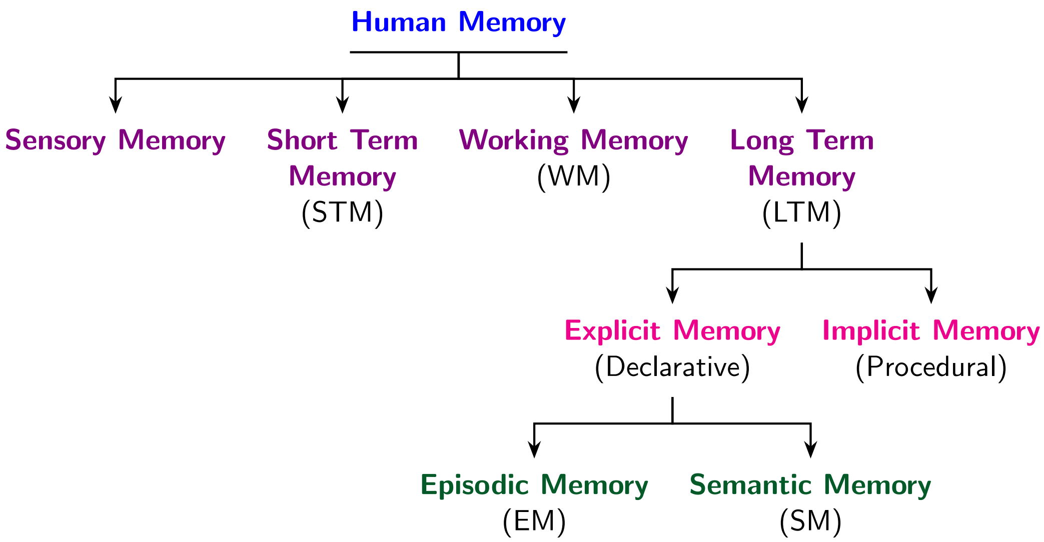


Figure 2.1: Categories of memory types.

As can be seen in Figure 2.1, human memory can generally be broken down into 4 categories - Sensory Memory, Short Term Memory (STM), Working Memory and Long Term Memory (LTM).

Sensory Memory is generally accepted as being the type of memory which receives information encoded from stimuli in the environment and can be broken down into *iconic* (visual), *echoic* (audio) and *haptic* (tactile) memory [Carlson and Miller, 2010]. It is not a conscious type of memory - that is to say, a human cannot control the content or duration of what is stored [Winkler and Cowan, 2005]. An example might be the memory of the tone of voice belonging to a person who just spoke. The retention duration is dependent on the type of stimuli - usually, this is a few seconds but some studies suggest sensory memories such as sounds of voices can be retained for longer than 30 seconds [Craik and Kirsner, 1974]. The ability of sensory memory remains at a constant level throughout a human's lifetime and is also unaffected by conditions and diseases such as Amnesia, Dementia and Alzheimer's [Cave and Squire, 1992, Ballesteros and Mayas, 2009, Fleischman et al., 2005]. Its role is said to be retaining information beyond the length of the exposure to the stimuli, to allow it to progress to short term and working memory [Coltheart, 1980].

Short Term Memory (STM) has longer retention time than Sensory Memory and concerns temporary storage of memories that are currently "*active*" as well as those recently retrieved from LTM [Jonides et al., 2008]. An example might be the memory of a phone number someone has just told you. A study by Miller [1956] explored the limits of STM and concluded that 7 ± 2 was the limit on the number of items humans could reasonably store and recall effectively in the short term. This exact number was reduced to 4 ± 1 by Cowan [2000] but the core idea of limited temporary storage remains accepted to this day. A common assumption is that the passage of time alone causes the decay of memories from STM. However, some research suggests that STM is actually cue driven [Nairne, 2002].

Working Memory (WM) was first modelled by Baddeley and Hitch [1974] in their Model of Working Memory which aims to explain its function in relation to short term memory, but some authors had hypothesised the existence of this type of memory beforehand [Miller et al., 1960]. A generally accepted definition made by psychologists is that working memory concerns the temporary storage *and controlled manipulation* of information [Baddeley, 1992, Aben et al., 2012, Cowan, 2017]. WM is relied upon for tasks such as language comprehension, arithmetic and reasoning [Oberauer et al., 2018] and was long thought to be identical to STM (as both pertain to temporary storage and authors such as Davidson et al. [2006] use the terms interchangeably). There is some evidence to suggest that STM and WM even use the same underlying cognitive processes [Unsworth and Engle, 2007] and some theories even suggest an equivalent WM exists for Long Term Memory [Ericsson and Kintsch, 1995]. There is also a proposed relationship between working memory and general intelligence levels in humans [Dang et al., 2013, Wongupparaj et al., 2015].

Long Term Memory (LTM) pertains to the storage of memories that can be recalled beyond the length of time they are held in STM [Squire et al., 1993]. Today, many in the research community agree that LTM is divided into Implicit (Procedural) and Explicit (Declarative) memory. Implicit (Procedural) Memory refers to non-conscious memory of skills such as motor skills, operating on an automatic level [Schacter, 1987, Schacter and Tulving, 1994]. In order to study the effects of this type of memory, participants are not asked to directly or consciously recall information they have memorized implicitly. Instead, they are asked to perform tasks to "prove" recall by demonstrating better performance before and after a trial [Schacter and Graf, 1986*a*,*b*]. Explicit (Declarative) Memory can be thought of as memory that is consciously stored. In contrast to Implicit Memory, this can be tested by conscious techniques such as recognition and cued or free recall [Schacter, 1987].

It is generally accepted that Explicit Memory can be subdivided into two types[1] - Episodic Memory (EM) and Semantic Memory (SM). The types and their differences were first proposed by Tulving [1972]. Tulving described EM as the conscious re-experiencing of personal events combined with the recollection of the phenomenological, spatial and temporal encoding contexts (for example, the places visited and experiences had on a particular day) [Tulving, 1972]. Wheeler et al. [1997] emphasised that EM stores a combination of *subjective experiences* of an individual along with specific information. In contrast, SM can be thought of as an organised long-term knowledge base of skills, rules, facts and meanings that a human holds such as "*the sky is blue*" [Braisby and Gellatly, 2005, Tulving, 2002].

[1]Some authors (e.g. Conway and W. Pleydell-Pearce [2000], Bluck [2003], Palombo et al. [2018]) consider Autobiographical Memory to be a third type of Explicit Memory, but this type is omitted from Figure 2.1 due to its large overlap with Episodic Memory. What distinguishes it from Episodic Memory in some psychologists' minds is the fact that this type of memory pertains to the memories of events and experiences of an **individual**. In this Dissertation, we shall simply refer to this as Episodic Memory.

2.2.2 Frameworks and Models of Memory

After describing an overview of accepted categories of memory, this section examines how psychologists have modelled the *workings* of memory. Many theories and models have been proposed over the years on how information is memorised, each offering a different viewpoint on how memories are formed, retained and recalled. For example, whilst the classical trains of thought of Ebbinghaus et al. [1913] consider memory to be a mechanical autonomous skill for information recall, others such as Bartlett and Burt [1933] disagree, proposing that it is very closely linked to the cognitive processes behind imagination. It is only until recently that psychologists have started to identify ties between humans' ability to remember and their ability to imagine and plan out an intention for future events - a phenomenon referred to as prospective memory [Mcdaniel and Einstein, 2000, Kliegel and Martin, 2003, Schacter et al., 2007, Kvavilashvili, 2011].

In what follows, we will examine 4 of the fundamental models and frameworks that have inspired different ways in thinking about how memories are encoded, formed and stored.

Atkinson & Shiffrin's Multi-Store Model (1968)

Short Term and Long Term Memory have long been thought to be distinct [James, 1890, Waugh and Norman, 1965, Norris, 2017]. The multi-store or *modal* model of memory conceptualised human memory as a series of modal stores [Atkinson and Shiffrin, 1968] (Figure 2.2). Here, memory is conceptualised as registers. There is a Sensory Register (SR), a Short Term Store (STS) and Long Term Store (LTS). Information from the environment (External Input) is said to enter the SR and if attention is given towards it, it enters the STS. After this, it can only pass ("transfer") to the LTS on the condition that it is repeated or rehearsed a sufficient number of times. Otherwise, as new information is received, the items not committed to the LTS are lost.

The time spent in STS was seen as a prerequisite for information to enter LTS. This built on the work of Murdock [1967] who also advocated a modal model and placed emphasis on paying attention towards a particular stimulus to observe long term recall. It also used the works of Miller [1956] whose "Seven Plus Or Minus Two" research concludes that the STS is restricted in capacity whilst the LTS is not. Even today there is seemingly a consensus amongst the general public that our long term memories have a limit on the amount of information that can be retained [Magnussen et al., 2006].

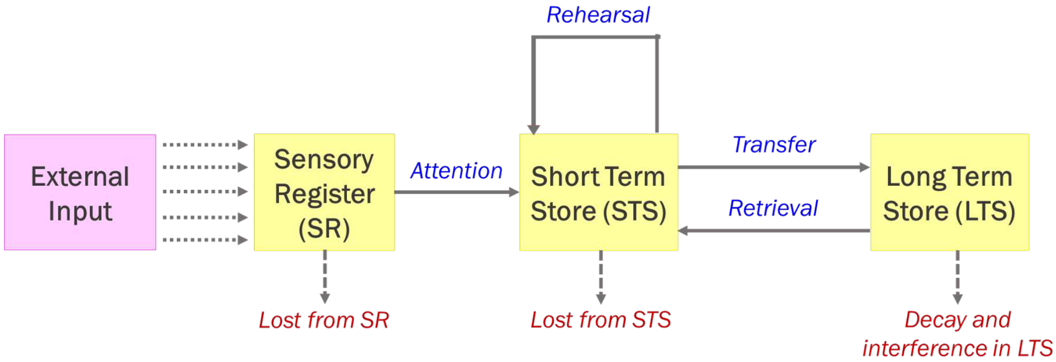


Figure 2.2: The Multi-Store Memory model, as proposed by Atkinson and Shiffrin [1968].

This theory explained the findings of the *serial position effect* observed by Glanzer and Cunitz [1966] whereby participants were asked to remember a list of words, of which the first and last few words were more likely to be recalled than those in the middle (Figure 2.3). This appeared to suggest the existence of a "primacy" and "recency" effect, supporting the separation of a short term and long term store.

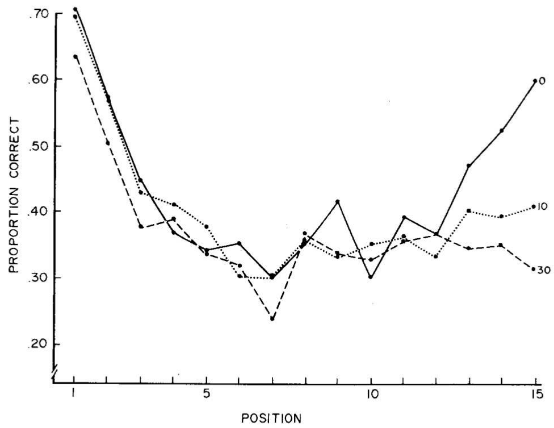


Figure 2.3: The serial position effect as observed by Glanzer and Cunitz [1966].

Whilst not without flaws, the Atkinson and Shiffrin [1968] model paved the way for later research to investigate the capacity of STM and its link with LTM in humans [Cowan, 2000]. It is still widely used today in order to study memory - whilst some believe the distinction between long and short term memory is not as black and white as the model proposes, there are still strong advocates of the multi-store model [Norris, 2017].

Craik & Lockhart's Levels of Processing (1972)

A few years later, Craik and Lockhart [1972] put forward "Levels of Processing" (LoP) - an alternative model to resolve the problems they saw with the structural view of

Atkinson and Shiffrin [1968]. Viewing Atkinson and Shiffrin [1968] as an oversimplified model, the LoP approach argues that the ability to memorise information for long term recall is not due to the length of time spent in structural stores, but instead due to the depth that this information is processed (encoded) when stimuli are received [Craik and Lockhart, 1972, Braisby and Gellatly, 2005, Ekuni et al., 2011, Craik, 2010, Baddeley, 1978]. This approach reiterates the importance of attention towards stimuli suggested by Atkinson and Shiffrin [1968] by correlating the likelihood of recall with the depth of processing. However, instead of viewing all types of information and stimuli as the same, this approach recognises that some types of encoding are more effective than others [H. Challis et al., 1996]. Levels range from shallow (perceptual/structural/phonemic analysis) to deep (semantic analysis). Using this model there is no meaningful structural separation between STM and LTM.

An example LoP approach to memorising the word "pen" is in Figure 2.4. Here, the word can be processed in a shallow way (perceptually) by considering the number of vowels it contains, studying the written word visually. A slightly deeper analysis to increase recall would be to process the word phonemically by saying it aloud and considering words it might rhyme with. Finally, the word can be analysed in an even deeper way by using semantic techniques - considering its meaning and appropriateness in certain contexts. Craik and Lockhart [1972] would argue the latter brings a greater likelihood of long term recall.

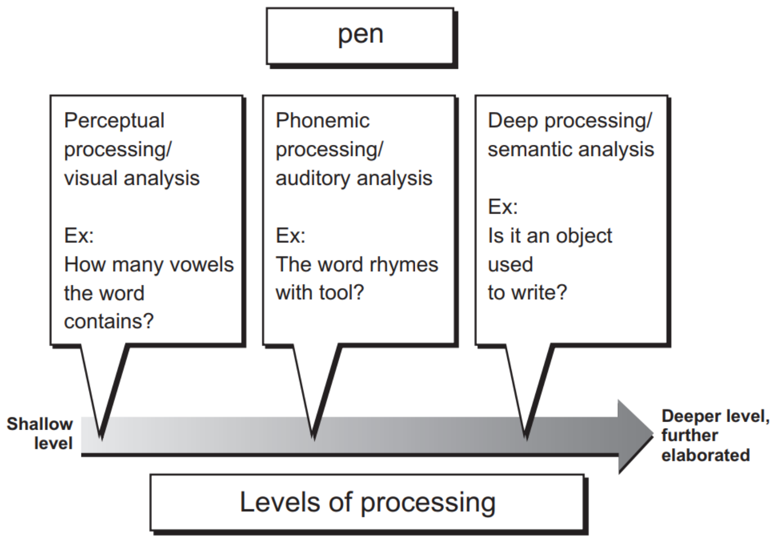


Figure 2.4: Levels of processing approach while encoding the written word "pen" [Ekuni et al., 2011].

This paper sparked a series of experiments into LoP such as Hyde and Jenkins [1973] where participants were presented with five tasks to perform on a set of words - those used in tasks with greater processing were better recalled. Another experiment by Craik and Tulving [1975] asked participants a set list of questions about certain words (Table 2.1). Again, those which had been processed to greater levels through questioning had better levels of recall among participants.

Table 2.1: Questions used in experiments by Craik and Tulving [1975]. Generally, participants showed enhanced recall for words which were processed at deeper levels.

Level	Type	Question	Yes	No
Shallow	Structural	Is the word in capital letters?	TABLE	table
Shallow	Phonemic	Does the word rhyme with WEIGHT?	crate	market
Deep	Category	Is the word a type of fish?	shark	heaven
Deep	Semantic	Does the word fit in the sentence "he met a ___ in the street"?	friend	cloud

This model was criticised by Eysenck [1978] for a lack of spectrum or index on which to scale the depths of processing relative to one another. Backed up by Nelson [1977], their concern was that it could lead to people thinking that just because they remember something well, they must have processed it deeply. Nevertheless, this model shaped later research into the relationship between levels of attention towards information and the ability to remember it at a later date (e.g. Eysenck and Eysenck [1980]) and is still widely accepted in modern literature [Winne, 2018].

Tulving & Thomson's Encoding Specificity (1973)

Related to Craik and Lockhart [1972] is the model proposed by Tulving and Thomson [1973] entitled the Encoding Specificity (ES) principle (Figure 2.5). This hypothesises that the conditions (for example, emotions, location, context) that exist at the time of encoding should mirror those that exist at the time of recall for effective retrieval to be possible [Tulving and Thomson, 1973]. This relationship between encoding and retrieval is sometimes termed *transfer appropriate processing* [Morris et al., 1977]. This plays on the idea of *state* dependent learning and *context* dependent learning which make it explicit which factors are dependent on the *individual* and *environment* respectively [Hall, 1996, Eich and Birnbaum, 1982, Hockley and Bancroft, 2015].

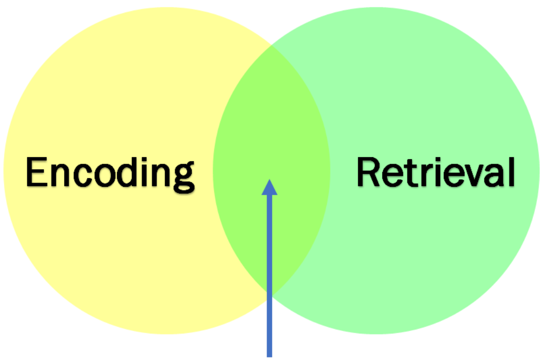


Figure 2.5: Tulving and Thomson's Encoding Specificity, as presented in *"Encoding Specificity and Retrieval Processes in Episodic Memory"* Tulving and Thomson [1973].

Many studies have investigated ES through use of alcohol to alter the state of the individual during memory trials [Goodwin et al., 1969, Weingartner and A. Faillace, 1972, Weingartner et al., 1976, Weissenborn and Duka, 2000]. Participants' recall performance is usually better if their state at encoding and retrieval is the same, reinforcing the validity of the ES principle. This theory is still accepted by many academics in the field of cognitive psychology [Unsworth, 2019].

Baddeley and Hitch's Model of Working Memory (1974)

Baddeley and Hitch [1974] proposed a new model which divided the concept of the Short Term Store in Atkinson and Shiffrin [1968] into several components as in Figure 2.6. This does not comment in detail on the exact relationship between STM and LTM but rather attempts to encourage the thinking of STM as 4 separate components instead of as a monolithic structure.

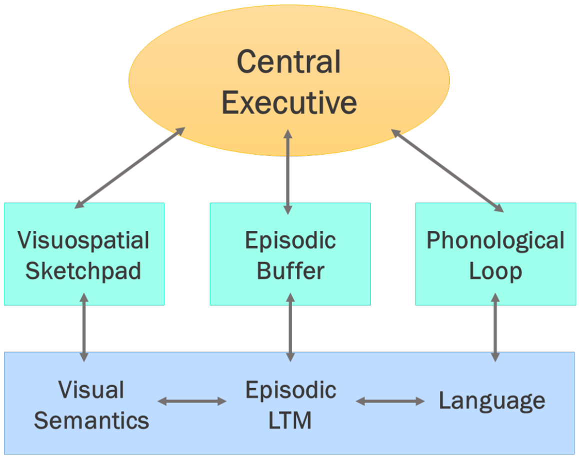


Figure 2.6: Baddeley and Hitch's model of working memory, as presented in *"The Episodic Buffer: A New Component of Working Memory?"* Baddeley [2000].

Under this model, the Central Executive is mainly in control of focussing on, processing and switching between pieces of information that the Working Memory attends to [Baddeley, 2000, Wongupparaj et al., 2015]. The Central Executive oversees and controls information flow between a series of slave components:

- **Visuospatial Sketchpad:** This is used in the short term memorisation of visual and spatial information [Holmes et al., 2008]. An example of this might be recalling a memory of a particular route taken on a morning jog. As in Figure 2.6, this component is concerned with visual semantics. Logie et al. [1995] divides this into the visual cache (for storing details about form and colour) and inner scribe (for processing spatial information and handling the transfer of information to and from the Central Executive).
- **Phonological Loop:** This subcomponent is concerned with the storage of acoustic (verbal) information spanning short durations, comprised of a Phonological Store (PS) and an articulatory loop (for rehearsal to maintain information in the PS) [Baddeley et al., 1998].

- **Episodic Buffer:** This was later added to the model to try and explain the transfer of memories between the Working Memory and Episodic LTM as in Figure 2.6 [Baddeley, 2000, Baddeley et al., 2011].

Baddeley and Hitch [1974] carried out a dual-task paradigm experiment in order to support the existence of the phonological loop and visuospatial sketchpad and investigate dual-task interference, whereby one type of task interferes with the effectiveness of another. This experiment involved asking participants to engage in two tasks simultaneously which rely on either one or both of the two types of skills (verbal and visual/spatial). Those carrying out two of the same type of task did not perform as effectively as those performing two different types. This is backed up by later research suggesting that human processing capabilities are limited and divided into categories, supporting the separation of the Visuospatial Sketchpad and Phonological Loop [Navon and Gopher, 1979, Wickens, 1981].

Whilst this model is not without its critics [Nairne, 2002, Jones et al., 2007], it is widely praised for bringing together a lot of previous research on working memory and short term memory, explaining the distinction of different encoding types (for example, verbal, spatial and visual).

2.2.3 Factors in Effective Long-Term Recall

With an understanding of the different types of memory and the important frameworks underpinning them, this section looks at how it can be possible that some memories can be recalled more vividly (in greater detail) than others. We shall examine 4 of the many factors which have been shown to make a positive impact on memorising information for long-term recall.

Repetition (rehearsal) has long been seen as a key way of transferring items into long-term memory [James, 1890, Waugh and Norman, 1965]. Maintenance rehearsal involves rehearsing an item in short term or working memory at the same "level" (c.f. "Levels of Processing" - Craik and Lockhart [1972]) usually through repeatedly looking at or saying the item multiple times, whereas elaborative rehearsal is akin to deep processing, whereby an item is rehearsed as part of a semantic analysis (for example, considering the item's context) instead of using pure verbatim repetition [Watkins and Peynircioglu, 1982]. Baddeley [2010] observed maintenance rehearsal when comparing the performance between a set of participants which were asked to say a list of words aloud and told they would be tested for recall, against a set of participants with no knowledge of this recall test. Those that knew of the test would repeat words verbally more than once, showing better recall. Both types of rehearsal can be used to assist recall, though it appears elaborative rehearsal is more effective in the long term than maintenance rehearsal [Greene, 1987]. This appears to be because as maintenance rehearsal is repeated, it requires less processing capabilities (e.g. attention) than elaborative rehearsal [Naveh-Benjamin and Jonides, 1984].

Spatial navigation also appears to be associated with showing enhanced rates of recall of information due to how humans engage their brains during navigation [Parmentier et al., 2005] [2]. Most existing studies into the effects of spatial navigation on recall rely on studying functional Magnetic Resonance Imaging (fMRI) scans in order to track neuron activity. Studies such as Mueller et al. [2012] show that navigation generally activates neurons in regions of the brain that are closely linked with episodic memory formation (Figure 2.7). Brooks et al. [1999] explored the effects of navigation on the recall of participants using Virtual Reality (VR) technology. Participants that actively explored the virtual environment using controllers recalled the environment better than those passive participants, who simply watched the active participants' actions[3].

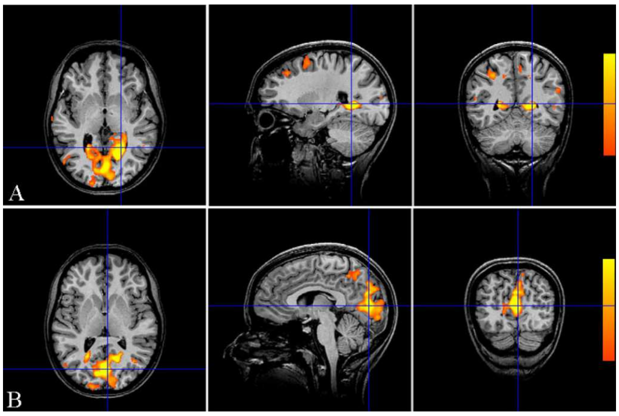


Figure 2.7: Images from the VR-fMRI CityMap experiment showing hippocampal activation during navigational tasks [Mueller et al., 2012].

Emotions also can have a large positive influence on the formation of memories (sometimes called "flashbulb memories") due to the increased stimuli in response to these events [Conway et al., 1994]. Increased stimulation is therefore likely to increase attention and elaboration towards a piece of information, allowing it to pass to long term memory more easily [Sharot and Phelps, 2004]. Several studies have shown increased recall rates if emotions are aroused [Bradley et al., 1992, Hamann, 2001]. However, emotions may also impact recall performance in a negative way; stress, in particular, has been shown to hamper performance in learning new information [Schwabe and Wolf, 2010, Vogel and Schwabe, 2016, Quaedflieg and Schwabe, 2018].

Finally, **semantic associations** can also play a role in effective recall. For example, if an image of a person is displayed and we are told that their name is John Baker, this is far less likely to be remembered than if we are informed that they are a baker by profession. Cohen [1990] coined this the "Baker-baker Paradox" and used this example in their experiment, observing that participants had greater recall if they were shown the image and told that the person was a baker by profession. Cohen reasoned that the brain is far less likely to have any existing memories associated with the name Baker than bakeries which account for these results. These kinds of semantic associations are also used in the "bizarre imagery" effect, where being exposed to extraordinary stimuli in an otherwise common setting (for example, visualising an animated set of stationery

[2] In section 2.2.4 we shall be discussing the accepted neurological theories behind this, specifically mentioning the role of the hippocampus in memory formation.

[3] More on the use of Virtual Reality (VR) to assist in memorisation in section 2.4.

on a desktop) are used to make information more memorable [McDaniel and Einstein, 1986, Burns, 1996]. This is a concept sometimes used in mnemonic techniques such as the Method of Loci to aid recall [4].

2.2.4 Physiology of Memory: The role of the Hippocampus

Understanding some of the neurological theory behind memory and which parts of the brain are involved in these cognitive processes is important as many studies rely on evidence of neural (e.g. hippocampal) activation to explain participants' performance in experiments. From current research, it appears that the biological mechanisms underlying memory formation and storage actually involve several different parts of the brain, rather than a single part managing all memory processes. Here, we shall only be focusing on the core brain structures that relate to long term memory.

The hippocampus, in particular, is a part of the brain that plays a very central and critical role in episodic memory formation [Harand et al., 2012] and memory consolidation during sleep [Rothschild, 2018] as well as spatial navigation [Eichenbaum et al., 1999, Gluck and Myers, 1997, Eichenbaum, 2000]. When monitoring the location of items and how each item relates to one another, it is the hippocampus that is relied upon [Cain et al., 2006, McClelland et al., 1995, Schacter and Tulving, 1994]. Consciously recalling events and experiences (episodic memories) in particular has been shown to be linked to detected increases in hippocampal activity [Squire, 1992, Harand et al., 2012]. This explains why London Taxi drivers (who are required to commit a vast amount of spatial and navigational information to memory in order to pass their exams) have been shown to have larger hippocampal regions than control subjects [Maguire et al., 2000].

A large proportion of the research available about the physiology of the human memory originates from studying subjects that are suffering from brain injuries or neurological diseases as this is the only ethical way of isolating parts of the brain to make conclusions on which areas are used in memory formation and recall. In many cases, humans with brain injuries that affect their LTM experience no tangible difference to their STM capabilities [Drachman and Arbit, 1966, Baddeley and Warrington, 1970, Milner, 1971]. Shallice and Warrington [1970] studied patient K.F who had damaged verbal memory but unaffected visual memory after a motorcycle incident, supporting the separation of Visuospatial Sketchpad and Phonological Loop in the Baddeley and Hitch [1974] Working Memory model discussed previously (Figure 2.6). Rudner et al. [2007] also made links between the Episodic Buffer and the temporal lobes and hippocampus of the brain. Damage to regions of the brain such as the hippocampus and temporal lobe hinders the ability of humans to memorise and recall new episodic memories [Scoville and Milner, 1957, Schmolck et al., 2000], whereas long-term semantic memories are left unhindered [Kensinger et al., 2001]. These findings were made by analysing patient H.M., who was of particular interest after the removal of his hippocampal structures in an attempt to relieve his epilepsy [Schmolck et al., 2002]. Studies involving H.M. emphasised the importance of the hippocampus in forming episodic memories and showed how short term and working memory can remain intact despite an impaired ability to

[4] More detail on Mnemonics and their effectiveness is found in section 2.3.

form and consolidate new episodic memories [Corkin, 2002, Eichenbaum, 2012].

2.2.5 Forgetting: Interference and Decay

In order to understand why certain memories can fade from short and long term memory, we shall now consider the theories of interference and decay.

Memories are prone to being forgotten (becoming irretrievable from LTM) over time when new memories are formed; a process known as *interference* [Anderson and Neely, 1996, Altmann and Gray, 2002, Altmann and Schunn, 2012]. This can be subdivided into retroactive interference (where old memories interfere with new) [Melton and von Lackum, 1941, Alves and Bueno, 2017] and proactive interference (where new memories interfere with old) [Waugh and Norman, 1965, Henson et al., 1998, Lustig and Hasher, 2001]. Decay can be thought of as the process of forgetting memories due to only the passage of time [Brown, 1958]. Baddeley and Scott [1971] demonstrated this by asking participants to remember items only once (to avoid interference effects) and by prohibiting rehearsal. Traditionally decay and interference were treated as conflicting views, but in modern times most psychologists accept that they can coexist [Altmann and Schunn, 2009].

It would also appear that to a certain extent, humans are able to control which pieces of information they *wish* to forget. This form of *executive control* has been shown in experiments where humans deliberately suppress or inhibit memories, showing decreased hippocampal stimulation in response to certain stimuli [Levy and Anderson, 2008, 2009, Anderson et al., 2004].

2.3 Memory Training and Mnemonics

In Section 2.2, we explored the models and theories behind memory and recall. In this section, there will follow an investigation into whether memory can be trained using certain techniques to improve recall. As mentioned, throughout a human's entire lifetime, the shape and size of the brain can change as new neurons are formed [Gould et al., 1999]. A popular belief is that human memory is akin to any other muscle of the body in that it can be trained to grow in strength and ability [Magnussen et al., 2006]. In what follows we shall be exploring the validity of this belief.

The idea of training memory is not a new concept. In the times of Ancient Greece, orators would be required to remember long speeches which they could commit to memory, with the very best drawing upon techniques such as the Method of Loci to remember speeches of 5000 words or longer [Cicero et al., 2001]. In modern-day memory competitions, participants will spend a long time practising many different techniques in order to improve their ability to recall information and compete at a national or international level. In 2006, American journalist Joshua Foer competed at the US Memory Championships[5] in order to investigate how mental athletes managed to recall a seemingly superhuman amount of information [Foer, 2011]. He went on to win the

[5] `http://www.usamemorychampionship.com/`

competition that year, which seems to indicate it is an achievable feat for most of us provided that we are aware of how to practice effectively.

2.3.1 Mnemonics

Mnemonics are simple devices used to aid memorisation and cue recall of information [Bellezza, 1981]. Sometimes mnemonics can rely on existing knowledge that has nothing to do with the information being memorised. Studies where mnemonics are used have shown consistent success rates compared to traditional styles such as rote learning [Roediger, 1980, Levin et al., 1992, Rummel et al., 2003, Scruggs et al., 2004, Mastropieri et al., 2010, Maghy, 2015]. These effects can be seen not just in the short term, but also over longer periods and in individuals with weak long term memory [O'Hara et al., 2007]. Mnemonics are said to be effective in a twofold manner - not only do they impose an inherent form of practising on the subject (allowing the subject to pay attention to the item being remembered) but they also form some form of connection with an existing semantic memory to aid recall [Levin, 1993, Wang and Thomas, 1995]. It is therefore important to consider how certain techniques can be used to improve recall.

In what follows we shall illustrate 3 commonly-practiced techniques that have been shown to improve recall: Chunking, the Pegword method and the Mind Palace (Method of Loci).

Chunking

Due to the limited number of items that the STM and working memory can store [Miller, 1956], humans often find it easier to simply group pieces of information into meaningful "chunks" stored in the same memory code, as in Figure 2.8. This technique groups atomic items into a meaningful collection, making each chunk easier to remember than the original whole [Johnson, 1970, Cowan et al., 2004]. For more effective recall of chunked information, this should be associated with a piece of semantic knowledge. For example, memorising the string "CIAFBINSA" is made far less challenging if these are remembered as a collection of U.S. government agencies [Chekaf et al., 2016]. The effectiveness of the chunking method has been linked to the success of some chess players [Chase and Simon, 1973].

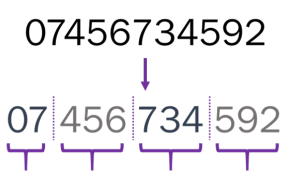


Figure 2.8: Example of the chunking technique, applied to a UK mobile phone number.

Pegword method

The Pegword method relies on making mappings between pieces of information in order to recall later information [Bower, 1970]. For example, one might use the mappings in Figure 2.9 such that the number 1 maps to "sun", the number 2 maps to "shoe" and so on (using rhymes can also help associations [Read et al., 2014]).

Figure 2.9: Example of the pegword technique, with mappings applied to digits 1-4.

Using this as a base point, an ordered list of 4 items such as a shopping list "apple, orange, banana, pear" can be encoded as:

1. The sun melting an apple.
2. A man squashing an orange with his shoe.
3. A tree slipping on a banana peel.
4. Opening a door to see a pear.

Bizarre visualisations are encouraged as referred to previously [McDaniel and Einstein, 1986]. The Pegword technique has proven successful in trials compared to control groups testing both immediate and longer-term (delayed) recall [Veit et al., 1986, Harris and Blaiser, 1997].

The Mind Palace (Method of Loci)

In this dissertation, we will be focussing on the Mind Palace or Method of Loci (MoL) technique for the reasons described below. This has been used since its first conception in the times of Ancient Greece [Yates, 1992, Cicero et al., 2001] and has been adopted in many experiments, showing enhanced recall in participants using the technique compared to those in control groups [Ross and Lawrence, 1968, Groninger, 1971]. In popular culture, it is the MoL technique that Foer [2011] adopted on his journey to becoming a US memory champion.

The technique is as follows for encoding and recall of a list of items we might wish to remember:

1. Choose an environment (or *palace*) that one is comfortable in navigating in their imagination (i.e. a well-known setting in which one is able to take a mental journey with very little cognitive effort required to recall its layout).
2. Navigate through the palace in one's mind until we reach a distinctive *locus* (a place to store the encoded item).

3. Visualise the encoded information at this locus (which acts a stationary cue in the overall palace). Fix this information at the locus before continuing navigation of the palace.
4. Repeat steps 2-3 until all items have been placed at distinct loci.
5. To recall, retrace this mental journey through the palace and view each encoded item at each locus.

An example can be seen in Figure 2.10. Here, the 7 items which we wish to remember are: "eggs, milk, cheese, flour, bread, ham, nuts". First, the subject chooses a familiar environment (in this example we shall assume the plan represents the subject's childhood home). Next, the subject navigates the environment whilst placing mental images of the item to be remembered at certain places (or *loci*) in the environment. In order to remember the items, the subject will navigate the same route they used during encoding by taking a mental journey to retrace their steps and view the images places at each locus.

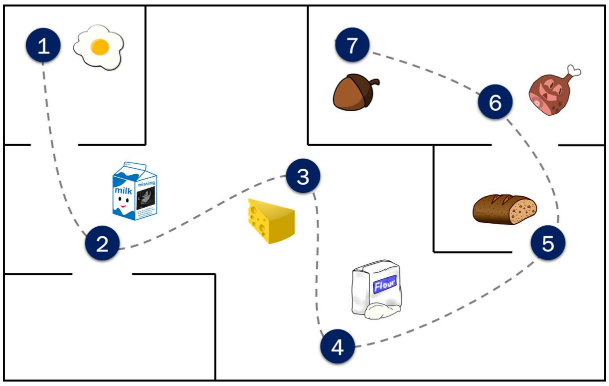


Figure 2.10: Example of the MoL technique, with loci labelled 1-7.

The technique is very powerful for a number of reasons, including but not limited to:

- **Spatial navigation:** By navigating the palace and becoming familiar with the location of encoded items and how these are connected, the hippocampal regions of the brain are activated; areas which (as discussed) have been shown to be closely related to episodic memory formation [Harand et al., 2012].

- **Encoding specificity:** The conditions (palace layout and item encodings) are identical during encoding and recall, which adheres to the ES principle [Tulving and Thomson, 1973]. The findings of Kemp et al. [1985] support this - participants showed greater recall if loci were physically present or totally imagined in *both* encoding and recall stages, compared to participants where loci were only physically present at one of the stages.

- **Levels of processing:** Placing images in a context (palace) and considering their semantic associations in order to encode and visualise them at each locus in a meaningful way requires attention and deep processing of information. Craik and Lockhart [1972] demonstrated that this improves recall.

- **Elaborative rehearsal:** The MoL by nature encourages repeating the steps taken in order to memorise encoded information. By visualising items in a context and thinking about what the encoded items represent, we are using elaborative rehearsal which improves recall [Greene, 1987]. [6].
- **Emotional stimuli:** In navigating a familiar environment we are not only reducing cognitive effort required to memorise the palace but also stimulating emotions by undertaking mental time travel [D'Argembeau and Van der Linden, 2007]. As discussed, emotional stimuli have been shown to improve recall performance [Bradley et al., 1992]. Images for the encoded information are quite often bizarre to make them more memorable [McDaniel and Einstein, 1986].

The technique does require upfront cognitive effort in the short term by imagining navigating the palace and creating encoded visual representations at each loci [Bellezza, 1996], but consistently shows improvement in recall in the long term [Wieland et al., 2017, Mccabe, 2015, Perrault et al., 2015, Ikei et al., 2007, Harman, 2001, Kemp et al., 1985, O'Keefe and Nadel, 1978]. Some studies even indicate that proactive interference discussed previously (new information causing old items to be forgotten) is reduced by using the MoL technique to remember categorically similar words [Bass and Oswald, 2014]. This is still the case over time, with the MoL technique appearing to retain its usefulness over extended periods [Massen and Vaterrodt, 2006]. The method itself is not strict in nature - encoded images do not have to be bizarre to be memorable [Bower, 1970, Briggs et al., 1970], and the environment chosen for a palace does not need to be totally familiar to the subject for improvements in recall to be observed [Crovitz, 1971].

2.3.2 Deliberate Practice

It is clear that mnemonics can encourage practice and greater attention towards items being memorised which improves recall compared to control groups. In this section, we shall further this idea by considering *deliberate practice* to assess whether its principles can be applied to improving one's ability in memorising information over time.

Whilst popular culture sees frequent use of the "10,000-hour rule" [Gladwell, 2008] as a rule of thumb for the number of hours required to become an expert in a domain, Anders Ericsson et al. [1993] instead found that there were many more factors than simply the number of hours a subject has spent training a certain skill. Classical studies demonstrate plateaus in humans' abilities as time goes on after an initial increase in ability when first learning a new skill using a particular technique [William and Harter, 1899]. This is due to the way they are practising this skill, which becomes rather mechanical and autonomous over time.

Deliberate practice aims to remedy this problem by introducing targets and a purpose to the process of learning, by consistently assessing what is necessary to get better at a certain skill and then practising it at a more challenging level [Lehmann and Ericsson, 1997, Davids, 2000]. Assessing what is necessary often comes from looking at how the

[6] The MoL technique also embraces the testing effect, whereby some of the learning period is devoted to testing for recall. This has been shown to improve long term recall. [Roediger and Butler, 2010].

current top performers achieve their goals [Toner and Moran, 2015], much like Foer [2011] when he started to compete in memory competitions. There is no question that innate and natural talent also plays a role in individuals' ability to improve [Campitelli and Gobet, 2011], but it is clear that through practising a technique in an intelligent way along with clear ideas of how to improve, then certain abilities can be improved beyond their natural plateau.

2.4 Technology and Memory

With the techniques and mnemonics mentioned in Section 2.3 shown to enhance memory and recall, this section explores whether technology can further assist or augment humans in creating or recalling memories. As personal devices become more ubiquitous in today's society, it is logical to first assess how technology has already changed the way we rely on our memories in everyday life. From there, we will see how technology is already being used to assist both information recall and memorisation, investigating the effectiveness of these techniques.

2.4.1 Digital Amnesia: Forgetting what and remembering where

With an increasing reliance on personal electronic devices to remember daily activities (a form of *external cognition* or *cognitive offloading*), it is no wonder that studies are suggesting a trend towards humans remembering *where* information can be found and not *what* the information is when they are told they will need to recall it at a later date [Sparrow et al., 2011, Yacci and Rozanski, 2012, Ward, 2013]. As computers and mobile phones provide the functionality to create appointments, reminders, alarms, to-do lists and notes, humans now live in a society that prefers to remember less and rely more on technology for information access and recall. Digital Amnesia (also known as the*Google Effect*) is the official term for this phenomenon.

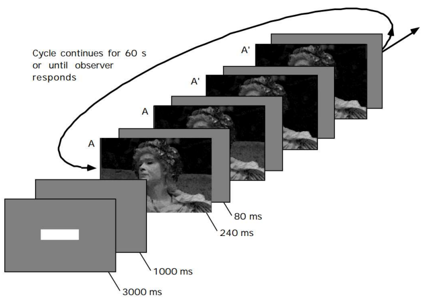
Digital Amnesia is a by-product of the *transactive* nature of the Internet. A transactive memory is a collective system where groups store information they may wish to retrieve [Wegner, 1987]. Whilst incredibly powerful as a collective searchable tool, it reduces the need for an individual to retain knowledge. Furthermore, if a person has relied on the Internet to access information once, they are more likely to rely on the Internet to access other information [Storm et al., 2016]. Thus, as ubiquitous devices store and retrieve more information than individuals need to remember, they in turn increase levels of reliance on these tools. This trend causes problems for the individual when access to the collective memory is not possible. For example, *Kaspersky Labs* [2015] showed that participants generally have less recall for current critical phone numbers than those from their childhood, which they have no longer have any practical reason to remember (Table 2.2).

Table 2.2: Most people cannot recall current critical phone numbers yet can recall past numbers from their childhood (*Kaspersky Labs* [2015], pp. 6).

Country	Home number aged 10	Home number aged 15	Partner number	Children's number(s)*	Place of work
Europe average	56% can recall	60.5% can recall	66.5% can (33.5% can't)	47% can (53% can't)	49.2% can recall (50.8% can't)
UK	45.4% can recall	50.1% can recall	50.8% can recall (49.2% can't)	29% can recall (71 % can't)	43% can recall (57% can't)
France	49.9% can recall	51.7% can recall	65.6 % can recall (34.4 can't)	48% can recall (52 can't)	48.5% can recall (51.5% can't)
Germany	55.3% can recall	61% can recall	61.1 % can recall (38.9% can't)	46% can recall (54% can't)	52.7% can recall (47.3% can't)

2.4.2 Assisting Recall: Lifelogging

The trend in ubiquitous devices being used to store information we wish to remember is furthered by lifelogging. The term is used to describe the capturing and recording of a subject's life events [Lupton, 2016, Wang et al., 2017]. A common belief is that the brain works like a camera, being able to record and recall life events with complete accuracy [Simons and Chabris, 2011]. In actual fact, studies show that visual information absorbed by the brain is not always perceptive to changes; a phenomenon called *change blindness* [Simons and Ambinder, 2005, Kentridge, 2015]. Rensink et al. [1997] demonstrated this in the flickering experiment, where participants struggled to observe differences between an original and slightly modified image when spaced between blank screens (Figure 2.11a). These flaws in the brain's ability to capture accurately all details for later recall open questions into whether lifelogging technology could assist with recall [Bell, 2009]. Currently, this technology manifests itself through wearable devices used to record everyday events, taking upwards of 3,000 photographs per day [Piasek, 2015, Gurrin et al., 2016] (Figure 2.11b). As the dataset from a certain subject grows, this data can be queried to help assist information retrieval (IR) [Gurrin et al., 2016, Duane and Gurrin, 2017, Gurrin et al., 2018, Zhou et al., 2018].



(a)

(b)

Figure 2.11: (a) The flicker paradigm [Rensink et al., 1997, 2000], (b) SenseCam (top) used in lifelogging for Dementia, with sample images (bottom) [Piasek, 2015].

Hamilton and Yao [2018] view lifelogging as a growingly feasible technique for assisting in information recall, highlighting 2 main justifications. Firstly, this technology has the potential to capture more episodic memories than the human brain is able to - events that some senses may have missed can potentially be augmented by technology. Secondly, humans are already trusting technology with the information they would otherwise need to remember by using calendars and note-based applications. This means that emerging systems can try to give context to this existing data. For example, Yi et al. [2013] attempt this by analysing the context (e.g. GPS location) of data stored in mobile phone appointments and SMS messages (to name a few), in order to assist with later recall.

That said, lifelogging systems raise some ethical concerns regarding how much data on a subject should be captured. As soon as this information is digitised, it is subject to the same legislative restrictions that all personal data within the EU is [Jones et al., 2015, Greengard, 2018]. Hamilton and Yao [2018] also raise an ethical problem with the lack of *higher cognition* in lifelogging systems. A subject using this technology currently has no control over the information they wish to capture. Some memories are best forgotten and some are incredibly important to remember; a user should have control over this [Sellen and Whittaker, 2010].

From these findings, it is clear that lifelogging technology is potentially very effective in supporting recall, but it remains to be seen whether this can *improve* memorisation or *replace* the need for humans to commit information to memory altogether. Fundamentally, lifelogging seemingly solves a different problem; one of *just-in-time retrieval* at the moment information is needed [Rhodes and Maes, 2000]. In contrast, the proposed system in this dissertation must explore ways to use technology to effectively *commit* information to long term memory ahead of times where technology is not present (for example, exams and speeches).

2.4.3 Assisting Memorisation with the Method of Loci

Using spatial cognition (and the MoL technique in particular) to assist memorisation is an active area of research. This section critically analyses the existing systems which aim to solve this problem. Systems which adopt the MoL technique to help users memorise information are usually *active* in nature - they tend to require a user to undertake some form of (physical or virtual) navigation or exploration using an interface in order to create a Mind Palace and practice using the technique. Examples relying on a *passive* approach are therefore difficult to find given that the traditional mnemonic itself requires some form of navigation (physical or virtual) for information to be encoded.

In what follows we will be examining existing systems and applications that use 3 different types of environment for building palaces. Firstly, we shall look at 2D graphical environments before moving onto 3D graphical environments that can be navigated virtually. Finally, we shall evaluate the 3D hybrid (e.g. Augmented Reality) approaches that rely on the navigation of physical spaces.

2D Desktop and Mobile approaches

Several approaches rely on the use of a desktop or mobile display in order to create a 2D mind palace. For example, Harman [2001] created a Java desktop applet to navigate 2D blueprints of a virtual house and scroll through fixed hyperlinked text in each "room" in order to explore and navigate ideas. When a user wishes to add a new item to their palace using this system, they must use a textbox to type out this information themselves, with the option to add a URL to link to further encoded content for recall. This system had the goal of allowing users to structure their thoughts into rooms to make cues easier to remember in comparison to worded lists. Whilst it somewhat achieves this goal, there is no visual information to encode loci which makes loci harder to distinguish during encoding and recall. Pieces of text alone are used against the same 2D floor plan for all palaces, with URLs being an optional extra. This approach uses the same blueprint for all palaces may arise in confusion between groups of items that require remembering and means the cognitive effort required in processing items at each locus is larger than it needs to be [Mayer and Moreno, 2003]. This system is more effective as a way of organising ideas than a way of implementing the MoL technique.

Some current mobile applications also adopt a 2D graphical approach whereby a user scrolls through 2D images in order to navigate a palace. *Mind Palace*[7] uses a set of images (either using the application's default pack or allowing the user to take and upload their own) to act as rooms containing loci of the mind palace (Figure 2.12). Each room can contain text or image-based Q&A style flash cards that the user interacts with to remember information. It must be noted that loci are not pinpointed to indicate where encoded items exist in a given room - a room will just have several listed flash cards next to it. Although a user can build multiple palaces, if they wish to store several encoded items in a single room then they must use extra cognitive effort in working out where each item was placed in the room.

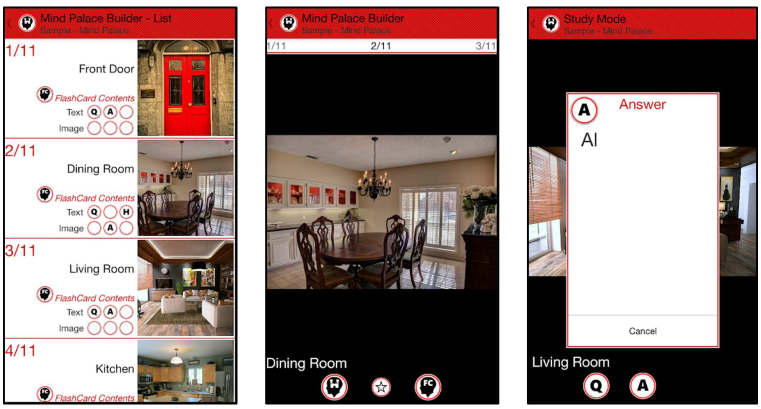


Figure 2.12: Mind Palace: 2D mobile-based approach to assisting users with the Method of Loci.

[7] `https://play.google.com/store/apps/details?id=com.mind_palace.pkg.free`.

Mnemo Route[8] relies on a similar, albeit slightly different approach - this time images are per-loci rather than per-room which distinguishes encoded items more effectively (Figure 2.13). "Routes" (palaces) consist of "routepoints" (loci) which are all image based with a title, with the option to include an audio snippet for extra sensory information.

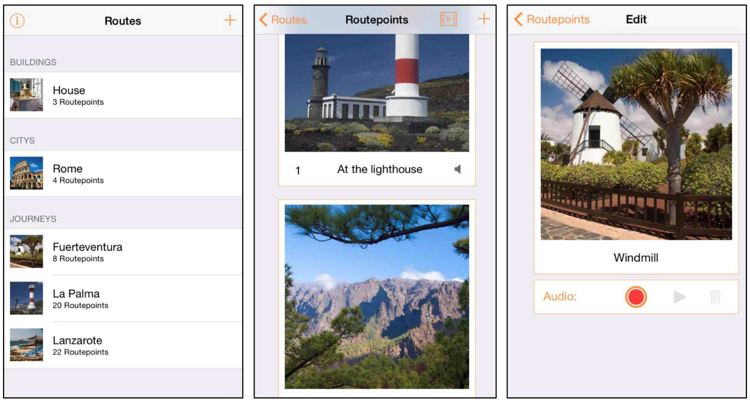


Figure 2.13: Mnemo Route: 2D mobile-based approach to assisting users with the Method of Loci.

In order to recall items stored using these applications with the MoL technique, one must imagine all 2D images as a coherent 3D environment. As such, both of these applications have the potential to assist in mind palace creation but have drawbacks in the large cognitive effort required to navigate their palaces.

3D Desktop, Mobile and Virtual Reality (VR) approaches

Using a 2D desktop or mobile application may indeed help facilitate the MoL technique to some extent, but in order to more effectively assist in the creation of palaces, several systems utilise 3D graphical spaces (sometimes with Virtual Reality (VR) Head Mounted Displays (HMDs)) for exploration of palaces. This is with the aim of making navigation more realistic to reduce cognitive load on the user and allow them to more effectively engage areas of the brain such as the hippocampus for enhanced recall [Brooks et al., 1999, Dinh et al., 1999, Tan et al., 2002, Huttner and Robra-Bissantz, 2017, Huttner et al., 2018].

Legge et al. [2012] performed a 3-way between groups experiment to contrast the performance of participants in recalling a group of 10 unrelated words using a 3D graphical desktop palace against a group using the traditional imaginary MoL technique and another group not instructed to use any particular mnemonic device or technology to assist them. Ultimately, those using the 3D graphical environment showed better free recall rates than those using imaginary palaces of their own creation. In turn, the group using imaginary palaces performed better than the control group. This suggests that technology can indeed assist in creating mind palaces by taking some of the cognitive

[8] `https://itunes.apple.com/gb/app/mnemo-route/id955836076?mt=8`.

load of the technique away from the user, allowing them to focus their attention on the navigation of the palace.

It may turn out that these systems do not show their true benefit until they are tested over longer periods. For example, the *Virtual Memory Palace* (VMP) [Fassbender and Heiden, 2006] produced no significant difference in immediate recall using a 3D graphical MoL approach compared a text-based list of words. However, after 1 week there was a significant difference, with VMP participants producing better recall. These findings show that in general, systems implementing and assisting with the MoL technique might not be noticeably better than simpler mnemonics or rote memorisation in the short term, but they can be significantly better for long term recall.

The above studies used 3D graphical approaches on desktop interfaces. However, some studies use HMDs in order to immerse the user into a 3D virtual environment to a greater extent than a desktop environment. After Ragan et al. [2010] discovered that a wider field of view (FoV) of objects in a virtual environment produced better memorisation performance, Krokos et al. [2018*a*,*b*] compared the use of HMDs against desktop environments, as HMDs can provide a wider FoV. Krokos et al. used a spherical FoV with an HMD to compare against the use of a desktop environment to navigate 3D graphical palaces. It was discovered that recall accuracy was significantly improved using the HMD than the desktop approach (Figure 2.14). Similar effectiveness was observed by Vindenes et al. [2018] in their recent experiments using MoL with an HMD. It appears that greater sense of immersion aids recall.

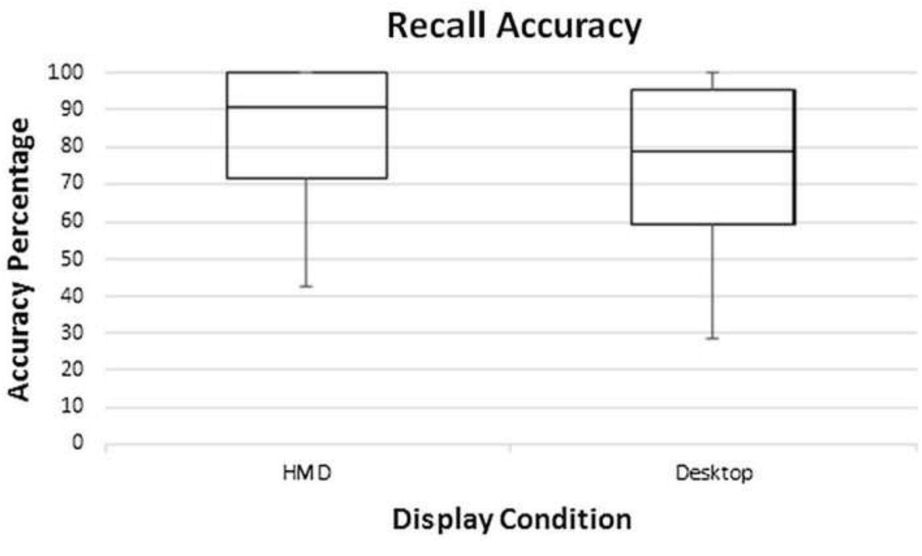


Figure 2.14: Memory Palaces using HMD versus desktop interfaces to navigate a 3D graphical palace [Krokos et al., 2018*a*].

A selection of current mobile applications also adopt an approach whereby a user explores a 3D graphical environment in order to navigate a palace. *Memory Mansion of Loci*[9] uses a game-style approach whereby text-based pieces of information are stored in graphical 3D chests (loci) which can be placed in different rooms of a virtual mansion

[9] `https://play.google.com/store/apps/details?id=com.TF.TestyLagoo`.

(palace). This relies on a mobile interface so the user isn't completely immersed in the environment but there is less cognitive effort involved than the 2D mobile approach in constructing a 3D mental palace from what is presented on the screen (Figure 2.15). *Memory Palace - US History*[10] is another example of a 3D graphical approach - loci are already created in the 3D world with distinctive visual features to help users remember names of past US presidents (Figure 2.16). For example, George Washington is encoded as a 3D man washing a (tonne) weight. These approaches are seemingly more effective than the 2D mobile approaches discussed previously.

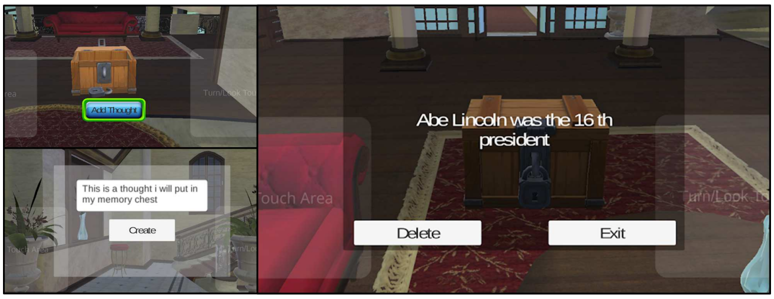


Figure 2.15: Memory Mansion of Loci: Mobile VR-based approach to assisting those with the Method of Loci.

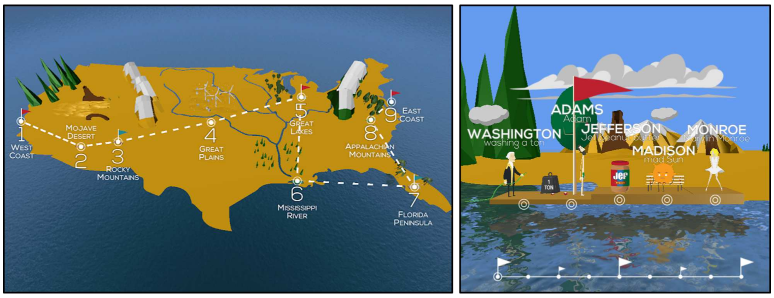


Figure 2.16: Memory Palace - US History: Mobile VR game assisting those with the Method of Loci to learn the names of past US presidents.

It can definitely be concluded that the 3D virtual environments provide more effective assistance with the MoL technique than the 2D systems described previously. In fact, VR has been used to assist memory in a more general sense than just the MoL technique, including applications for rehabilitation [Brooks and Rose, 2003]. However, one particularly strong and valid criticism of VR approaches to MoL is that it is very difficult to measure or indeed track what activity that navigation in virtual environments is doing in terms of engagement of the neocortex and hippocampus [Taube et al., 2013]. In other words, a user does not need to physically engage their motor skills in navigating these graphical environments. Mueller et al. [2012] performed an fMRI scan during their virtual CityMap experiment to observe activation during navigation (Figure 2.7). Some hippocampal activation was observed but due to the nature of fMRI being a scan whilst the subject is stationary, it is difficult to compare this against activation levels whilst a subject physically navigates a 3D space.

[10] `https://play.google.com/store/apps/details?id=com.memorypalace.ushistory.android`.

3D Augmented Reality (AR) approaches

The questions raised over whether VR technology can actually be counted as meaningful navigation (in comparison to the hippocampal activation stimulated from the navigation of a physical environment) has prompted several studies into the effects of AR technology in assisting with the MoL technique. This time, physical objects are used and augmented for recall instead of relying on virtual objects alone.

One such example is *Physical Loci* [Perrault et al., 2015] (Figure 2.17), which applies the MoL technique to the field of Human-Computer Interaction (HCI). It is designed for users to learn a large number of commands (around 48) which are used to control a gestural (Kinect-based) interface by associating textual labels with physical objects with the help of AR technology. Users first set up mappings between physical objects in the room and textual labels by pointing at the object in the room and making a confirming gesture. Much like the participants of the VR experiments by Fassbender and Heiden [2006], participants using the Physical Loci system demonstrated near-perfect recall for commands even after a whole week had passed between trials. This was also discovered to be independent of the layout of the loci in the physical space. Loci were also found to be transferable between participants. In other words, a user did not have to create the loci in order for them to show enhanced recall.

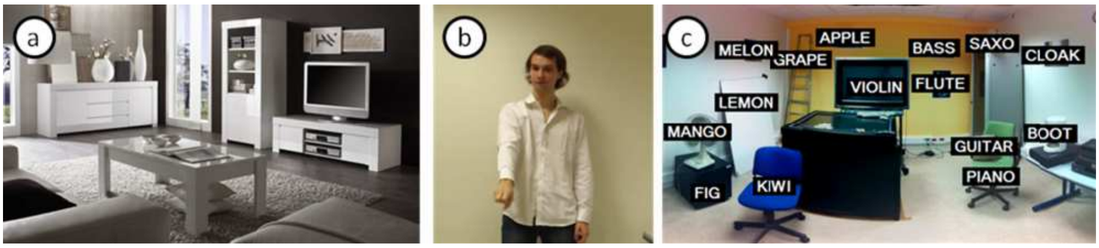


Figure 2.17: Physical Loci: (a) A physical space is chosen. (b) Users point to physical objects (loci). (c). Mappings are set up between commands and objects [Perrault et al., 2015].

Another AR approach is *HoloMoL* [Yamada et al., 2017*a*,*b*] (HoloLens's Method of Loci - Figure 2.18) which uses a Microsoft HoloLens HMD to interact with virtual loci using physical spaces, instead of using real-world objects as above. As with Physical Loci, HoloMoL replaces an otherwise imaginary environment to build palaces with one that a user is already familiar with. A user places fiducial markers at locations they wish to create loci. A mapping is maintained between the fiducial marker and virtual content to ensure the correct virtual content appears when the user approaches a specific marker. The benefit of this approach is that the information to be remembered remains fixed in space along with the fiducial marker regardless of the user's head movements with loci automatically appearing as they navigate the physical space. The downside is the need to create unique fiducial markers for each different piece of information to be remembered.

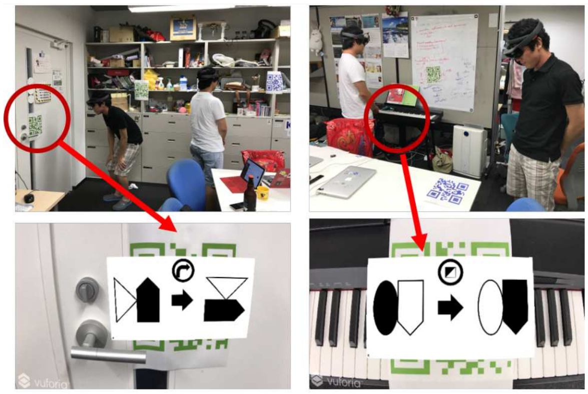


Figure 2.18: HoloMoL: Users place fiducial markers in a physical space (top), which are mapped to virtual content. Content is retrieved by looking at markers through the HMD (bottom) [Yamada et al., 2017*a*].

NeverMind [Rosello, 2017] (Figure 2.19) also uses an AR HMD, except this time with a mobile phone application to select images to be displayed against the background of 3D space as a user walks around their chosen location to create a palace. NeverMind builds on the findings of Tenenbaum et al. [2011] to aid users in creating a "one shot" memory of images (representing information to remember) against a familiar environment using an Epson Moverio BT-200 headset and a mobile device to choose images. After a user has finished selecting an image at each locus in a building, they must retrace their steps and query the mobile application to display the desired image against a physical background of a familiar environment.

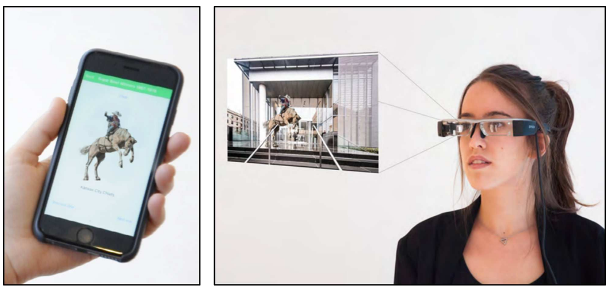


Figure 2.19: NeverMind: An AR interface for memorisation assistance [Rosello, 2017].

Experiments comparing the accuracy of information recall using NeverMind against the rote memorisation of a paper list showed that whilst there was no immediate significant difference between groups, the former yielded three times better recall accuracy 7 days after the trial [Rosello, 2017]. This backs up the aforementioned studies that indicate technology can indeed augment the MoL technique. One notable criticism of the system is that images supplied by the NeverMind mobile interface and displayed on the headset are not anchored to a specific spatial location and move with the user's head motion which is likely to interfere with a user's ability to remember where exactly in the physical space that image is located.

The final system we will evaluate is *Loci Spheres* [Wieland et al., 2017] (Figure 2.20).

This is a recent mobile based application using AR via the device's camera itself for practising the MoL technique which aims to reduce the upfront effort in loci creation - a demanding part of the technique [Kemp et al., 1985]. Here, users can leverage their smartphone's ability to take *photo spheres* - photos with a field of view of 360°. Loci Spheres is a natural extension of mobile applications that allows users to pinpoint loci in a photograph. Once a spherical photo is selected as the palace's background image and loci are pinpointed by different spherical coordinates, users can navigate the photo in different ways, with a central fixed cursor on the mobile device to select and interact with loci. The path between loci is mapped onto to background to assist the user in navigating.

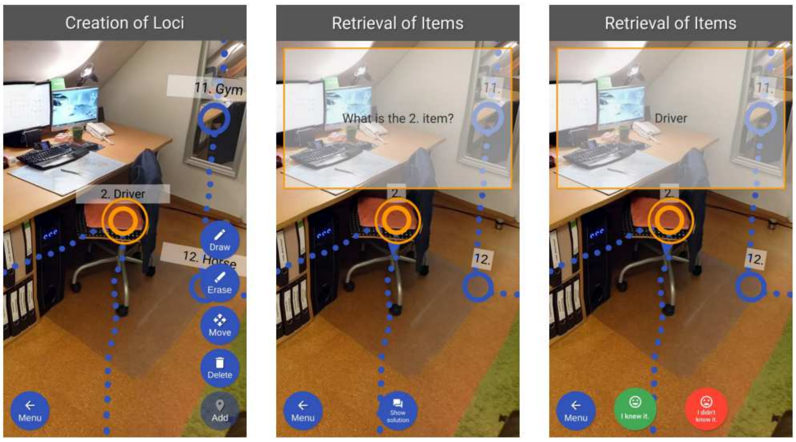


Figure 2.20: Loci Spheres: Spatial and panning loci modes [Wieland et al., 2017].

Loci Spheres was created with 3 navigation modes: *spatial loci* (users navigate by physically moving in concentric circles around their current location), *panning loci* (users pan the image manually using the phone's touch screen interface) and *no loci* (a text-based list is used as a palace instead of a spherical image that can be navigated (Figure 2.21). Some valid criticisms of the experiments which use Loci Spheres system include that a small participant group size may have impacted results and use of an online survey to test recall 1 week later was heavily relying on participant honesty in the absence of system designers. Despite this, results seem to suggest that the spatial and panning loci modes were most popular amongst participants compared to the no loci mode. Comparing the 3D hybrid (physical space with AR) approach against a graphical one, it would appear that use of a physical space allows users to choose to build palaces in locations they are already familiar with, reducing the cognitive effort involved in remembering the palace surroundings itself. Also, in navigating a physical palace a user is fully immersed in their palace at all moments which is a factor strongly linked to enhanced recall [Dinh et al., 1999]. Finally, using physical spaces as palaces means it is possible for users to engage their motor skills more effectively and arguably activate the hippocampus more naturally than virtual environments can allow.

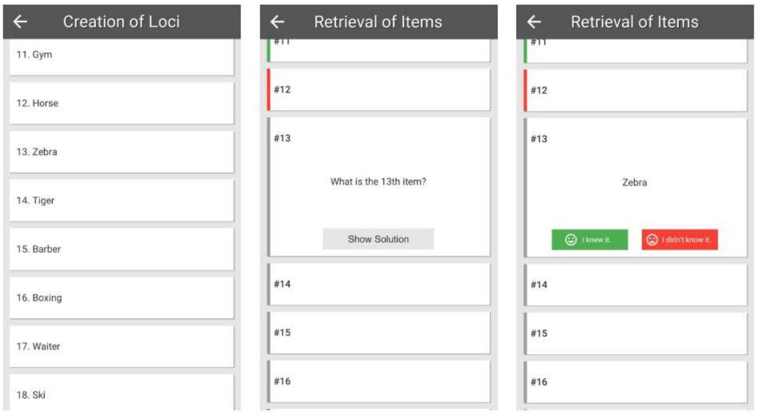


Figure 2.21: Loci Spheres: No loci mode [Wieland et al., 2017].

As Table 2.3 shows, most existing systems using the MoL technique rely on image and text-based loci for encoding information. Those listed as "graphical" are examples where a 2D or 3D virtual environment is used to build and explore mind palaces. Those listed as "hybrid" use a mix of physical (real world) spaces along with augmented loci (i.e. physical objects overlaid with images and text using AR technology) to enhance the realism and sense of presence of a user in their palace. These systems also tend to use image and text-based loci, except they are overlaid onto physical spaces instead.

Table 2.3: Loci media types in existing systems (Y=Yes, N=No).

Study	**Environment**	**Image**	**Text**	**Physical**[11]	**Animated**	**Audio**
Harman [2001]	2D Graphical	N	Y	N	N	N
Hedman and Bäckström [2003]	3D Graphical	Y	Y	N	N	N
Fassbender and Heiden [2006]	3D Graphical	Y	N	N	Y	Y
Legge et al. [2012]	3D Graphical	Y	N	N	N	N
Mann et al. [2017]	3D Graphical	Y	Y	N	N	N
Krokos et al. [2018*a*,*b*]	3D Graphical	Y	Y	N	N	N
Perrault et al. [2015]	3D Hybrid	N	Y	Y	N	N
Yamada et al. [2017*a*,*b*]	3D Hybrid	Y	Y	Y	N	N
Rosello [2017]	3D Hybrid	Y	N	Y	N	N
Wieland et al. [2017]	3D Hybrid	N	Y	Y	N	N

[11]Relies on objects in the physical world.

2.5 Chapter Summary

In this chapter, we have reflected on the current state of the art about memory, mnemonics and existing technology which aims to assist and augment these techniques.

In Section 2.2, we explored the categories and models underpinning our modern understanding of how memory works. From this point onward, we shall be targeting the improvement of long term memory (in particular, episodic memory). By assessing the psychological models and findings of Atkinson and Shiffrin [1968], Craik and Lockhart [1972], Tulving and Thomson [1973] and Baddeley and Hitch [1974], we can make some useful conclusions about memorising information for long term recall. Memorisation requires attention towards information, and the level at which this information is processed is a bigger factor than the amount of time it is attended to for effective recall. Due to Encoding Specificity, it is important that conditions during encoding and retrieval are closely mirrored. It is also possible for humans to focus on more than one type of information or stimulus at a time, so long as they require different parts of working memory. We also considered how factors such as spatial navigation and elaborative rehearsal can improve recall which are key reasons as to why the MoL technique is so successful.

Based on the literature reviewed in Section 2.3, it was discovered that mnemonic techniques can be used to improve recall by employing techniques that suit the way our memory works. The Method of Loci technique will be taken forward to be used in the proposed system. Knowledge of the MoL technique appears to be low amongst students [Mccabe et al., 2013], which is surprising given its effectiveness in the long term. In addition to the MoL, we will also be incorporating aspects of deliberate practice into the proposed system to see if training memory with an idea of how to improve can indeed enhance recall.

It is clear from Section 2.4 that ubiquitous technology has meant we increasingly trust mobile devices with the storage of information we wish to remember. For this reason, the proposed system will take the form of a mobile application where users may store information they wish to memorise using the MoL technique. Lifelogging technology may indeed prove a useful way of enhancing and supporting recall, but due to its just-in-time retrieval approach, it cannot be considered a suitable solution to assist those in memorisation itself in domains such as examinations where this technology is not available to the user. For this reason, the technology needs to support memorisation, which in turn enhances recall. There are several existing technologies which employ the MoL technique. Systems most similar to the proposed solution include the HoloMoL, NeverMind and Loci Spheres projects, which also interact with physical spaces in the creation of loci using the MoL technique (with the latter two also using mobile devices). Navigating virtual or physical spaces in comparison to use of 2D graphical approaches appears to engage the hippocampus most successfully and hence seems to be more effective in assisting the MoL technique.

In the next chapter, a set of formal system requirements will be presented which are mostly elicited from the research presented in this chapter. These will act as a set of formal criteria that the system must adhere to in order to build upon current research, and a crucial foundation for the system design presented in Chapter 4.

Chapter 3

Requirements

3.1 Introduction

After evaluating the state of the art underpinning our current psychological understanding of memory, the techniques that can be applied to enhance recall as well as how technology can assist with this, we shall set out a formal collection of requirements to base the design of the system on. In order to do this, the findings from the Literature Review chapter will be considered in line with user feedback. This chapter also discusses the key choices made in the scoping of the system. It is this set of requirements which will inform the design of the system in Chapter 4.

The Proposed System: "Hold That Thought"

From this point onwards the proposed system shall be referred to as "Hold That Thought" (HTT) (Figure 3.1). This name was chosen for the system as an appropriate branding of the system's purpose. The phrase is used in common language to mean the temporary pausing of a given idea for a period of time until it can be revisited (requiring the item to be committed to memory for later). Given the premise of the application (using the Method of Loci technique), ideas are often put on hold in a given location until they are revisited (sometimes physically). With the system taking the form of a mobile application, this also acts as a play on words - in storing their notes and ideas, they are using a hand-held device to "hold" onto them. It is hoped that in giving the system a brand identity, it will improve the user experience.

Figure 3.1: "Hold That Thought" (HTT): Logo of the proposed system.

In the interest of meeting the project objectives in a way that adheres to the final project deadline, the HTT system needed to be scoped in such a way that the system achieved its core aims and allowed for a thorough empirical evaluation and user study with time to reflect on these results. Hold That Thought was therefore specified as an Android mobile application which could assist a user in creating Mind Palaces using physical spaces, with the aim of investigating whether this requires less cognitive effort compared to the traditional MoL technique and a control group whilst remaining an effective method of memorisation. This work is completed under the guise of being used for students' exam study, but it is important to note that it is equally applicable to learning speeches or preparing for presentations.

3.2 Requirements Elicitation

When eliciting requirements for the HTT system, it was important to consider existing work, the theories behind effective recall and end-user input in order to make the application usable and appealing for students revising for their examinations.

Whilst this project does produce a piece of software in the form of an Android application, it is important to note that its primary focus is research-based. In particular, this dissertation investigates how technology may be used to effectively assist users with the Method of Loci technique whilst reducing the level of cognitive effort the traditional technique requires. In that respect, the majority of the system requirements are elicited from the findings of the Literature Review chapter. However, there is also a consideration of responses to initial user surveys and interviews that is reflected in some of the system requirements. The findings of each of these elicitation stages are documented below.

Literature Review

Key findings that can be translated into requirements from the Literature Review chapter can be summarised in 3 categories: *Engaging Episodic Memory*, *Elaborative Rehearsal and Deliberate Practice*, and *Supporting the Method of Loc*i.

Engaging Episodic Memory

This project will be targeting episodic memory in particular, using the definition given by Tulving [1972]. The system must, therefore, interact with users in such a way that supports this. Users should be able to engage their hippocampus by partaking in some form of spatial navigation whilst information is encoded and retrieved using the application, as this has been shown to enhance recall of episodic memories [Eichenbaum et al., 1999, Parmentier et al., 2005, Harand et al., 2012]. By activating the hippocampal region of the brain whilst using the system and considering items and their locations in a physical environment, it is hoped that this will improve users' abilities to recall the information stored using the application. As such, the application should encourage active exploration of an environment for enhanced recall.

Elaborative Rehearsal and Deliberate Practice

Simple repetition (maintenance rehearsal) is helpful but not as effective for long term memorisation as elaborative rehearsal is as it becomes more autonomous over time, requiring less attention [Naveh-Benjamin and Jonides, 1984]. In order for items to be encoded effectively, one must employ *elaborative* rehearsal of items [Greene, 1987], considering them in a context and processing them at a deeper level [Craik and Lockhart, 1972]. The application must go beyond simple verbatim repetition of items by forcing the user to consider these items in a context.

Deliberate practice was also explored in the previous chapter; a concept whereby a user is aware of their weaknesses and what is needed to improve their performance so that they can act on these during practice to improve performance [Lehmann and Ericsson, 1997]. It would be interesting for the application to apply this principle to the MoL technique - users could track their performance and assess which loci in their palaces they are currently struggling to recall in the interest of improving over time, potentially changing the encodings for certain items that are not being remembered effectively.

Supporting the Method of Loci

It is well understood from the previous chapter that mnemonics can enhance recall [Roediger, 1980, Maghy, 2015]. The Method of Loci, in particular, will be supported or augmented by the HTT application, rather than replacing it.

When practising the MoL technique, it is the monitoring of encoded items' locations and their relation (i.e. position in relation to one another) that stimulates the hippocampus most effectively [Cain et al., 2006, Schacter and Tulving, 1994]. As such, the system should support users in monitoring the location of items in the palace and focus their attention towards this during encoding and retrieval in order to increase the likelihood of items entering long term memory (c.f. Sharot and Phelps [2004]). Due to the Encoding Specificity (ES) principle, users of the application should be able to replicate the conditions present during encoding and retrieval of items in order for recall performance to noticeably improve [Tulving and Thomson, 1973]. This is further supported by the findings of Kemp et al. [1985]. As such, the proposed application must allow loci to be physically present or totally imagined in *both* encoding and recall stages.

A large number of system requirements involving engaging the hippocampus and catering for deep processing of items are mostly met by the nature of the traditional Method of Loci technique itself, as described in section 2.3. That said, from looking at existing systems and technologies that implement this technique in the previous chapter, there are many ways the MoL technique can be interpreted using technology - existing solutions use a myriad of approaches ranging from exploration of 2D graphical environments, 3D graphical environments and a hybrid approach of graphics augmenting 3D physical spaces.

Approaches which engage users with a physical 3D space appear to lessen the cognitive effort in reproducing the palace in one's mind by immersing them fully in an environment [Ragan et al., 2010]. This allows more cognitive effort to be placed onto the items to be encoded. Also, VR approaches to supporting the MoL technique have been criticised by the likes of Taube et al. [2013] as it is difficult to be sure of the level of hippocampal activation stimulated when users undergo navigation of a virtual environment that doesn't necessitate physical movement around spaces. In this respect, users of HTT should make use of their physical surroundings when creating palaces instead of using a 2D or 3D graphical environment in which they must focus extra attention on remembering the palace environment as well as the items to be encoded. Most existing solutions use image and text-based encodings of items to be stored (Table 2.3). This is the case especially with systems like HoloMoL, NeverMind and Loci Spheres that all use the physical surroundings of a user as the palace. As such, the HTT system should also support image and text-based items.

User Survey

In the interest of gathering a general consensus of opinion from the prospective user group, a user survey was carried out. Surveys or questionnaires can allow a wide variety of potential users from different backgrounds to describe in detail their needs to a system designers [Preece et al., 2015]. This approach gives mainly quantitative responses, though some qualitative responses can be gathered. (Full results of the survey can be found in Appendix A.1).

Overall, 47 responses were gathered (59.6% male, 40.4% female) with the vast majority of responses (93.6%) being from those aged 18-22 - either students or very recent graduates from a wide variety of subject backgrounds. There is an almost even split between iOS and Android device owners. This shows that a significant number of Android users are present in the chosen target user group, and so by making use of an Android application for the project, users are likely to be familiar with the native interface from using other applications on their personal devices.

The main section of the user survey focuses on awareness and use of memory techniques (mnemonics). Three main techniques are explicitly mentioned and explained as examples - Chucking, Pegword and the Mind Palace (more detail in Section 2.3.1). Interestingly it appears that amongst the group of users surveyed most were aware of the Mind Palace technique compared to the Chunking and Pegword techniques (Figure 3.2). This contradicts the findings of Mccabe et al. [2013] who discovered that knowledge of the MoL technique was particularly low amongst undergraduates. The fact that 55.3% of participants surveyed were aware of the MoL technique but had never used it suggests that either there is a consensus of opinion that the technique is not as effective as it has been proven empirically to be (c.f. Wieland et al. [2017], Mccabe [2015], Perrault et al. [2015], Ikei et al. [2007], Harman [2001], Kemp et al. [1985], O'Keefe and Nadel [1978]), or that perhaps that the cognitive barrier for entry or use of this technique is too high. In other words, it is known that a large upfront cognitive effort is required to encode items at loci [Bellezza, 1996]. It could be that users feel the effort required in the short term is too large to make the technique worthwhile.

The technique used most often was actually the chunking technique (27.7%), with many users highlighting the use of "acronyms" as a form of chunking information into smaller, more manageable pieces, backing up the findings of Johnson [1970] and Cowan et al. [2004]. There were also many comments made about the use of repetition (*"Flash-cards", "Writing out information more than once."*), backing up the literature that demonstrates the popularity of maintenance rehearsal (repeatedly processing information at a similar level when rehearsing and encoding).

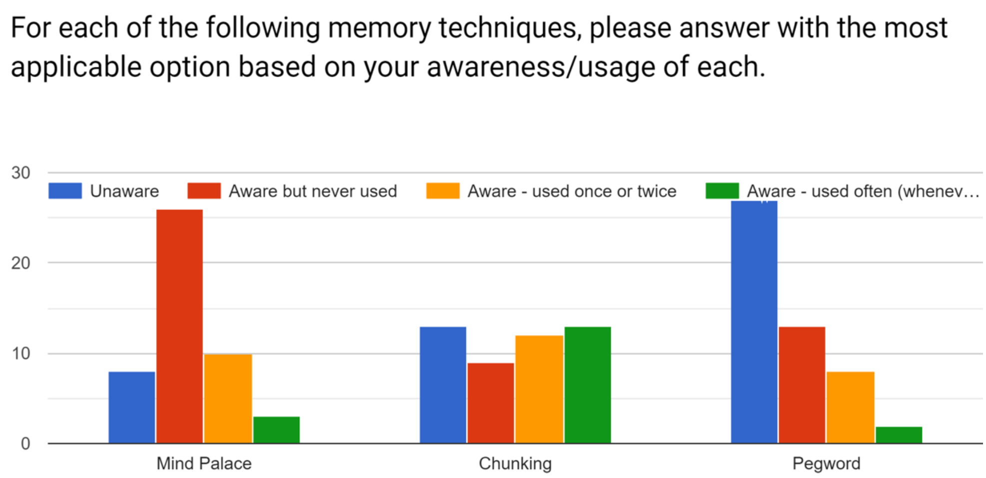


Figure 3.2: User Survey Q6: For each of the following memory techniques, please answer with the most applicable option based on your awareness/usage of each.

Some particularly interesting comments highlighted that the technique used varied depending on the type of information to be remembered:

- *"Mind palace [is used] for presentations, essays and speeches. I use a different room in my house for different points/paragraphs. Pegword [is used] for specific case studies, revising lists. Chunking doesn't work as well for me as the others.".*
- *"I sit down and write out what I need to memorise. I pick a method based on the structure of the data and then sit and learn it. I practice in my head over a few days."*
- *"Chunking [is used] when memorising a list of things, using an acronym. Used mind palace technique similarly before - I try to remember it as a story."*
- *"Used memory palace technique. I would enter my house and in each room something was happening (funny/scary/anything emotive). This 2 years ago so I can't remember it well, but I can still see faint images of what was happening. I used a variant of Pegword for a shopping list once, but it was pretty pointless since I could just use my phone!"*
- *"In year 8, we were asked to memorize as many stanzas of Horatius (poem) as we could, so I went through it on my way to school and can still remember the place I learned a particular stanza."*

These comments seem to suggest that the MoL technique has been very effective for some - the fact that memories of locations where information was encoded are still present years later just shows how long term the effects of the technique can be. This also demonstrates the importance that the MoL technique is practised in a well-known environment that is easily re-traceable on a mental journey.

An overwhelming majority (78.7%) saw examination revision as the main use case for the mnemonic devices they were aware of, with presentations in second place at 44.7% (Figure 3.3). This backs up the previous hypothesis that the HTT application is most applicable for undergraduates undertaking exam revision.

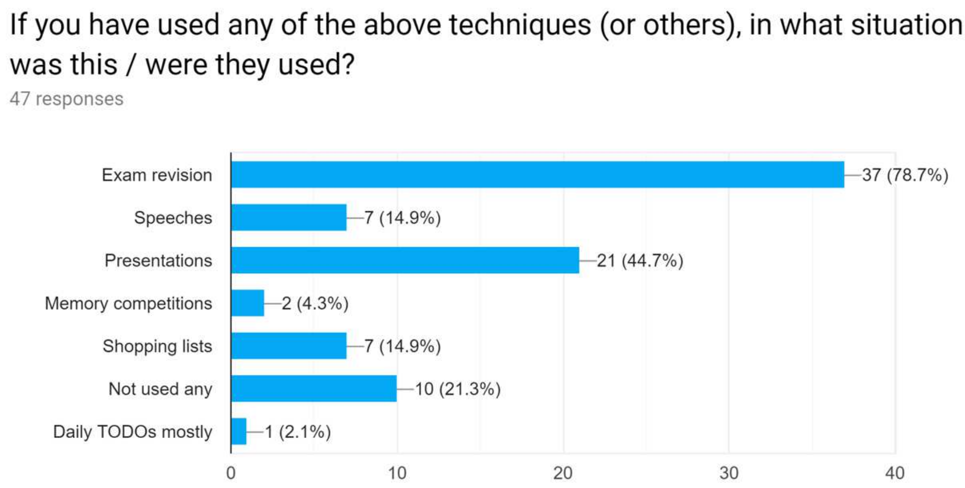


Figure 3.3: User Survey Q8: If you have used any of the above techniques (or others), in what situation was this / were they used?

In terms of sources of knowledge of these techniques, it seems to be that most mnemonics are learnt through word of mouth from friends and family rather than through digital applications that are designed to assist with these techniques. This is interesting given that almost half of the participants had used digital applications (computer or mobile based) for revision or memory/brain training. When participants were asked if they felt they would benefit from a mobile application to assist with memorising information on a Likert scale of 1 to 5 (where 1 represents very unlikely and 5 represents very likely), the most common answer (38.3%) was 4 (Figure 3.4). It appears that many people were also quite neutral towards the idea (voting option 3) which appears to suggest that there is a consensus that the Mind Palace technique takes some upfront cognitive effort that might make people reluctant in the short term towards its usage, despite its scientifically-proven effectiveness. From these findings, it is clear that the proposed system should lower the barrier for entry to users inexperienced with the traditional MoL technique. The system should do this by reducing the upfront cognitive effort required by the user in palace creation and navigation.

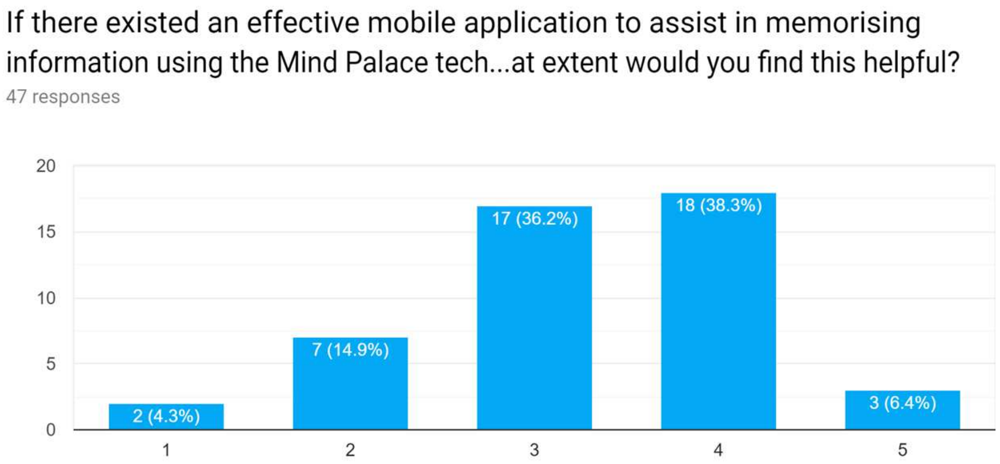


Figure 3.4: User Survey Q13: If there existed an effective mobile application to assist in memorising information using the Mind Palace technique, to what extent would you find this helpful? (1 = Very Unhelpful, 5 = Very Helpful)

Interviews

Following the user surveys, a structured interview was carried out with a prospective user of the system. Interviews allow for a greater variety of open questions to be responded to, with probing from the interviewer in case a question is not answered by the interviewee. It is important for system designers to meet with potential stakeholders early in the requirements elicitation process [Preece et al., 2015]. The chosen user to be interviewed was selected based on their response to the survey in section 3.2 - they left their email address and indicated that they use the Mind Palace technique often to assist them with their revision. (The transcript from the full interview can be found in Appendix A.2).

The user chosen was a final year Computer Science student at the University of Bath who claimed to use the Mind Palace technique in their revision without the aid of any technology. Their technique for memorising unordered lists relied on them using their university accommodation as a Mind Palace, whereas for ordered lists they would encode lists of words as images of actions that tell a story. Their approach to encoding information mainly relies on their semantic associations and visualisations of emotive, stimulating or strange events. This is in line with the findings of Burns [1996] and the "bizarre imagery" effect discussed in Section 2.2.3.

The student commented on how the MoL technique allows them to remember lists of around 20 items at a time for their examinations. Whilst acknowledging the large upfront cognitive effort required in order to come up with effective encodings (c.f. Bellezza [1996]) they generally seem to need only a single iteration through the palace of items for them to recall the information for 10 to 30 minutes afterwards. Their main difficulty with the technique is encoding words or phrases which do not directly correspond to easily-visualised objects (known as *low imageability* items [Paivio et al., 1968]). Notably, they had not previously tried to use the *same* location for different palaces, and were curious to see if exploring a *physical* palace would make a difference to their existing technique.

Interestingly, a lot of their technique also uses audio or verbal stimuli at various loci in their palace through characters speaking the words that need to be remembered. They also tended to keep a 1 to 1 mapping between items to be encoded and rooms in their mental palace. The student does not use a checklist or alternative method to identify which items have been successfully committed to memory, but they were interested to see if this improves their approach by allowing them to change the encodings of items in their palace that they are struggling to remember. Familiarity is the major factor in their choice of palace environment - by using a physical palace that exists in real life, they can easily reduce the cognitive effort required in remembering its layout.

Elicitation Summary

From the three elicitation approaches adopted, the method which was most successful at yielding concrete requirements was the Literature Review. This is not surprising given the fact that existing systems supporting the Method of Loci also are derived from theoretical foundations.

It could be argued that some conflicts exist between the findings of each elicitation technique. For example, the User Survey suggests that knowledge of the MoL technique in undergraduates is not as low as discovered by Mccabe et al. [2013]. Also, the student interviewed was not confident about whether the use of the same physical location for palaces would be effective, which is contradicted by the findings of Rosello [2017]. Whilst it was useful to consult users on their opinion of the proposed application and interview subjects on their approach to using the MoL technique in their revision, these user-focused elicitation techniques did not yield as many requirements because the use and effectiveness of the MoL technique is quite unique to the individual. As such, there must be an appropriate priority given to requirements elicited from user research. In most cases, it will be the literature driving the high priority requirements of the HTT system.

3.3 Towards a System Supporting the Method of Loci

The ultimate aim of this dissertation is to create a system capable of supporting the Method of Loci technique, retaining its effectiveness whilst reducing the initial cognitive effort it requires. As such, it is pertinent to review the key findings of the requirements elicitation stages documented in the previous section and extract meaningful conclusions for the requirements of this system. It is clear from the User Survey conducted that many people use rote memorisation (maintenance rehearsal) techniques, relying heavily on their semantic memories in order to build a set of facts, rules and meanings. This is seemingly how a lot of people are taught to engage with information in order to memorise it in schools and early education [Carey, 2015]. The approach that HTT aims to provide is an alternative - allowing users to encode items to be remembered as episodic memories in a physical mind palace, stimulating areas of the brain such as the hippocampus during spatial navigation of a physical space. It has been shown by recent studies that prolonged use of mnemonics such as the MoL over several months, the network of neurons in the brain of a control participant changes to match more closely that of a memory champion [Dresler et al., 2017]. This makes the story told by Foer [2011] somewhat more scientifically credible.

Below are the main conclusions that can be made from the Literature Review chapter and other requirements elicitation stages.

Honouring the Encoding Specificity principle

It is clear that for effective practising of the MoL technique, the ES principle (Figure 2.5) should be adhered to. The HTT system should facilitate (as much as possible) the match in conditions between encoding and retrieval stages of items being stored in the palace. The process and interface used for users to encode information must match closely the process that users follow when they retrieve the information using the system for recall.

Separating the stages of encoding and recall into separate cognitive tasks can be easily articulated into system design through the use of different system "modes". The "create" mode of HTT can be thought of as the part of the system responsible for palace creation and storing items in these palaces. The "training" or "retrieval" mode can be thought of as the part of the system responsible for recalling information at each locus once users have navigated their palace. The system design will be divided in such a way that separates and conceptually divides these two modes to make the task of mind palace creation and training even simpler.

Physical environments as palaces

The environment chosen for Palace creation in the HTT system will be real-world, physical spaces. From the observed success of 3D hybrid systems such as NeverMind and HoloMoL that use AR techniques to display images over familiar physical environments, it is clear that these lessen the cognitive effort required for users to remember the palace layout and environment before focusing on the items themselves to be remembered. Approaches that adopt navigation of virtual (VR) environments such as early iterations of the NeverMind project (Figure 3.5) cannot truly be interpreted as navigation as they do not engage the motor skills that physical spatial navigation does [Taube et al., 2013].

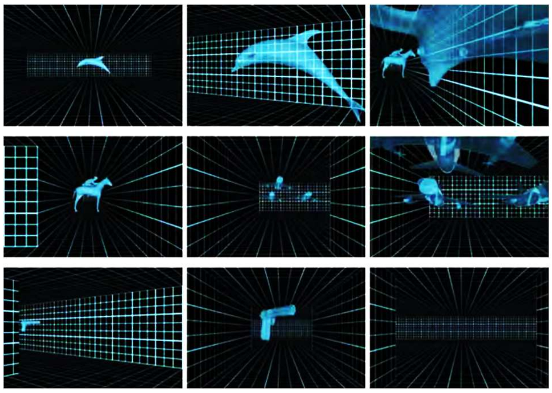


Figure 3.5: NeverMind: Early iterations of the design experimented with virtual environments such as the above [Rosello, 2017].

The traditional imaginative MoL technique relies heavily on the creativity and imagination of the user to navigate their palace and create encoded items. As such, not only will palaces be physical, but the HTT system should provide support for users not familiar with visualising images themselves by allowing visual cues to be retrieved. These should ideally be in the form of images uploaded from the device itself or those that are retrievable from online sources.

The initial experiments performed during the creation of NeverMind suggest that a single physical space can be used effectively to remember different sets of content (Figure 3.6). For this reason, experiments using the HTT system will employ a single physical space to store different sets of content. Importantly, unlike HoloMoL [Yamada et al., 2017*a*,*b*], physical fiducial markers will not be needed to be placed by users of the HTT system in order to encode items at locations in the palace.

Figure 3.6: NeverMind: Encoding different information using the same physical spaces [Rosello, 2017].

Mobile-based approach as a symbiotic interface

A symbiotic interface is a framework in Human-Computer Interaction that describes a device as a conceptual extension of a human, be it physical or mental [Licklider, 1960]. Memory assistance or augmentation systems can be considered a subcategory of these symbiotic systems. The HTT system, therefore, should fit the typical properties and behaviours outlined of a symbiotic system: taking a digital form, empowering humans to increase their potential and being integrated such that the human and device are tightly coupled. A mobile device is a perfect technical solution to permit this.

Several of the successful existing systems for supporting the MoL technique rely on mobile devices to act as means of adding content to Mind Palaces and act as visual cues during retrieval [Rosello, 2017, Wieland et al., 2017], as exemplified by Figure 3.7. It is important for users of the system to be able to navigate the palace. If users are to use a physical environment for their navigation, it logical to use a hand-held device at all times to assist them as they navigate the physical space.

Figure 3.7: NeverMind: The mobile application used to create content at loci [Rosello, 2017].

Location-based approach

It is clear from reviewing the state of the art that physical navigation and complete immersion in the chosen palace is what stimulates the hippocampus most effectively over passive methods and hence promotes the effective formation of episodic memories. The aim of the HTT system is to allow users to interact with their physical surroundings without needing to place fiducial markers like other systems such as HoloMoL, and without requiring the HMD equipment used by systems such as NeverMind and HoloMoL.

By adopting a location-based tracking approach such as in Figure 3.8, the goal is to force users to physically retrace their steps to return to the physical location in their palace that they stored the information, in order to be presented with the visual cue of the information they wished to encode. This promotes spatial navigation and means that loci are not simply mapped to physical fiducial markers, but the physical location the information was stored at (enabling a more natural approach). This encourages *elaborative rehearsal* rather than maintenance rehearsal. Not only are users presented with the information they wish to remember when they revisit the physical location, but they are also considering the item in a wider context - the fixed location in the physical space where it is encoded.

From studying the hippocampal structures of memory champions that use the MoL technique, it has been found that these areas of their brains are stimulated without them necessarily realising the importance of spatial memory in the technique [Maguire et al., 2003]. The HTT system should, therefore, use a method of spatial navigation in a physical space that allows novices to practice the technique effectively without needing to be aware of the psychological background theory. Location-based tracking appears to be the logical solution to this.

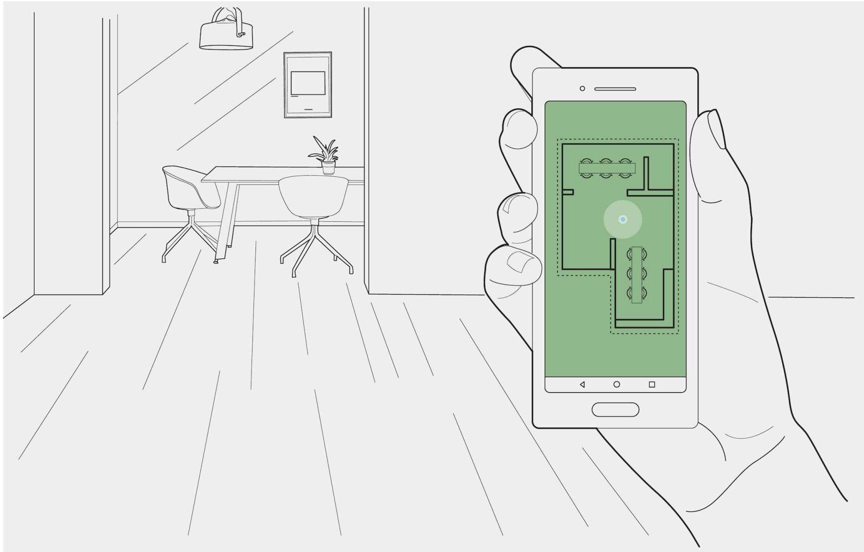


Figure 3.8: Indoor Location Tracking via Mobile Devices

Progress Tracking

From the literature that describes deliberate practice, it is clear that in order to improve a given skill, one must be able to consistently assess their current ability at a given skill with the aim of practising this skill at a higher level and an idea of how to improve. As such, one of the aims of the HTT system will be to incorporate a way of tracking progress in how many items have been remembered in a given palace, allowing users the ability to have an idea of what items they are struggling to commit to long term memory. The incremental approach adopted by Foer [2011] followed this philosophy on his journey to becoming a memory champion. The sizes of his mind palaces gradually increased in size before he was able to encode many more items using the technique, by constantly assessing what was needed to remember more items in his palace.

The progress tracking feature of the HTT system is another behaviour that sets it apart from existing solutions supporting the MoL technique. No known existing project gives the option for users to provide feedback on whether they remembered the information being cued correctly. Ideally by tracking progress the effects should be twofold - this should act as a motivational factor for users to continue using the technique to boost their recall rates (as a light form of gamification), and also allow users to review the locations in the palace the information they are struggling to remember is located, to prompt their focus during the next journey of that palace. It also makes more explicit the crucial *testing effect* nature of the MoL technique [Roediger and Butler, 2010].

In what follows we shall be documenting a full formal set of functional and non-functional requirements for the HTT system. Therefore, it is necessary to consider how these requirements can be prioritised and grouped into categories. This is the focus of the following section.

3.4 Prioritisation and Grouping

The below requirements are prioritised according to the MoSCoW descriptions described by Waters [2009]:

Must have: Features and standards that the system *must* implement or adhere to. These are critical for the system to have in order to prove useful for the evaluation and experimental stages.

Should have: Features and standards that the system *should* implement or adhere to. These are important but do not critically impact the project if they are not implemented.

Could have: Features and standards that the system *could* implement or adhere to. These are desirable or additional to the project scope, but it is not important whether they are implemented or not.

Won't have: Features and standards that the system *will not* implement or adhere to. These are a collection of requirements that are not important or within the scope or remit of the project.

Typically the *must* and *should* have requirements were elicited from the Literature Review chapter, and the *could* have requirements were elicited from user surveys and interviews. Currently, there is no formal term for the encoded items stored in a memory palace. From this point onwards, the word "**note**" will be used to describe an item stored in a particular palace. (The full formal requirements specification can be found in Appendix B).

Functional requirements are grouped according to several categories based on their role in the overall system functionality:

General Requirements that relate to general system functionality. Typically these are not core system requirements that relate to mind palace creation or training.

Palace Creation Users must be able to create palaces in which items to be encoded are stored at particular loci.

Palace Navigation Users must be able to navigate their created palace.

Note Creation Users must be able to create notes in their palace.

Note Retrieval The application needs to facilitate the training and testing stage once a user has created a particular palace.

Progress Tracking Users should be able to track their progress in recalling items in the palace successfully as they train using the technique.

Conceptual Data Flow Diagram

Figure 3.9 demonstrates the conceptual flow of data between subcomponents (categories) of system functionality identified above. Initially, palace data is entered into the system to be stored. Once this is complete, this data can be retrieved and operated on, either to navigate the chosen palace or display its progress. Displaying progress involves extracting information from the palace, such as the number of notes which are still to be marked as "remembered" and their details. Palace navigation involves roaming the physical location where the location of the user can be determined from their mobile device. This location data is either used to query for nearby notes or to create new content, depending on which mode of the application the user has selected. Note creation involves capturing this location data and storing the note. Note retrieval involves using the location data to query the stored data to see if any notes are anchored nearby the user's current location.

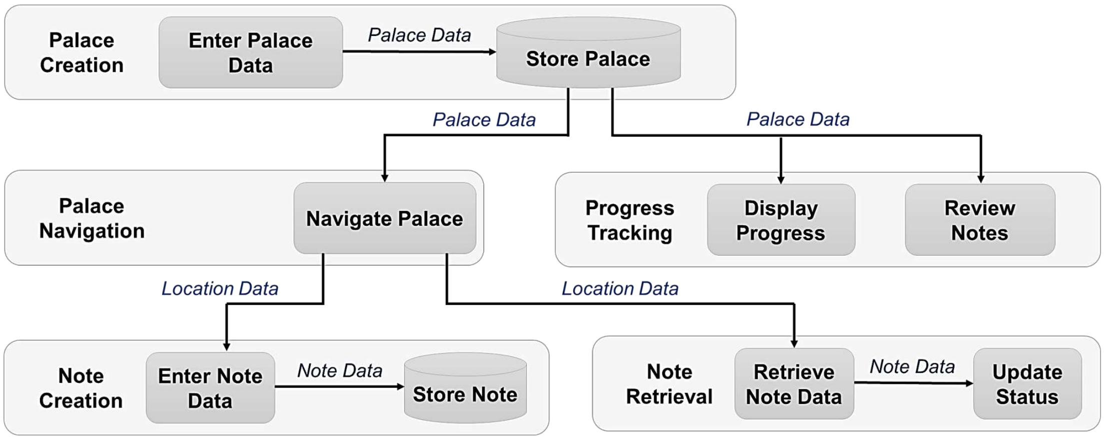


Figure 3.9: "Hold That Thought": Conceptual Flow Diagram.

By breaking the HTT system down into conceptual subcomponents of functionality as above, this will make the design of the system architecture presented in Chapter 4 more manageable.

3.5 Summary of Requirements

Before we move onto the design section to discuss the method of translation of these requirements into a tangible product, we shall briefly reflect on the core functional and non-functional requirements based on their MoSCoW priorities outlined in Appendix B. Ideally, all requirements synthesised from the elicitation stages will be implemented, but a suitable scoping of the system necessitates different priorities being assigned to different requirements to ensure at least all core functionality is implemented before focusing on non-crucial features that might improve the application but are not critical to its purpose. Resource limitations (such as the time to complete the project) necessitate this approach.

Firstly, we shall summarise HTT's functional requirements (Table 3.1).

Table 3.1: Breakdown of functional requirements for the HTT system and their respective priorities.

Category	Must	Should	Could	Won't
General	3	3	1	0
Palace Creation	4	4	1	1
Palace Navigation	3	0	0	1
Note Creation	6	2	1	0
Note Retrieval	3	0	0	0
Progress Tracking	3	0	2	0

General

The most important general requirements pertain to user account management - being able to allow users to sign up and into the application to start using it. The HTT system will use an Android-based application as a means of creating palaces and notes, which interfaces with hardware designed to track a user's location. Based on the User Survey, many users will be familiar with the Android material design interface[1] and operating system components, so this should be a popular choice. Due to the use of this location-tracking hardware, the application needs to be functional in physical spaces of at least classroom sizes such that meaningful user studies may be carried out in these spaces.

Palace Creation

For palace creation, the most important requirements include the association of a palace with a user, giving it a meaningful title and description. Notably, users should be able to create multiple palaces, even if they are only utilising one physical space at the time for their palace. This comes from the findings of Rosello [2017] where it was discovered that the same physical location could be used for more than one set of items to be remembered. For the user study, it is important that users can create palaces of the same title (and if necessary the same contents) such that the system does not confuse the two palaces. In other words, the user should be associated with a palace, which is in turn associated with notes to be remembered. Users will therefore not be able to share palaces. After creating palaces (which remain empty until notes are added), it is important for users to be able to view a list of their names to eventually allow them to select one to view their progress.

[1] More detail on Android's material design here: `https://developer.android.com/guide/topics/ui/look-and-feel/`

Palace Navigation

Requirements relating to the navigation of the created palace refer to how a user can understand the system's detection of their current location, in order for them to take the appropriate action based on its feedback. The technology designed to track the user's location needs to listen out for changes in the user's position and based on this event, the user interface must update its status to inform the user that the system is ready for them to either create a new note or retrieve an existing stored note (depending on which mode of the system the user has previously selected). The key difference with HTT is the lack of physical fiducial markers being needed in the environment in order to anchor items/notes to the location in the palace they are to be stored (c.f. Yamada et al. [2017*a*,*b*]).

Note Creation

Note creation is a subcomponent of the overall system that relies on there being location data readily available in order to associate the information being stored with the user's current location. A note must be able to be given a title and description to jog the user's memory about the item to be encoded. Also, there should ideally be a way to associate an image with a note to provide a visual cue that has proven effective in other systems adopting the MoL technique (see Table 2.3 in Chapter 2 for a summary of loci media types). This can be implemented either through native camera roll upload from the device or via an image URL. It is also of high priority that the system can associate a "status" field with each note stored under a given palace. This is so that a user can update this value based on whether they recalled the note correctly when it is retrieved during a session of training with that particular palace. A topic brought up in interviews and by McDaniel and Einstein [1986] and Burns [1996] in the previous chapter was that of "bizarre imagery". To make notes more bizarre, there could be support for adding animations or videos with the aim of making them more memorable.

Note Retrieval

Note retrieval concerns the actions taken by the system when the user queries the system for a note they believe to be stored at their current location. It is then the responsibility of the system to present information to the user. The HTT application must, therefore, handle cases where a note does or does not exist in a user's current location. This handling will be done in one of two ways:

- **Note Details:** Details about the closest note to the user's current detected position.
- **Error Message:** A message informing the user that there is no note for the selected palace associated with their current position. It is then up to the user to move to another location and query the application again.

Regardless of the technology used to track the user's location, (x, y) co-ordinates of the physical space may have high precision in their measurements. It is therefore important to factor in a radius around each coordinate to "smooth" the sensitivity of location detection to a given radius, optimised for the size of the physical room in question being used as a Mind Palace.

Progress Tracking

The final sub-component of functional requirements refers to Progress Tracking whereby a user can use the system to help them record which items in their palace are still to be "remembered", along with the locations of these items in the physical space to help them focus extra cognitive effort on that area of the space the next time they navigate the palace. Eventually, users could see their progress over time for a given palace. However, for now, it is sufficient to see which items they are yet to remember, along with a percentage representing how many items have been marked as remembered already. It is hoped that by adding this kind of analysis, users will be motivated to continue practising the technique, and see whether the technique itself is working for them. In the future, this tracking feature could be extended to add a rewards-based scheme along the lines of "gamification" [Goshevski et al., 2017].

Non-Functional Requirements

Most notable and high priority non-functional requirements are related to Software Quality, Data Storage and Hardware Interaction (Table 3.2). As previously specified, the application must be able to run on the Android operating system. In particular, it should run on devices running at least Android 5.1 and above which covers a large range of devices made in the last 5 years[2]. As the application is created to help users with a range of experience practice the Method of Loci technique, it must be robust, and reliable which ensures smooth operation. Any requests made to write or read from data storage (local or remote) should take no longer than 5 seconds, which is extremely generous. Also, changes in the user's detected position should take no longer than 15 seconds to update. Both of these requirements need the user to consent to enabling Bluetooth and Network permissions on the Android device. A consistent design should be adopted in terms of colour scheme and functionality in order to make the application more usable (c.f. Nielsen [1994] discussed in more detail in the next chapter). As the application is intending to support multiple users, it is wise to use a remote storage solution for data, to minimise dependencies on local data on the device.

Table 3.2: Breakdown of non-functional requirements for the HTT system and their respective priorities.

Category	Must	Should	Could	Won't
Software Quality and Maintenance	4	5	2	0
Data Storage and Hardware Interaction	4	1	0	0
Security	0	0	0	2
User Evaluation	2	0	0	0

[2] https://www.digitaltrends.com/mobile/android-version-history/

The HTT system must provide consistency in the way notes are stored and retrieved in palaces using the system in order to comply with the Encoding Specificity principle to maximise similarities between the encoding and retrieval stages [Tulving and Thomson, 1973]. This is reflected in requirement NF1.7[3] which stresses the importance of consistent design, as well as F4.5 and F5.1 which discuss the role of associating a user's location with the note being created. We can trivially separate the notions of "creation" and "retrieval" of notes by introducing different modes for the application and enforce identical conditions for encoding and retrieval - in both cases, it is the movement towards a physical location that leads to system action. Only by returning to the same location notes were created can they be retrieved.

3.6 Chapter Summary

After laying out a formal set of requirements from those elicited in section 3.2, we can come to a conclusion on how the HTT system can extend the work of existing solutions to discover how technology can assist the Method of Loci technique. It is clear that it is of paramount importance for the HTT system to support the Mind Palace technique rather than replace it altogether.

Standing on the shoulders of giants

The HTT system is a natural extension of the work completed by similar systems such as HoloMoL, NeverMind and Loci Spheres discussed in the Literature Review chapter. Here we will discuss how the HTT system can extend these works.

Importantly, HTT will build on the findings of the existing systems that leverage physical spaces as mind palaces by also adopting a physical space as a place to create Mind Palaces. Instead of requiring unique fiducial markers to be placed in the physical space (e.g. Yamada et al. [2017*a*,*b*]), the fiducial markers will be chosen freely by the user from what they can identify as distinct loci in the physical environment which adopts a more exploratory approach. For example, a window, desk or physical object in the environment can be chosen as more natural loci instead of a unique Quick Response (QR) code which needs to be mapped to visual content by the system and might make the environment slightly less natural to users by adding unfamiliar markers all around the physical environment.

Instead of requiring AR HMD technology for viewing notes, users will simply have to revisit the physical location where notes were created and anchored in order to recall content using their mobile device which acts as their symbiotic interface [Licklider, 1960]. Instead, the HTT system will use "Physical Loci" as in the study by [Perrault et al., 2015]. In this study, the loci were physical (instead of imagined) objects. This approach was found to be intuitive and robust to environmental changes. Using the Physical Loci approach means the system is more flexible - users can choose whether to use the actual objects in the room as loci or imagine images themselves at these places. The intention is to make users feel as natural as possible when navigating their

[3] One of the formal requirements listed in Appendix B.

physical environment. Here, the user can use interfaces they are more familiar with - only requiring a mobile application as a way of interacting with their palace. Users will be familiar with the concept of tracking their movements from using applications such as Google Maps to reach their destination, so incorporating a map feature (F2.9) will be a helpful cognitive aid to navigate the palace. Images supplied by the NeverMind interface [Rosello, 2017] are not anchored to a spatial location when viewed through the headset and move with the user's head motion which is likely to interfere with their ability to remember exactly where in the space that image is located when exploring the environment. To remedy this, the HTT system will instead anchor information at a fixed location in a room to increase the sense of spatial navigation between loci and allow easier mapping between location and item in the user's mind.

Existing systems such as NeverMind, HoloMoL and Loci Spheres also do not include any feedback from the user to detail whether they recalled the information correctly (e.g. F6.1). The introduction of a light form of *gamification* or *deliberate practice* should encourage increased motivation to participate with the memorisation activity, as users aim to beat their previous personal records [Goshevski et al., 2017]. If users can view where the notes they struggle to remember are located in their palace, they may be able to focus more cognitive effort on navigating that part of the palace in the next training session.

Next steps

Equipped with a formal set of requirements and an analysis of their elicitation, it is time to translate these requirements into a design for the HTT system. This will be the focus of the next chapter. From these designs, the Implementation and Testing chapter will describe the way the requirements and designs were implemented in a tangible product.

Chapter 4
Design

4.1 Introduction

In this chapter, we shall be translating the requirements elicited in the previous chapter into an overall system design. During the process of requirements elicitation, it was noted how wide and varied the implementations of existing technical solutions that adopt the MoL technique are. This presents us with some interesting design choices to make in this chapter regarding how to implement the practice and training of the technique.

As well as deciding on a design for how each of the system subcomponents will achieve their requirements, we shall be considering the user interface (UI) as a way of adopting user-centered design [Abras et al., 2004, Preece et al., 2015]. Users will be incorporated into the design process to help create several iterations of user interface prototypes to base the implementation on. Finally, a development plan will be presented to indicate the order and dependencies of tasks involved in creating the HTT application.

4.2 Hierarchical Task Analysis (HTA)

HTA is a technique used to break an overall user goal into its component subtasks [Preece et al., 2015], chosen as the adopted task analysis model as a hierarchical view of functionality is most appropriate. A user wishes to perform 4 main tasks with the HTT system - palace creation, note creation, note retrieval and progress tracking. Each of these goals (tasks) is composed of a series of actions to complete it which makes HTA a suitable approach.

In order to synthesise a suitable design for the HTT system from the requirements formalised in the previous chapter, we shall be taking a hierarchical view of the core tasks involved in creating a mind palace, and using this palace to retrieve items. Figure 4.1 shows the root (top-level) HTA diagram for the system. The system can be seen as having two "modes" in which users can use the application: a "create" mode whereby a new palace is created and new notes can be added to it and a "training" mode whereby existing notes can be retrieved in order for users to track their progress in remembering those items.

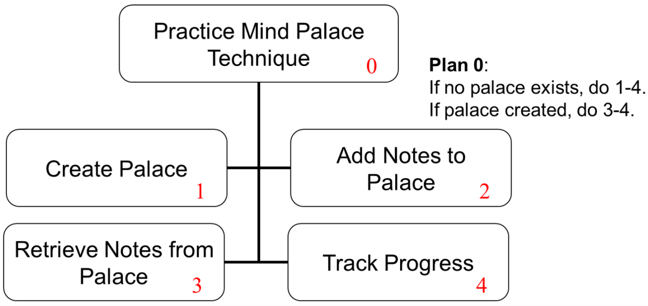


Figure 4.1: HTA: Root level.

"Create Mode": Add new palace and notes

In this mode, users first wish to create a new palace of items to be remembered (Figure 4.2). The first task involved in this (after navigating to the correct screen) will be to enter the details (title and description - see F2.2[1]) of the palace before creating it. It makes logical sense to separate the creation of a palace from the creation of a note so that a user can add notes to their palace at any time instead of only when a new palace is created. From the interview answers in the Requirements chapter, it is important that new notes can be added at any time to a palace - not just at the start when the palace is first created.

Figure 4.3 shows the subtasks involved in adding a note to an existing palace. This has more subtasks and is, therefore, a more complex task to carry out. First, a user selects the palace they wish to store the item in, then they must navigate the palace by physically moving around the space until they reach the location where they wish to store the item. Once they have navigated the palace and decided on a suitable location, they can enter the details about the note. In theory, this could be done the other way around (entering details, then navigating to the chosen place), however it would be more powerful if the traditional MoL technique is followed using the HTT system (fixing an encoded item at a locus after navigating to it - see Section 2.3 for a reminder on the MoL technique). As per requirement F4.6, it would be ideal if an image is added to the note in addition to its title and description (F4.2) in order to represent a visual cue of the information to be remembered. A user should then verify that the image is the correct visual cue to represent the item to be remembered, before submitting the note to be stored under that palace. It is hypothesised that the cognitive effort involved in selecting an image to represent the item (and verifying this in a separate step) is sufficiently large to warrant deeper processing of that item. The selection of an appropriate image for the item will honour the Levels of Processing (LoP) model discussed in Chapter 2 [Craik and Lockhart, 1972].

[1]Found alongside other requirements in Appendix B.

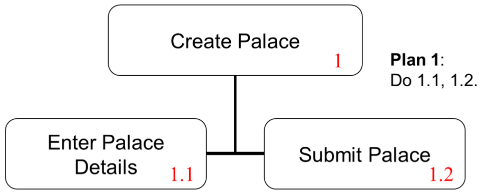


Figure 4.2: HTA: Create palace.

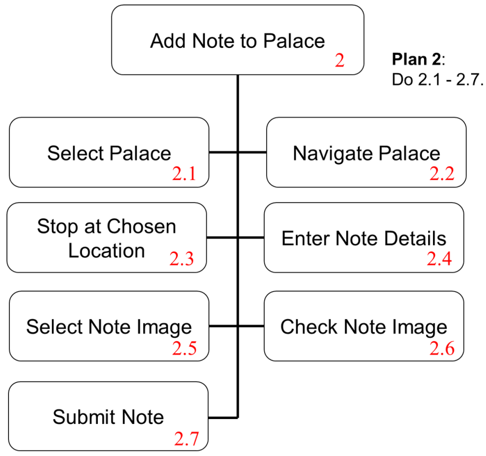


Figure 4.3: HTA: Add note to palace.

"Training Mode": Note Retrieval and Progress Tracking

Another part of the root level HTA (Figure 4.1) pertains to retrieving notes from an existing palace and recording whether they have been remembered correctly or not, with the aim of tracking progress and highlighting to the user which notes they are yet to recall correctly using the technique.

The tasks involved in Note Retrieval (Figure 4.4) are deliberately as closely-matched as possible to those tasks involved in Note Creation to honour the Encoding Specificity (ES) principle [Tulving and Thomson, 1973] which makes the MoL technique so powerful as a mnemonic device. First, a palace is first selected to use during training. Second, a user navigates this palace by moving around the physical space until they stop at a location where they believe a note is located. Next, a user must check for a nearby note at which point there is a conditional branch. If a note exists then they must update its "status" (F4.7) to indicate if it was remembered correctly. Else, if no note is detected nearby, they must repeat the sub-tasks starting from **3.2** to enable them to explore the palace further.

Finally, as in Figure 4.5, users must be able to track their progress (number of remembered notes in a palace as well as the details of ones still marked as "unremembered"). Progress tracking can be broken down into a series of simpler subtasks. First, a user chooses a palace to view the progress of. Upon selecting this, they may view the progress information presented to them (this could be presented or manifested in many ways - e.g. a graph, a progress bar, a percentage or fraction). Ideally, there should be a way of users being able to select and view the notes that are currently marked as "unremembered" in order to see more detail, such as a description and a representation of where it can be found in the palace.

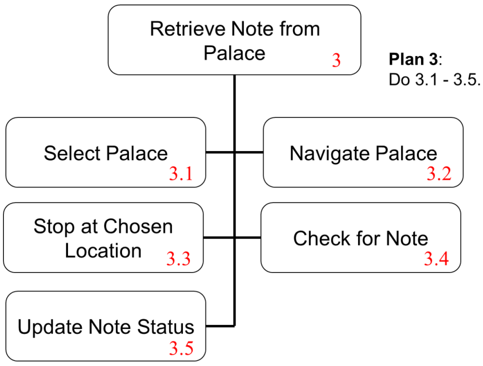


Figure 4.4: HTA: Retrieve note from palace.

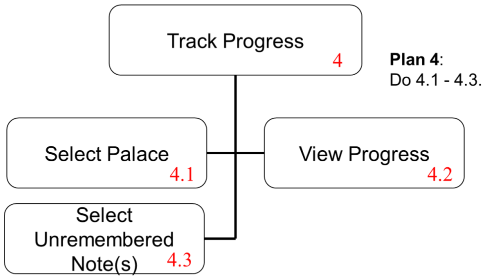


Figure 4.5: HTA: Track progress.

After decomposing the main tasks involved in creating a palace and training using the MoL technique, it is important to reconsider the subcomponents discussed in the previous chapter in order to translate this into an architectural specification for the HTT system.

4.3 Modelling Subcomponents as System Interactions

In the previous chapter, the HTT system was modelled as a series of subcomponents of overall system functionality:

- Palace Creation
- Palace Navigation
- Note Creation
- Note Retrieval
- Progress Tracking

These subcomponents of the system are the main tasks to be handled by the mobile application through user interaction with the device. At this point, it is important to distinguish the application from the system responsible for detecting the user's location in the physical space. Functional requirements such as F3.1, F3.2, F3.3 and F4.5 necessitate that a form of positioning or location tracking system be used in conjunction with the mobile application itself.

We can, therefore, translate the subcomponents listed above into a skeletal system interaction diagram (Figure 4.6). Whatever the chosen location-tracking system, this will need to be queried from the device itself. At this stage, it is not decided whether this will use a Bluetooth transmission or network connection (e.g. cellular or Wi-Fi). To be safe, it is specified in NF1.10 that the application should ask permission from the user to allow Bluetooth and network connections. The options for location tracking will be discussed in greater detail in the section below. For now, it is sufficient to assume that the device queries its location from an external system.

On receiving a response from this location tracking system, the user can see their detected location from the mobile client's interface. In order to facilitate the requirements in the previous section regarding multi-user support (NF2.3) and progress-tracking support (F6.2), there needs to be some solution for tracking data over multiple sessions such that a user can see if the number of notes remembered in a given palace is increasing over time, and which notes in particular are still to be remembered. As such, there will be a web service to handle and support the back-end of the application which the mobile application can interface with. Here, endpoints in the remote service can be requested in order to indirectly query the database. The database will also be hosted remotely along with the web service.

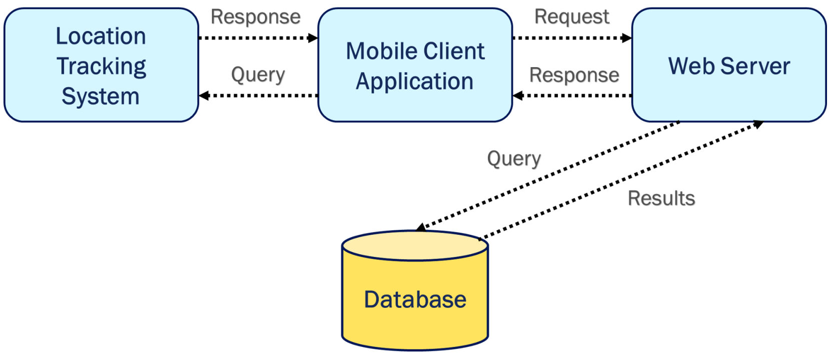


Figure 4.6: “Hold That Thought”: Modelling system subcomponent interaction.

4.4 Contextual Computing and Location-Based Services

As discussed above, a core part of the technical implementation of the HTT system relates to the implementation of location-based tracking of a device in a physical space, enabling them to create notes at certain positions in their chosen space and retrieve them upon revisiting this location. For this requirement to be met, there needs to be consideration of the technologies available that permit a device’s location to be tracked.

In recent years there has been a trend towards devices being used for *contextual computing* in a *context-aware* environment. This refers to the capturing of the context of an action (e.g. location, identity, date or time) with minimal interaction needed by the user. This context is then used by the system to perform certain actions, conditional on the context [Aversente et al., 2016]. These simple pieces of context allow an element of dynamic interaction with a user’s environment through their hand-held device [Bruno and Delmastro, 2003]. *Location-based services* (LBS) can be considered a subset of this as they capture the location of a device within a particular environment at a certain time. Based on this location information, the system can perform certain actions, such as providing direction, pushing notifications to the device or performing a custom action. Most of these systems are reliant on a stable network or Bluetooth connection being established [Bruno and Delmastro, 2003].

A variety of technologies have been used as a way of implementing location-aware devices. What these technologies have in common is their reliance on *Received Signal Strength Indicator* (RSSI) measurements which are levels of signal strength of radio signals transmitted by nearby transmitters. According to Hightower and Borriello

[2001] and Kriz et al. [2016], these systems commonly use one or multiple of the following techniques to determine the location from RSSI values:

Triangulation A calculation is performed using RSSI readings from multiple points which have a known separation between them.

Proximity A measurement of closeness to a single point (or set of points) in a given set of known points.

Scene analysis ("fingerprinting") Analysis of a view from a given position. RSSI values are used in two stages - a learning stage and a testing stage. Signals in the testing stage are matched to those recorded in the learning stage via a probabilistic model.

Here, we shall look at a subset of the technologies available and consider which would be more suitable in the design of the HTT system for providing the application with knowledge of the user's location such that a note can be stored alongside this contextual information. We shall be looking at 3 approaches - GPS, Wi-Fi and Bluetooth. The approaches differ in their granularity of precision, accuracy, technological implementation amongst other factors [Bruno and Delmastro, 2003].

Global Positioning System (GPS)

There is no denying that GPS is an extremely successful and widespread system which can be used to track mobile device signals over very large physical distances due to its reliance on Satellite technology and triangulation using this technology [Bajaj et al., 2002]. It is used in very successful large-scale location tracking software such as Google Maps. Due to this, many Application Programming Interfaces (APIs) exist in order to determine the approximate location of a device based on the nearest cell tower or Wi-Fi access points[2]. It is important to note that despite being very useful for tracking devices over large distances, GPS is not a suitable solution for the HTT system due to the large error granularities in location calculations. If GPS values were used, users would have to move very large physical distances to create palaces without worrying about precision errors (caused by inaccurate location detection). Also, this technology fails to support indoor locations effectively enough, Therefore, a more *localised* location-based service is required with smaller granularity in distance calculations.

Wi-Fi

Most Wi-Fi (IEEE 802.11 standard) location-tracking systems rely on either triangulation or fingerprinting techniques described above [Papapostolou and Chaouchi, 2009]. It must be stressed that this technology is primarily aimed at providing a wide range of users with an internet connection - location-tracking is only a by-product of its use of wireless signalling and transmission [Tsang et al., 2015]. That said, Wi-Fi technology

[2] Examples include Google's Geolocation API: `https://developers.google.com/maps/documentation/geolocation/intro`

is shorter range than GPS and is, therefore, more suitable in granularity for the HTT system's location tracking technology. According to Aversente et al. [2016], this can yield location accuracies of between 2 and 3 meters of the real position with 95% room classification if the signal is strong enough. This kind of accuracy is far more suitable to the distances users of the HTT system will be navigating when travelling through their chosen palace. However, the main disadvantage of a Wi-Fi-based approach is the reliance on a convenient topology of Access Points (APs) in order to triangulate signals effectively [Kriz et al., 2016]. Ideally, the location tracking system needs to provide flexibility over where transmitters are located. As a result of this, a Wi-Fi approach is not feasible for the HTT system.

Bluetooth 4.0 Low Energy (BLE) Beacons

By far the most flexible option for location-based tracking in indoor systems and the chosen method for the HTT system is Bluetooth Low Energy (BLE) beacons. Use of Bluetooth devices for indoor positioning systems has been a popular method in recent years [La Delfa and Catania, 2014, Tsang et al., 2015], mainly due to the devices' low energy, battery-powered usage and low cost (compared to Wi-Fi approaches) to create context-aware applications[3]. Another strength over a Wi-Fi-based LBS is that BLE beacons can cover similar distance ranges, providing similar accuracies and precisions whilst being flexible over where they are placed in the physical location. Due to their potential, Google has created the Eddystone BLE beacon platform and Apple has created the iBeacon protocol.

Many commercial implementations of BLE beacons are available as a way of allowing developers to implement their own applications using these sensors in the spirit of the *Internet of Things* (IoT) - see Figure 4.7. This branch of computing embraces the connection of simple physical devices to a wider network in order to provide distributed connectivity and compute power for context-aware applications [Cirillo et al., 2019]. For example, a network of devices can be connected to buildings in a city for monitoring atmospheric pollution. Whilst exact implementations of BLE beacons vary slightly, they all use the same underlying Bluetooth technology and are flexible in where they can be placed in an indoor location which is what makes them so powerful for context-aware applications. Like Wi-Fi, they also have limitations when encountering physical obstacles that can interfere with or occlude the transmitted signals. This is a limitation that can be mitigated (although not totally overcome) by optimising their placement in the physical space, unlike Wi-Fi approaches which are limited by the location of power supplies that APs can utilise.

[3] Here is a video displaying an example of Bluetooth beacons' commercial use cases: `https://youtu.be/SrsHBjzt2E8`

Figure 4.7: Internet of Things (IoT) approach: Bluetooth beacons and their typical architecture.

Estimote BLE beacons are one such type of commercial beacon that - when arranged in a suitable topology in an indoor location such as a room or building - enable proximity and location detection of a Bluetooth-enabled device such as a smartphone via triangulation of RSSI values. It operates via "undirected advertising"[4] such that any Bluetooth device can *scan* for and receive these signals in order for it to calculate a location co-ordinate in the physical space. In Figure 4.8 we can see a set of 3 beacons that can be fixed at appropriate locations in the indoor space such that smartphone devices can detect a signal from a given distance, as shown in Figure 4.9.

Figure 4.8: Set of Bluetooth beacons.

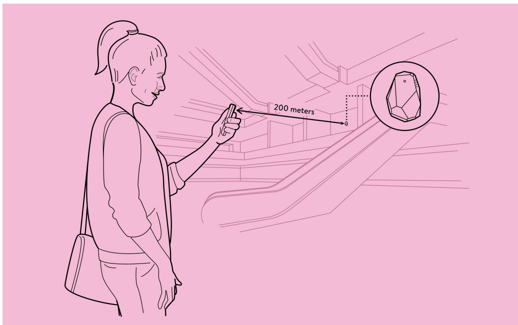


Figure 4.9: Detection of a beacon.

Chosen Method for Location Tracking

From the potential options available, BLE beacons are a clear front-runner in the design choice concerning the location-tracking aspect of the HTT system due to their flexibility and suitable accuracy for indoor locations. Through making this choice, requirements F3.1, F3.2 and F3.3 are met. Also, as the BLE option is low power, we will also be meeting requirement NF1.3 with this approach going forward. Now that this design choice has been made, it is important to make clear the separation in actions involved in note creation and note retrieval, seeing as both tasks will rely on the values calculated from signals received from the selected location-tracking technology.

[4] More detail in the official specification: `https://www.bluetooth.com/specifications/bluetooth-core-specification`

4.5 Distinguishing Note Creation and Retrieval

As shown above, the subtasks involved with Note Creation and Note Retrieval are deliberately very similar in order to replicate as closely as possible the conditions at encoding and retrieval stages (Figures 4.3 and 4.4) and honour the ES principle that the MoL technique encourages as per requirement NF1.7.

In order to distinguish the two tasks and ensure the user is aware of whether they are creating a note in a palace or retrieving it, it would be wise to have this functionality separated and handled on different screens of the application, perhaps accessible by a different set of selected options from the root level main menu of the mobile application. As discussed above (Sections 4.3 and 4.4), both of these tasks will rely on the same underlying location tracking system responsible for determining the current physical position of a user in their palace. In this case, we shall be using BLE beacons in order to triangulate RSSI signals and associate the calculated physical position of the device with the note to be stored.

Figure 4.10 shows the sequence of steps performed when notes are created and retrieved using the system. When the screen for either task first loads, it is the responsibility of the user to navigate to the location where they either want to create or retrieve their desired note (`Change position`). Once this subtask is complete, the mobile client application must communicate with the BLE beacons in order to scan for and receive signals to be used in triangulation calculations of RSSI values to determine the user's device's current location. This interaction is done in a continuous loop - BLE beacons will intermittently broadcast signals (`broadcastSignal()`) which is scanned for by the mobile client application in order to be received and used in calculations (`scanForBeacons()`).

The next stage in the sequence is where Note Creation and Note Retrieval tasks start to differ. If the user has selected the "Create Mode" of the application, they must enter note details into the designated screen of the mobile application before clicking a button responsible for making a HTTP POST request to send note data and the user's current detected location to the remote web server (`sendNoteData()`). On the server side, the request is parsed and handled and a response is sent back to the client application indicating whether the note has been successfully created in the database (`returnHttpResponse()`).

Alternatively, if the user selects "Train Mode" in order to retrieve notes in a palace that already exist, they must check for a note by clicking a button in the mobile application to check for nearby notes. On making this action, the client application makes an HTTP GET request to query note data and along with the user's current detected location as parameters to the remote web server (`queryNoteData()`). On the server side, the request is parsed and handled and a response is sent back to the client application indicating whether a note exists within a given radius of the user's current detected location (`returnNearestNote()`).

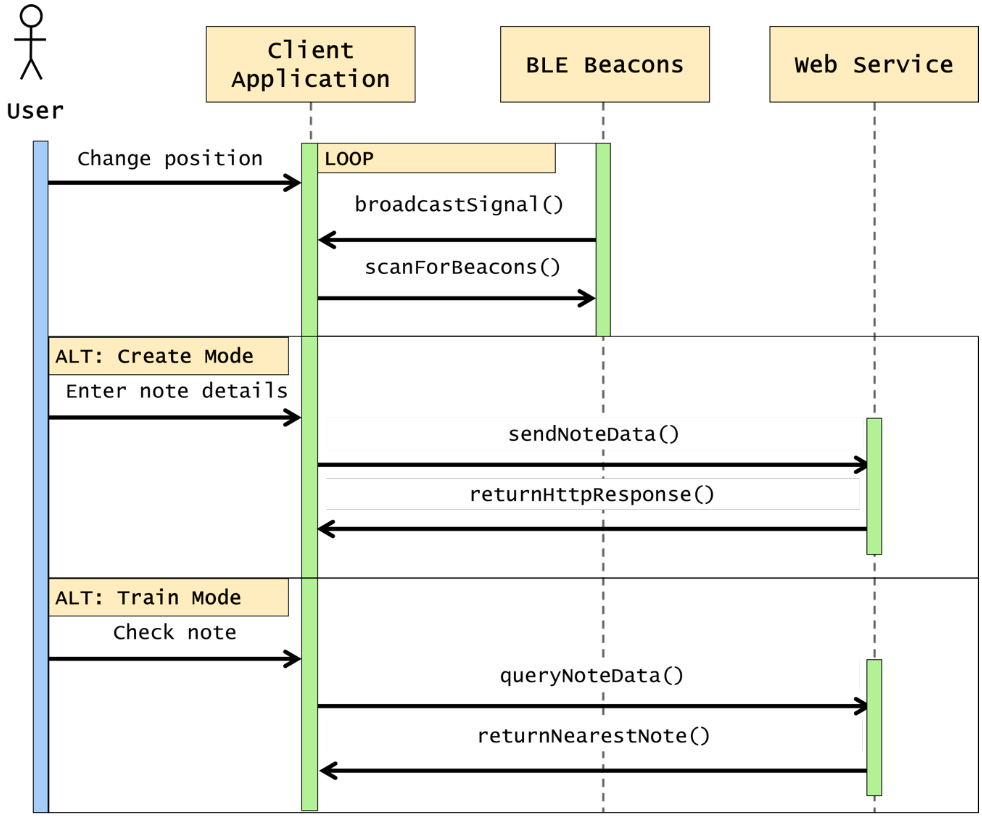


Figure 4.10: Sequence digram showing the separation between actions performed during note creation and retrieval.

4.6 Design Considerations

So far in this chapter, we have completed a comprehensive analysis of the subtasks involved in each of the main system functionality, modelled subcomponents as system interactions and made a core design choice on the method of location-tracking (Section 4.4). This section reflects on other design considerations that will affect the scope and design of HTT's subcomponents. Some of these design considerations are more theoretical, whilst others relate to practical architectural decisions that must be made to create a functional application in the simplest way possible that fulfils the requirements laid out in Appendix B.

Remote vs Local Data Persistence

It has already been established that in order for users to insert, update, read and delete data (e.g. palaces and notes) in long-term storage, there must be a database for this purpose. One common architectural choice that must be made relates to whether this is hosted and accessed *remotely* as described in section 4.3, or whether it is *local* to the device (Figure 4.11, options 1 and 2 respectively). Whilst maintaining a local database using a solution such as SQLite is common for software such as Android applications [Allen, 2012] and this approach usually boasts faster access speeds than a remote alternative, there are a few key reasons why a remote database (and a server responsible for communication between device and database) is required:

- **Multi-user support:** Data should not be local to a given device because users must be able to log into the application from any supported Android device, and the application should support multiple user accounts (See F1.5, NF2.2, NF2.3 and NF2.4).
- **Distributed data:** Data should not be local to a given device to reduce single points of failure of the application. If one Android device fails, users should not lose all of the data created using the application.
- **Use of network connection:** Users will already have Bluetooth and cellular data or Wi-Fi settings enabled in order to interface with the BLE beacons. Using a remote database, therefore, does not impose any extra restrictions.

For the reasons outlined above, a remote web server and database is required.

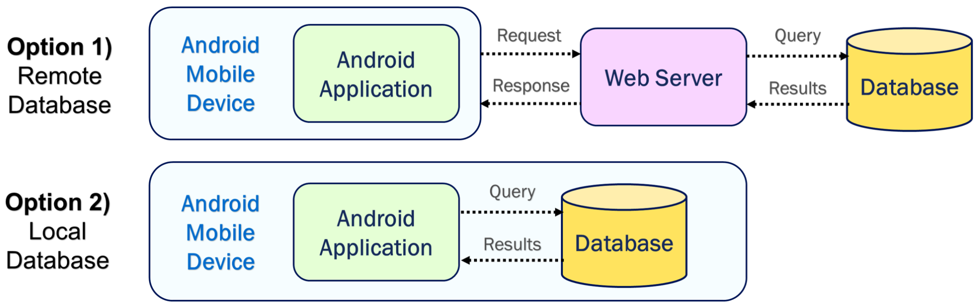


Figure 4.11: Diagram demonstrating the difference between remote and local database options.

Authentication and Security

As data is stored in a remote database in order for users of HTT to practice the MoL technique over time, this immediately raises the question of authentication and security of data. As this project's primary focus is research-based, requirement NF3.2 specifies that no encryption will be performed on data stored using the application. Users will have passwords, but will be made aware during experiments *not* to use passwords that they use for other accounts as this data is not going to be stored in an encrypted form. No data will be collected without the explicit consent of users (NF3.1). Should the HTT system be developed as a commercial application, this would be a high priority design consideration. However, for the purposes of this dissertation, considerations such as authentication and security are outside of the remit of this project (although worth mentioning).

Compatibility and Portability

Next, a more important consideration is compatibility and portability with older devices and other hardware used in the HTT system. The mobile application will take the form of an Android application which does limit its usage to Android devices only (i.e. not Apple devices) but this is not a large loss of portability. By specifying a minimum Android API level, it is possible to maintain a form of backwards compatibility with earlier versions of Android in order to meet requirement NF1.1. As such, the application will be specified as compatible with at least Android 5.1 to allow interoperability with the chosen BLE beacons[5] and deliver on requirements NF1.4 and NF1.5.

Supported Media Types

Table 2.3 in Chapter 2 presents a good summary of loci media types used in existing technical solutions that aim to support or augment the MoL using 2D or 3D graphical or hybrid approaches. From this table, we can see that the main form of media types supported is textual or visual items (raw text and images) to represent items to be stored in the palace. As such, HTT will continue this trend in the following way. As specified in requirement F4.2, notes are going to be given a title and description. Per requirement F4.6, a note should also be associated with a visual cue such as an image. As the database for HTT is to be hosted remotely, it makes the most sense to use images than can be accessed remotely (in other words, those retrievable from a location on the web rather than on the device's local storage). More sophisticated media types would be interesting to explore (i.e. bizarre types such as animations or video as in requirement F4.9), however, this is not crucial to the core aims of the project. Recall from Chapter 2 that the MoL technique is not strict. That is, the visualisations of items to be stored do not have to be bizarre to be memorable [Bower, 1970, Briggs et al., 1970]. In this respect, a textual representation of the item with a potential visual cue is enough for the system to implement the MoL technique.

Choice of Environment

Typical usage of the MoL technique encourages the subject to use the layout of an environment that they are very *familiar* with as the chosen palace such as their childhood home (e.g. Figure 4.12). Indeed, the student interviewed during requirements elicitation (Appendix A.2) found that using their student house to store items was extremely helpful as a technique to remember exam content. Using a familiar environment reduces the cognitive effort required to recall the palace layout when navigating it on a mental journey, allowing the subject to focus on the items to be remembered.

It would, therefore, be completely idealistic to use the family home of each and every participant when carrying out experiments using the HTT system to investigate if using a location-based approach using a physical environment with BLE technology and the HTT mobile application can effectively assist users practising the technique.

[5] See BLE Beacon prerequisites: `https://developer.estimote.com/indoor/android-tutorial/#prerequisites`

However, this is neither practical nor necessary, as another finding from Chapter 2 was that the environment chosen as the palace does not need to be completely familiar to the subject for improvements in recall to be observed [Crovitz, 1971]. As such, the experimental chosen physical environment for palaces to be created with the HTT system is a lecture theatre that is large enough to allow meaningful physical exploration of the space. In this case, room *1W 2.101*[6] on University of Bath's campus has been chosen as the location for experiments (Figure 4.13). For all intents and purposes, we will be treating this room as a typical environment where palaces can be created using the application.

Figure 4.12: Typical palace envionment: A family home.

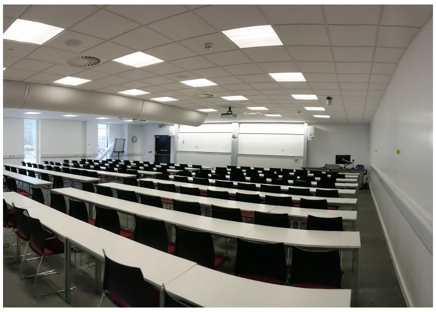


Figure 4.13: Experimental palace envionment: A lecture theatre.

Physical layout of notes

Experiments of Rosello [2017] suggest that different sets of items may be stored in the same physical space without issue. In this sense, using the same physical room as a palace to store multiple sets of items is not a design flaw of the system as users should be able to distinguish these sets of items without trouble. Furthermore, experiments by Crovitz [1971] suggest that multiple items may be stored at a given locus in a palace. For example, if 32 items were to be encoded in a palace using 2, 4, 8, 16 or 32 separate locations, the most effective combination of items-per-location in their experiment was around 4, using 8 separate locations which suggests there does not need to be a 1 to 1 mapping between item and location for the MoL technique to prove effective. In terms of design implications, this may mean that more than one note could be stored in the same physical location. Using a single room for the creation of multiple notes is, therefore, a valid design approach.

Integrating Deliberate Practice

In Section 2.3.2, the concept of deliberate practice was introduced as the constant assessment of what is necessary to get better at a certain skill to practice it at a more challenging level [Lehmann and Ericsson, 1997, Davids, 2000]. Through adding a way of tracking progress (i.e. number of items remembered in a given palace), users should be presented with a metric by which they can improve. There is no doubt that progress

[6] `http://www.bath.ac.uk/timetable/roominfo/1W%202-101.htm`

tracking is a weak form of deliberate practice - by assessing which notes are still to be marked as “remembered”, users can focus their attention towards that particular area of their palace. A stronger and more sophisticated design might include some form of coaching, including tips for how to practice the MoL technique in order to improve performance. For the purpose of this dissertation however, it is sufficient to include basic tracking to see if this makes any impact of users’ usage or opinion of the MoL technique.

4.7 User Interface (UI) Design

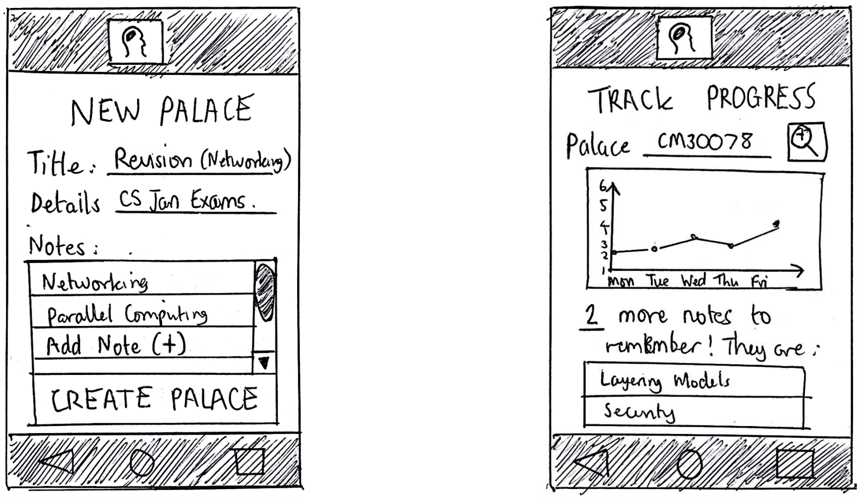
Even though we have addressed many important design considerations in the previous section, one large consideration remains, which is the focus of this section. In what follows, we will detail the iterative process of creating a user interface for the HTT system that satisfies the requirements specification summarised in the previous chapter. We begin by prototyping the user interface of the HTT mobile application in the form of sketches, before presenting these designs to a subset of potential users who will be giving feedback on them with the aim of adopting an iterative approach. Suggested improvements will be adopted in the next iteration where appropriate, with the end-goal being to establish a UI design which meets the requirements in Chapter 3 and satisfies user feedback. As such, it can be said that a user-centred design approach was adopted [Abras et al., 2004, Preece et al., 2015].

By performing this iterative style of UI design in a user-centred approach with low and high fidelity prototyping and heuristic evaluation, it is possible to identify usability problems with the interface at the *design* stage instead of waiting until a solution is implemented. The ten usability heuristics set out by Nielsen [1994] shall be considered in relation to the application’s interface to help build usability into the design of HTT. In some instances, such as “*consistency and standards*”, the usability heuristic coincides with system requirements (NF1.6 and NF1.7). A set of 8 of students aged 18-23 at University of Bath were asked for their opinions on the design at each stage. (Full responses can be found in Appendix D).

Iteration 1 - Low Fidelity Mockup

Initially, pen-and-paper low fidelity designs were created for the mobile interface as a mockup to demonstrate the layout of core application functionality. Low fidelity prototypes enable rapid and cheap demonstration of key application functionality early in the design cycle [Sauer et al., 2008]. Figures 4.14a and 4.14b are examples of two screens that were mocked-up in this iteration - palace creation and progress tracking screens. (Full wireframe designs for this iteration can be found in Appendix C.1).

“*Consistency and standards*” and “*aesthetic and minimalist design*” were the main usability heuristics targeted by this iteration. By adopting native-design screens and buttons that clearly explain their functionality, it was hoped that users would not need further explanation in how they should be used. When successful actions are made, *Toasts*[7] will be used to give user feedback on actions, meeting requirements such as F2.7 and F4.8. In order to mark a note as remembered, a user will tick an appropriate *checkbox*[8] on the note retrieval screen. Palaces can be searched for by clicking on a magnifying glass icon to unveil a *search dialog*[9]. When creating a new palace, a *ListView*[10] of existing notes in the palace is displayed to ensure users do not add two identical notes. Co-ordinates of the currently-detected location are displayed when a note is added or retrieved. When a user tracks their progress, another *ListView* displays the set of notes that are still to be remembered.



(a) (b)

Figure 4.14: Iteration 1: (a) Palace creation, (b) Progress tracking.

Feedback

Once the first design was presented to users, the main points of positive feedback were centred around the simplicity of the layout and the ability to track the progress of items that are not yet marked as remembered. The sketches received fairly positive feedback, though some important points were raised as ways of improving the design:

- *"Can the tracking screen just show latest results instead of progress over time?"*
- *"The interface is quite cluttered with a lot of text and no icon-based buttons."*
- *"I would like to be able to select palaces from a list instead of searching by name."*
- *"Shouldn't note content be shown above its location when a note is retrieved?"*
- *"It would be nice to add some personalisation to screens such as displaying the name of who is logged in."*

The above comments are certainly valid and will be addressed in the next design iteration. The use of low fidelity methods, in general, is somewhat limiting in how much it

[7] `https://developer.android.com/guide/topics/ui/notifiers/toasts`
[8] `https://developer.android.com/guide/topics/ui/controls/checkbox`
[9] `https://developer.android.com/guide/topics/search/search-dialog`
[10] `https://www.tutorialspoint.com/android/android_list_view.htm`

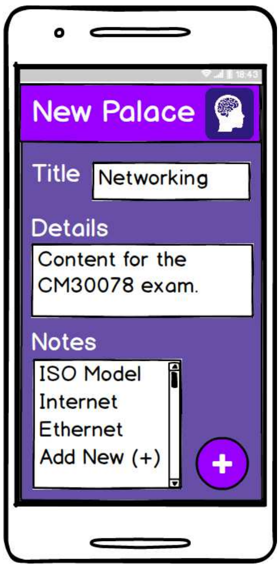
allows users to spot usability flaws or improvements. As such, a higher fidelity approach is required to help encourage more valuable feedback [Zhang et al., 2013].

Iteration 2 - High Fidelity Wireframe

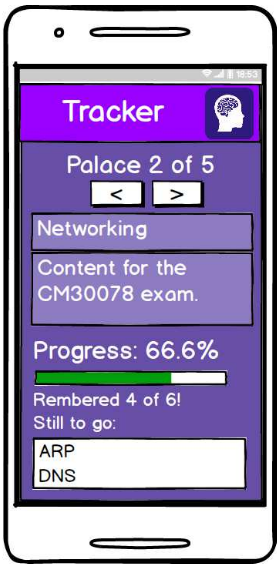
The next phase of UI design involved using *Balsamiq*[11] to mock-up some digital wireframes and incorporate feedback gained from the initial sketches in a higher fidelity prototype. Figures 4.15a and 4.15b are examples of two screens that were mocked-up in this iteration - palace creation and progress tracking screens. (Full wireframe designs for this iteration can be found in Appendix C.2).

Use of Balsamiq has enabled a more sophisticated prototype to be created to expose more usability problems at the cost of a longer prototype creation time [Hall, 2001]. A colour scheme has been chosen that matches closely the branding of the current HTT logo to provide better consistency and standards (c.f. Nielsen [1994]). User feedback from iteration 1 has been implemented in the following ways:

- **Tracking:** Instead of a graph-based approach, users now see a progress bar.
- **Reducing clutter:** Screens contain less text by condensing titles and moving content to the toolbar.
- **Personalisation:** The name of the currently logged-in user is displayed.
- **Selection over search:** Palaces are selected from a drop-down list instead of requiring a search.
- **Symbols over text:** Where suitable, symbols are used for buttons in place of text where the meaning of the action is clear.



(a)



(b)

Figure 4.15: Iteration 2: (a) Palace creation, (b) Progress tracking.

[11] https://balsamiq.com/wireframes/desktop/docs/intro/

Feedback

After showing the same group of users the second design, they were pleased to see a more sophisticated design containing less text and more icon-based buttons, especially on note and palace creation screens and on the progress tracking screens. Users also liked that the *Checkbox* in design 1 indicating whether a user remembers the note when it is retrieved has since been replaced by buttons with a tick and a cross symbol, to make the actions clearer. The wireframe designs received some positive feedback, though some important points were raised as ways of improving the design:

- *"It would be nice to separate palace and note creation screens."*
- *"Currently all functionality is displayed in one main menu. Can this be separated into menus for creation, tracking and training if these are separate features?"*
- *"Use a visualised map instead of textual co-ordinates as locations."*
- *"Make note creation and retrieval screens more consistent in design."*
- *"Instead of navigating back and forth sequentially through palaces using back and forward buttons, I would prefer to select the palace beforehand."*

Iteration 3 - High Fidelity Wireframe

The feedback from iteration 2 was then implemented in more sophisticated prototypes. *Proto.io*[12] was used for the third iteration to design some more realistic native Android designs. Figures 4.17a and 4.17b are examples of two screens that were mocked-up in this iteration - note creation and note retrieval screens. (Full wireframe designs for this iteration can be found in Appendix C.3). One large change in this iteration was the abstraction of system functionality into 4 menus as users requested in order to make clear which screens are for creating content in palaces, which are for retrieving this content and which are for tracking progress. The menus in the third iteration are:

- **Create mode:** Including palace creation and note creation, which have been separated into separate screens since the last design.
- **Train mode:** Where a palace is selected from a drown-down list, in order to retrieve notes and navigate the palace.
- **Track mode:** Where a palace is selected from a drown-down list, in order to view the progress a user has made in remembering its items.
- **Settings:** A menu for deleting palaces and user's account (meeting requirements F1.4 and F2.4).

Instead of using text-based buttons, these menus are accessed via the icons shown in figure 4.16. This is inspired by the usability heuristics "*match between system and the real world*" and "*consistency and standards*" [Nielsen, 1994]. By using a home with and without a plus sign, one can distinguish the creation and training functionality of the HTT application by matching the choice of icons with real-world objects and images. For example, a graph is to represent progress tracking functionality and "cogs"

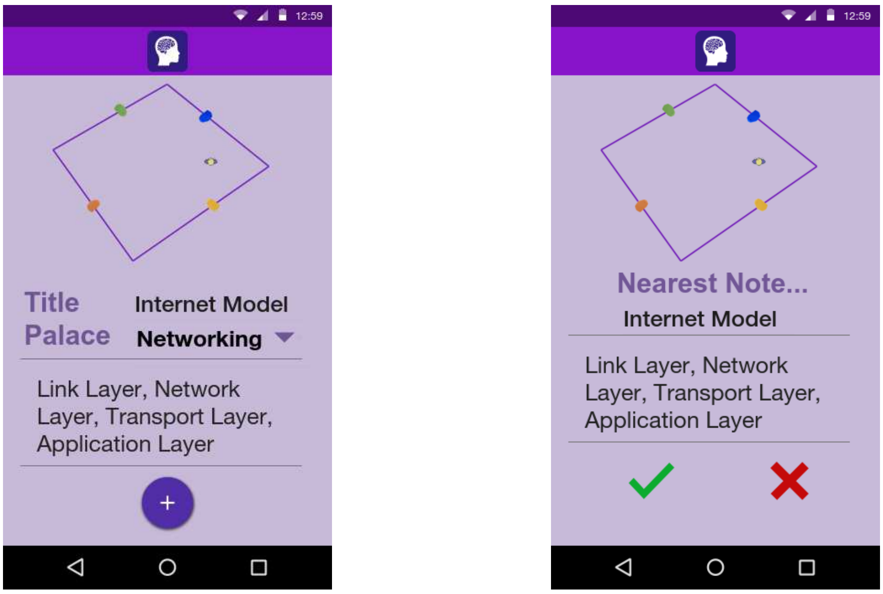
[12] A sophisticated online mobile application prototyping tool: `https://proto.io/`

are used to represent settings which is a common design pattern providing consistency between HTT and other applications.

Figure 4.16: Iteration 3: Main menu redesign.

User feedback from iteration 2 has also been implemented:

- **Map-based location:** Importantly, text-based co-ordinates have been scrapped in favour of a visual representation of the user's location to make their detected location more meaningful.
- **Separating palace and note creation:** These screens are now accessible from the same menu but when a palace is created it is initially empty and does not require notes to be added to it until the note creation screen is used.
- **Consistency between note creation and retrieval:** The layout between these two screens is more closely matched, which should help enforce the ES principle [Tulving and Thomson, 1973].
- **Selection over forward-back navigation:** When viewing progress, it is no longer necessary to use navigation buttons to switch between palaces. Instead, the design is consistent with the training menu.



(a) (b)

Figure 4.17: Iteration 3: (a) Note creation, (b) Note retrieval.

Feedback

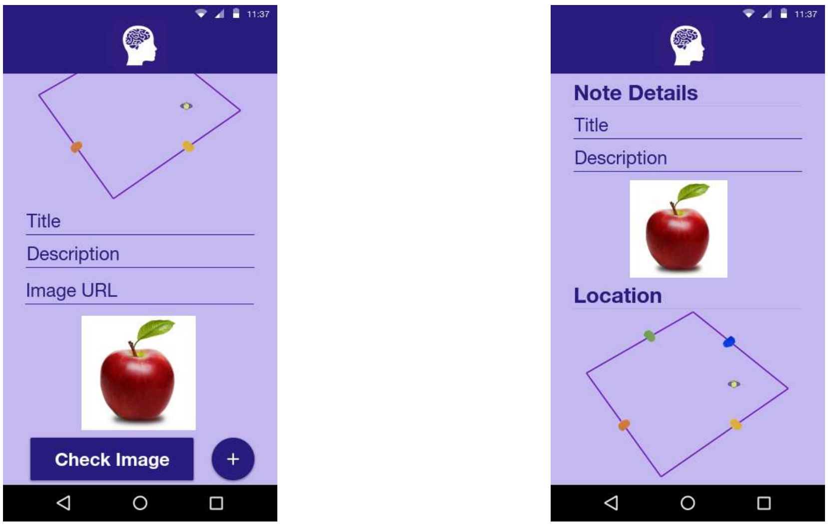
Again, the same users as in iteration 1 and 2 were asked for their feedback on the new design. Positive comments referenced the new menu structure and use of icons in favour of text, as well as the map-based visualisation of a user's current location which is consistent with what they are familiar with when using other applications such as Google Maps. The wireframe designs received mainly-positive feedback, though some important points were raised as ways of improving the design:

- *"Allow users to add an image via URL or camera roll."*
- *"Add a screen to view the note's location from the progress tracking screen."*
- *"Match the colour scheme more closely to the logo colours."*

This will be the final iteration of the designs presented to users for feedback. However, the comments made for improvements will be taken forward into the final implementation.

Summary and Outcomes

The main pieces of feedback on the third design could be implemented in the ways suggested by Figures 4.18a and 4.18b which were created using *Proto.io* as with design 3 above. The colour scheme in these designs matches those used in the logo more closely, and an additional field has been added to the note creation screen in order to add an image via a URL, which satisfies requirement F4.6. Also, a separate screen entitled "note details" has been added whereby a user can see the location where the note was created upon clicking on any of the unremembered notes in a given palace on the progress tracking screen.



(a) (b)

Figure 4.18: Iteration 4: (a) Note creation, (b) Note details.

From user feedback gathered across the three designs, the implementation should minimise the use of text and instead favour icons as buttons. Also, having textual coordinates of a user's current location makes little sense as they will find it tricky to map their coordinates back to a meaningful location in the room. As such, a bird's eye view map of the room's perimeter should be displayed with a marker representing the user's current location. This map should update each time a user moves around the physical space. Users also find it more concise and productive to track their current progress, without finding it useful to view this over multiple training sessions of a given palace over time.

Comments from each iteration will be considered carefully when implementing the UI of the application to minimise usability issues. That said, once the solution has been implemented there is still a need to evaluate the usability of the system to highlight issues which were not flagged at the design stage [Preece et al., 2015].

4.8 Entity Relationship Design

As discussed previously in this chapter, there is a clear need for a remote database that the mobile application can communicate with (c.f. NF2.4). Thus, it is important at this stage to sketch an Entity Relationship Diagram (ERD) for the HTT system in order to design how data is modelled using the application. An ERD is a high-level description of the data model and how objects or entities are related to one another [Li and Chen, 2009]. The schema that will be implemented in order to store user data created when using the HTT mobile application is represented in Figure 4.19. This can be summarised succinctly as:

- A user may create many palaces (*one to many*).
- A palace is composed of many notes (*one to many*).

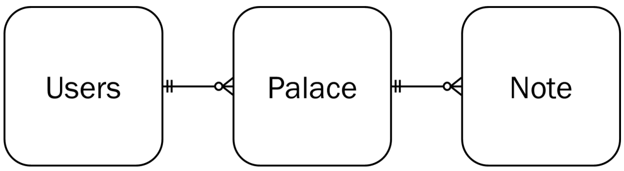


Figure 4.19: High Level Entity Relationship Diagram (ERD) for the system.

This diagram simply shows the names of entities and their relationships instead of their full representation. The final schema (including attributes or "fields") will be discussed in greater detail in the next chapter.

4.9 Development Plan

This chapter has documented the major steps in designing a system to meet the requirements discussed in Chapter 3. From here, it is important to consider the order and dependencies of tasks involved in creating an implementation that satisfies this design.

The development plan displayed in Figure 4.20 shows a list of development tasks required to implement the system that was designed in this chapter. The tasks are broken down into 7 separate stages which demonstrate the dependency of development tasks. For example, stage 1 tasks should be completed before stage 2 tasks are started. Tasks are also broken down by their role in each system subcomponent. Once all tasks are complete after the first 6 stages, the application should be fully functional and we will enter the testing and improvements stage (stage 7). Stages are described in more detail below:

Stage 1: Initially, the overall database schema needs to be designed and implemented such that the data a user creates using the application can be stored in the long term. Whilst this is completed, the Bluetooth beacons responsible for location detection are able to be configured. Once beacons are configured, a physical location can be chosen for the palace content to be created.

Stage 2: This stage involves the development of web service endpoints around the entity relationship model. Whilst this is being completed, the work to be completed on the Android client application can commence. This includes integrating the SDK for location detection to initiate communications between beacons and the mobile device. This is independent of whether the endpoints in the service are up and running just yet so it can be completed in parallel.

Stage 3: At this stage it is possible to start work on creating user accounts using the Android application. The main menus for the application can be created ready for functionality to be added in the next stage. In parallel, the functionality surrounding listening for location/position updates from the Bluetooth beacons can be implemented to track the Android device in the physical space.

Stage 4: Seeing as user accounts can be created, the functionality to delete them can be implemented too. Also, palaces can be created as they now have a user account to be associated with.

Stage 5: By this point, a user can sign in and add a new palace and the location of the device can be determined. The next stage is to merge the location detection functionality with note creation - the location must be associated with the note which is being created. Palace deletion can also be implemented at this stage.

Stage 6: The final stage of development before all core functionality is complete involves retrieving the notes that have been created under a given palace. This can be done in parallel with progress tracking as both depend on a note existing (stage 5) in order to record the number of items that have been remembered.

Stage 7: Testing and improvement can be carried out across all application functionality at this stage.

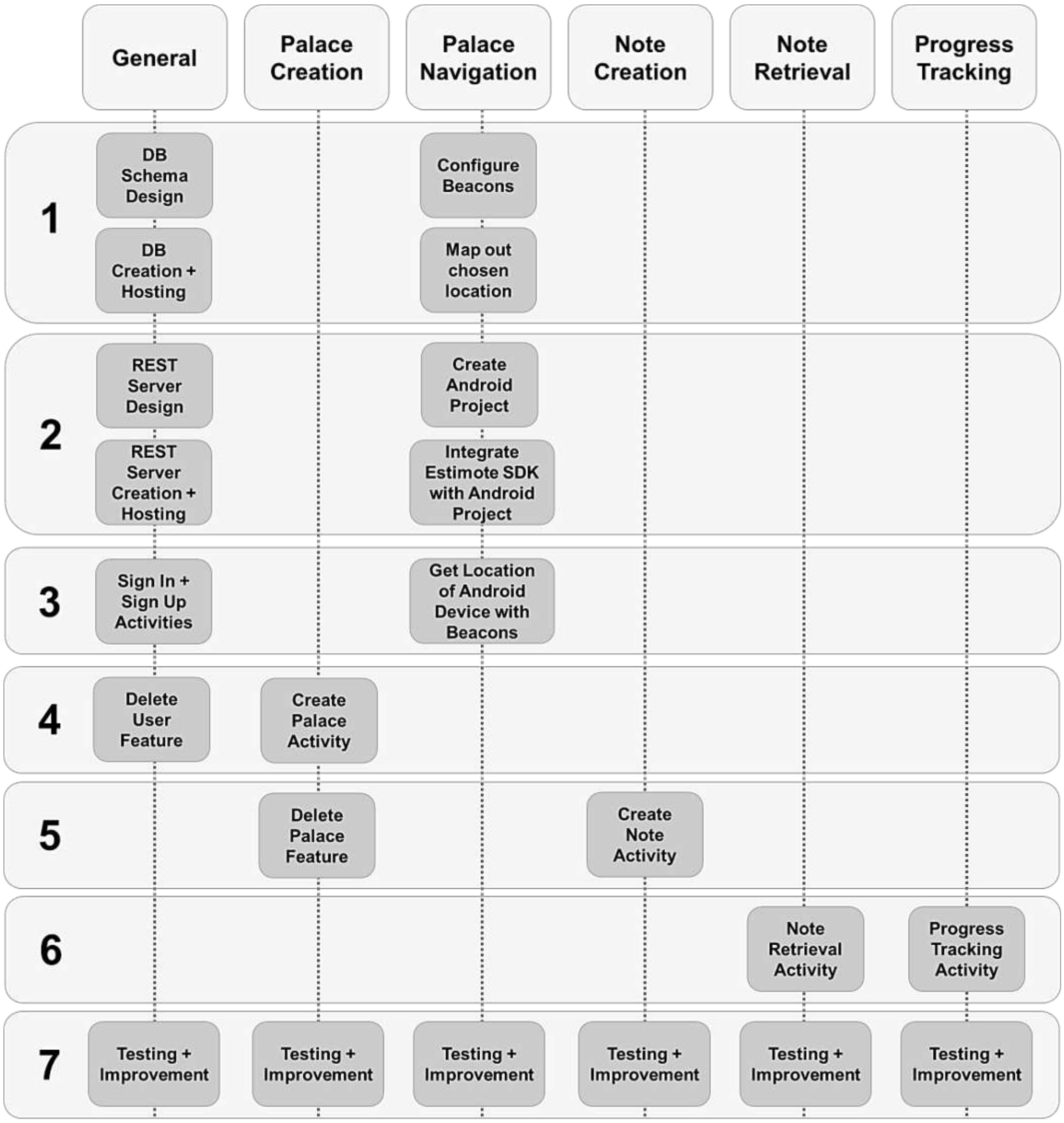


Figure 4.20: Development Stages Dependency Diagram: Here, stages must be complete before the next can begin.

4.10 Chapter Summary

The problem specified in Chapter 3 has been analysed an articulated into a suitable design. In this chapter, we have decomposed the main tasks a user wishes to complete using the HTT system, considered a high-level architectural design along with other considerations, designed a UI using an iterative user-centred approach and considered the data model that the application will adopt. The outcomes from each of these activities will all contribute to the activities of the next chapter: the implementation.

Chapter 5

Implementation and Testing

5.1 Introduction

So far in this dissertation, we have defined the problem space, explored the state of the art in the area of memory, scoped out requirements for a system that can assist with the Method of Loci and (most recently) designed a system that can perform this task. In this chapter, we will present the main details relating to the HTT system's implementation. We shall be analysing the software and hardware components, considering the challenges and implementation details at each stage. (Details on the implementation source code can be found in Appendix H).

5.2 System Architecture and Interaction

As Figure 5.1 shows, Hold That Thought (HTT) in its current carnation is composed of the following system subcomponents:

- **Android Mobile Application:** Written in Android Java and utilising the Estimote Indoor Location SDK.
- **Location Tracking System:** Estimote Indoor Location BLE Beacons (x9).
- **Web Service:** Python 3.6.7 with Flask (REST) - hosted on Heroku.
- **Database:** PostgreSQL - hosted on Heroku.

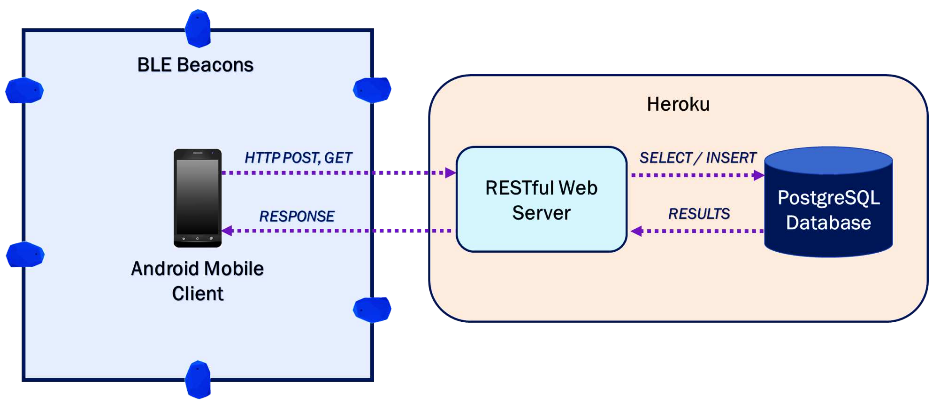


Figure 5.1: "Hold That Thought": High-Level Architecture diagram.

HTT is a location-based and mobile-based system. A set of beacons and a mobile device with the application installed is required. It relies on the use of an Android mobile application which communicates with a set of Bluetooth Low Energy (BLE) beacons to track the mobile device's location in a physical space. By physically navigating the space, users can effectively engage their hippocampus and easily create episodic memories of the items they wish to remember using the application. In this sense, the application permits practising the Mind Palace technique in a context-aware physical environment.

Using the HTT application, users create palaces which consist of sets of notes (e.g. speaker notes for a presentation or revision notes for an exam). Notes are associated with a physical (x, y) location (of the device in the room) so that once a note belonging to a particular palace has been created, a user can retrace their steps and recall notes on their screen to help them remember things when they approach the location the notes were created. A palace is given a name (i.e. a collective name for items to remember). Different palaces can be created using the same application, and only one is ever defined as the "active" palace during training sessions to avoid confusion. The overall goal for a user will be to remember all notes in a given palace. Users are able to track their progress in remembering items in the palace by physically retracing the path they originally took during note creation and recording a response based on whether they remembered the note when it pops up on their device.

5.2.1 Language, IDE and Platform Choices

An important part of the project was deciding on the choice of programming language, IDE and platforms available to write and host the application. HTT takes the form of an Android application, but in the future, it could equally be rolled-out on Apple devices. It would require a rewrite of application logic, but the Estimote SDK does support Objective C and Swift and so this would be a possibility in a future version of the application.

- **Java for Android** - Java was chosen as the language in which to create the Android application despite the recent rise in popularity of Kotlin[1] due to a stronger personal ability in Java and richer selection of resources for Android Java. As such, the mobile application adopted an Object Oriented design.
- **Android Studio IDE** - As Google's official *Integrated Development Environment* (IDE) derived from JetBrains's IntelliJ IDEA, Android Studio was an obvious choice for writing, debugging and maintaining the Android application. Dependencies were managed by *Gradle*, which managed the use of libraries, SDKs and APIs. Version control with Git was integrated in order to ensure new features were pushed to a remote repository and control versions of the software.
- **Python 3.6.7**- Python is freely available as well as being maintained and supported by a large community of developers. The decision to use Python was motivated by previous development experience and the availability of the Flask

[1] `https://www.konstantinfo.com/blog/kotlin-vs-java/`. Accessed 02-02-2019.

libraries for creating RESTful web services for C.R.U.D. (Create, Read, Update, Delete) management of data. All Python code was written in the *Visual Studio Code* text editor rather than using an IDE.

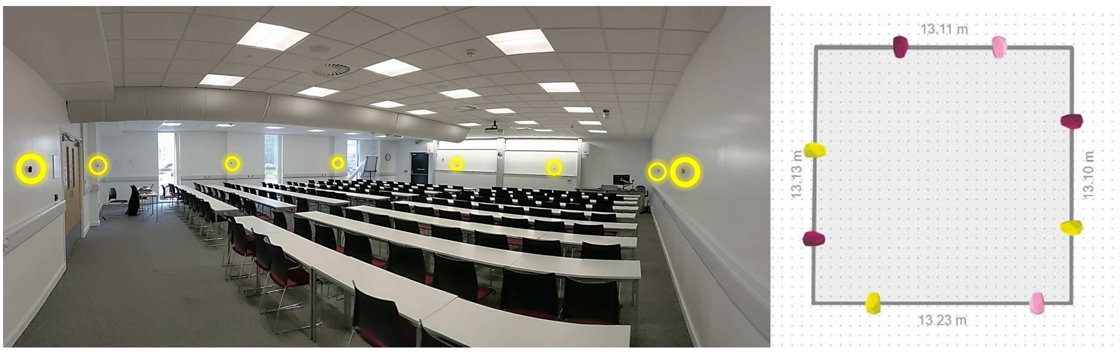
- **Heroku and Heroku PostgreSQL** - In order to deploy the RESTful service onto a remote host, Heroku provides a free hosting solution with support for PostgreSQL database hosting[2]. Seeing as it supports Python, it made sense to deploy the web service and database on Heroku. Whenever new changes to the web service were pushed to the master branch, it was automatically deployed and turned-over on the remote host for immediate testing.

5.2.2 Hardware

The main hardware components of the system are the location beacons and mobile device. This section will describe these components in more detail.

Estimote BLE Location Beacons

Many experiments successfully use BLE to locate users in an indoor environment [La Delfa and Catania, 2014, Kriz et al., 2016, Decuir, 2010, Bruno and Delmastro, 2003]. Estimote beacons[3] were required to map out the dimensions of the physical space and use the Android SDK to determine where a user's device is in that space[4]. Estimote was chosen due to their established platform and reputable clients, including Google, Apple and Amazon. These beacons use Bluetooth 5.0, have a battery life of 3-5 years and a maximum range of 150m. As well as functioning as a BLE transmitter, there are integrated sensors - an accelerometer, temperature sensor, ambient light sensor and a magnetometer for creating versatile IoT applications. As shown in Figure 5.2, these beacons are placed at chest-height and spaced in roughly-equal distances apart from each other to allow them to cover a greater distance and detect Bluetooth devices in the physical space.



(a) (b)

Figure 5.2: Estimote Beacons: (a) Set up in 1W 2.101, (b) Floor plan.

[2] `https://devcenter.heroku.com/articles/heroku-postgresql`
[3] `https://order.estimote.com/buy/location-devkit`
[4] `https://developer.estimote.com/how-beacons-work/`

Android Mobile Device

Due to its ubiquity[5], the Android platform was chosen for use in this project. Whilst the emulator provided by Android Studio is sufficient for most development work, at least 1 Bluetooth-enabled device is required for integration testing with BLE beacons. A phone capable of running Android 5.1 (*Lollipop*) (or newer) is required due to the need to communicate with Estimote BLE beacons. This still covers at least 85.4% of Android devices on the market[6], so it is not a huge restriction. The newer the device, the better - later versions of the Estimote SDK will be optimised to newer Android versions. In theory, the application can also be used on a tablet device, so long as there is an available network connection and Bluetooth 5.0 support. Seeing as different devices run different versions of Android, the selection of a minimum API level in Android Studio projects allows backwards-compatibility with older, cheaper devices which meets requirements NF1.1 and NF1.4.

5.2.3 Software

The software components considered in this section are the HTT application itself, the Android Debug Bridge, the Estimote location wizard and SDK, the web service and database. This section will describe these components in more detail.

HTT (Android) Mobile Application

The Android application allows users to create palaces, add notes and act as a device by which to determine a user's location using the Estimote beacons. As Figure 5.3 shows, the application displays a map that indicates a user's current position. In this case, the phone is held next to a yellow beacon and so this is represented on the map accordingly. The map updates in real-time when the user moves the device with the application running (allowing scans for Bluetooth signals to take place in the background). (See Appendix E.1 for full screenshots of the HTT mobile application).

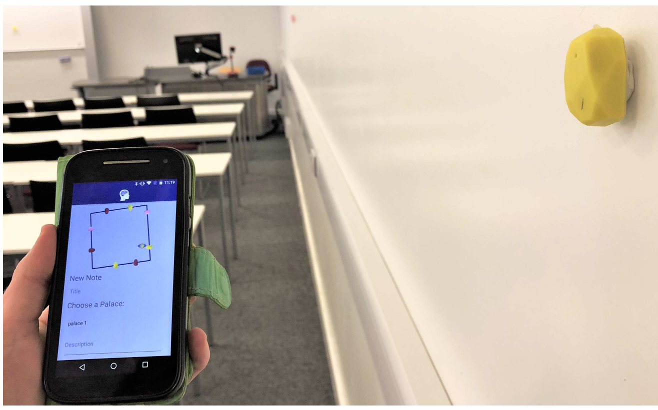


Figure 5.3: The application detecting nearby beacons.

[5] http://gs.statcounter.com/os-market-share/mobile/worldwide
[6] https://developer.android.com/about/dashboards/

Figure 5.4 illustrates the activity class diagram of the HTT mobile application. These activities encompass all system functionality. The arrows between activities signify the navigational structure of the application.

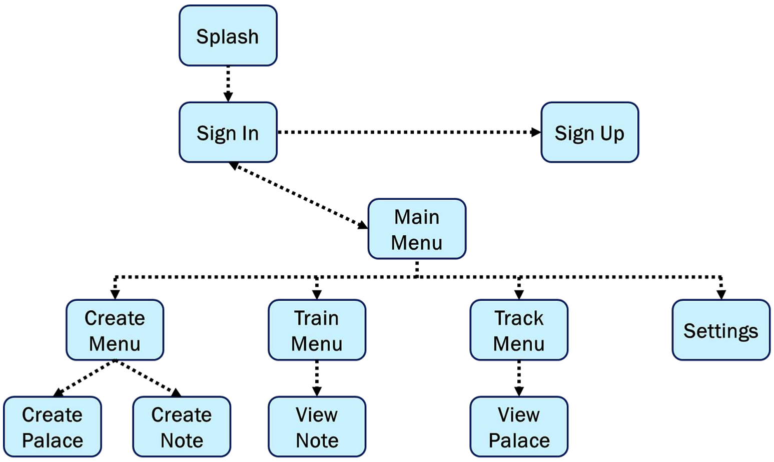


Figure 5.4: Activities of the Android application and their respective navigation paths.

Android Debug Bridge (ADB)

Integrated with Android Studio, Google provides the ADB as a means of testing and debugging the created software whilst it is physically running on a device. This is extremely useful for viewing application logs on the console as it is running in real-time to spot the source of errors. By adding breakpoints in the code using Android Studio, it is possible to *step-through* and *step-into* different parts of the code whilst it is running on the device. If the device is disconnected from the computer running Android Studio, these application logs are not accessible to the developer. This presented a particular technical challenge because navigating the palace involves physically moving with the device around the location - something that is difficult to do when a computer is attached to the device to receive its application logs.

Estimote Indoor Location Wizard

Once a physical space has been chosen for the palace to be created, there must exist a method for mapping out its dimensions and storing its particular beacon layout and configuration to optimise Bluetooth scanning. Estimote handles this task by giving users an account on their *cloud* by which they can create *locations* which have a particular identifier, GPS location and a set of registered beacons in a particular floor plan (Figure 5.2b). In order to map out the physical location and store this location on the Estimote cloud, the Indoor Location Wizard[7] is used. The Wizard sets up this location on the cloud after the user has paced around the perimeter of the physical space multiple times with and without the beacons in place whilst holding their device with Bluetooth enabled. Figures 5.5 and 5.6 illustrate this process.

[7] `https://itunes.apple.com/us/app/estimote-indoor-location/id963704810?mt=8`

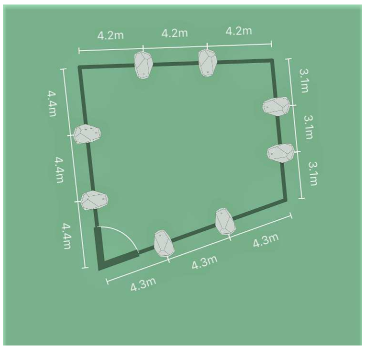


Figure 5.5: Suggested beacon placement.

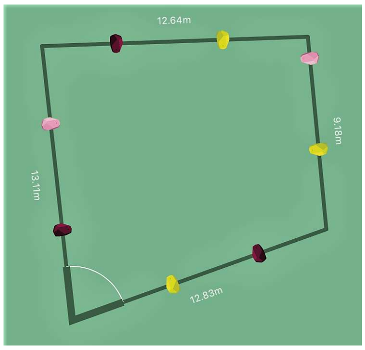


Figure 5.6: Successful location creation.

This is a one-off process which is completed for each new physical space to be used for indoor tracking. After beacons have been configured and the properties of the physical space are stored in the Estimote cloud, it is possible to use the Estimote SDK to determine a user's position in this space.

Estimote Indoor Location SDK

In order to track an (x, y) co-ordinate of a user's device in a location in real-time, there needs to be some communication (scanning and receiving of Bluetooth signals) with the Estimote BLE beacons in the room. This is handled by the Estimote Indoor Location SDK[8] (version 2.5.4). After the dimensions of the physical space are mapped out using the Indoor Location Wizard (described above), this location's information is retrieved from the Estimote cloud by the SDK (locations in the cloud can be viewed via a web browser as shown in Figure 5.7). The SDK[9] then establishes a connection with the beacons before allowing developers to handle detected updates in the position of the Bluetooth device by implementing a listener method. The code within the listener method is executed every time there is a detected change in the position of the Bluetooth device based on the signals received during scanning. Credentials such as the *location identifier* and a unique *application token* are required for the SDK to communicate with the beacons.

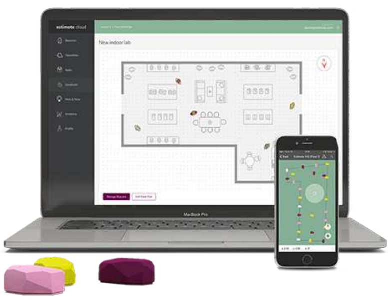


Figure 5.7: Viewing configured beacons and locations in Estimote Cloud.

[8] `https://github.com/Estimote/Android-Indoor-SDK`
[9] `https://developer.estimote.com/indoor/android-tutorial/`

Python (Flask) RESTful Web Service

As the data created using the HTT mobile application is committed to long-term remote storage in a database, it made sense to introduce a web service as an intermediary between the client application and the database. A web service can be described as a purpose-built, web-hosted server that supports a client application's needs [Masse, 2011]. This service is then deployed to Heroku for remote hosting.

Representational State Transfer (REST) was termed by Fielding [2000] when describing the web's general architecture. It is therefore based on the Hypertext Transfer Protocol (HTTP). A client typically communicates with the server via an Application Programming Interface (API). The addition of a REST API to a web service makes it "*RESTful*". Using Masse [2011] as a reference point for its design, a REST API was implemented in order to perform C.R.U.D. operations on the project's data. (See Appendix E.2 for full details on the REST API implemented).

The service is implemented in Python, using the *Flask* web framework as a way of providing an out-of-the-box REST API implementation for `GET`, `POST` and `DELETE` HTTP methods on endpoints without needing to handle complex network or transport layer logic. Flask instead allows developers to focus on the application logic. The alternative without using a web server would be for the Android application to execute and manipulate Structured Query Language (SQL) directly which is an extremely insecure approach that is prone to security vulnerabilities such as SQL injection [Devi et al., 2016].

PostgreSQL Database

The final software component of the implementation was the database that the REST service was interfacing with in order to store data long term. This is also hosted remotely on Heroku[10], allowing up to 10,000 rows of data and 20 simultaneous connections which is more than enough for the purposes of this project. This makes requirement NF2.4 a realistic expectation of how long it should take to retrieve data from remote storage. There is an extensive *Command Line Interface* (CLI) for interacting with the database and running queries of the existing data for debugging purposes, which made it much less challenging to design configurable queries based on the parameters of the REST calls to the web service described above. (See Appendix E.3 for a snapshot of the database dashboard on Heroku).

Figure 5.8 shows a more detailed schema of the database that was first designed in section 4.8 of the previous chapter. Here, it is clear that a user can create many palaces and in turn, a palace is associated with many notes. *Identifiers* (IDs) such as `palace_id` are defined as serial keys (auto-generated). As explained in the previous chapter, passwords are stored as plain text and hence are not encrypted for this proof of concept implementation (NF3.1). Users will be made aware of this during experiments.

[10] `https://devcenter.heroku.com/articles/heroku-postgresql`

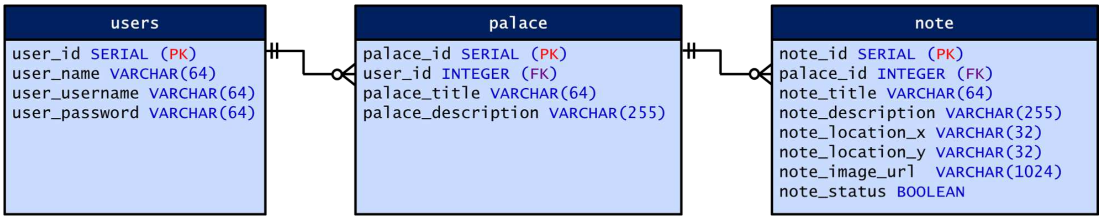


Figure 5.8: Database schema (PK = Primary Key, FK = Foreign Key).

5.3 Code Reuse and Software Management

Raymond [2001] describes the development of open-source libraries as a method of software development that encourages wide participation in the development and maintenance of software from volunteers. It is a powerful way of maintaining a reliable source of software that many people can re-use in their applications instead of implementing their own logic from scratch. Code re-use is one of the three implementation considerations highlighted by Sommerville [2016] that arise during software development (that are independent of the choice of language or platform). These are described below, with detail on their relevance to the project.

1. **Code reuse:** This project aimed to maximise code re-use to reduce risk of failure. Libraries have been well-tested and reduce the need for "*boilerplate code*"[11]. The main open-source libraries and SDKs used in HTT are:
    - **Estimote Indoor SDK 2.5.4**[12]: Android SDK for interfacing with Estimote Location beacons.
    - **Volley 1.1.1**[13]: Android HTTP library for handling network requests.
    - **OkHttp 2.2.0**[14]: Android client library for HTTP and HTTP/2.
    - **Flask 0.12.3**[15]: Python WSGI web microframework for creating web services.
    - **psycopg2 2.7.5**[16]: Python library for interfacing with PostgreSQL databases.
    - **scipy 1.2.0**[17]: Python library for mathematics and science calculations.
2. **Configuration management:** Sommerville [2016] separates this into version management, system integration, problem-tracking and release management. These were handled in this project by use of Git, Gradle and Heroku:
    - **Git**: Allowed versioning of the software and problem-tracking on different branches to prevent loss or overwriting of code that causes a bug in the software.

[11] This is a term for code that is not crucial to the functionality or logic of the application, but is needed for infrastructure or hosting reasons.
[12] https://github.com/Estimote/Android-Indoor-SDK
[13] https://developer.android.com/training/volley/
[14] https://square.github.io/okhttp/
[15] http://flask.pocoo.org/
[16] http://initd.org/psycopg/
[17] https://www.scipy.org/

- **Gradle**: Allowed system integration. The *build.gradle*[18] file would specify the versions of dependencies.
- **Heroku**: Allowed system integration and release-management of the web server. Pushes to master branch would automatically trigger a build and turnover of the web-service for rapid testing of new changes. The *requirements.txt*[19] file would specify the versions of dependencies.

3. **Host-target development:** This consideration refers to the difference between the local environment used for development and the environment or host being deployed to. In this project, a remote host was used to deploy the web service and database using Heroku. As such, application logic was first tested locally with an IDE, before making additional code changes to ensure code could run on a remote host (e.g. retrieving the URLs of the web service and database and specifying required libraries that the remote host must install).

5.4 Implementation Details

So far in this chapter, we have analysed the choice of hardware, languages, IDEs, SDKs, libraries and other software used to create HTT. In what follows we shall be looking at the implementation details of the main system subcomponents that were first defined in Chapter 3.

Palace Creation

As explained in Chapter 3 and 4, this system subcomponent is kept separate from the task of adding notes to the palace in order to not restrict users in deciding on all of the items they wish to add to a palace at the time it is created. Palaces are given a name and description to group the notes in a logical collection.

Palace Navigation

The HTT system uses the physical environment as the palace. In this respect, navigation is performed in the most natural way possible - moving around the room selected as the palace. The aim of this implementation detail is to reduce the cognitive effort required to recall details about the environment when retracing steps of the mental journey and retrieving items. Whenever a user moves around the room that has been set up with the BLE beacons (such as in Figure 5.9), there is a constant interaction between the mobile device and beacons in real-time in order to determine the user's location as accurately as possible. The calculated (x, y) location is used as parameters in REST calls to add new notes and retrieve notes near the current location.

[18] `https://guides.gradle.org/creating-new-gradle-builds/`

[19] `https://devcenter.heroku.com/articles/python-pip#the-basics`

Figure 5.9: Estimote Beacons for indoor location tracking.

In an ideal world, this process would involve a user setting the beacons up in their environment of choice, such as their own homes. For experiments, however, the same room at the University of Bath will be used. When the screens relying on location tracking (e.g. Note Creation, Note Retrieval) are first loaded, a number of steps are carried out in order to start location tracking functionality. The code listing below illustrates these main steps in Java code. These steps can be summarised as:

1. Fetch location (layout and dimensions of room) from Estimote cloud - line 1.
2. Set up Bluetooth scanning on the device (including parameters such as scanning interval) - line 7.
3. Set up listener for acting on position updates (changes in calculated location) - line 12.
4. Start scanning to receive signals from beacons - line 18.

```
1  cloudMgr.getLocation(LOCATION_ID, new CloudCallback<Location>() { // Fetch
   ↪  location
2      @Override
3      public void success(Location location) {
4          iLocMgr = new IndoorLocationManagerBuilder(getApplicationContext(),
5          location, cloudCredentials)
6                  .withPositionUpdateInterval(501L).withDefaultScanner()
7                  .build(); // Configure and build scanner
8          iLocMgr.setOnPositionUpdateListener(new OnPositionUpdateListener() {
9              @Override
10             public void onPositionUpdate(LocationPosition locationPosition) {
11                 iLocView.updatePosition(locationPosition);
12                 loc_x = locationPosition.getX(); // Fetch (x,y) co-ordinate
13                 loc_y = locationPosition.getY();
14             }
15             // Handle position being outside location (omitted for brevity)
16         });
17         iLocView.setLocation(location);
18         iLocMgr.startPositioning(); // Start scanning
19     }
20     // Handle location fetch failure (omitted for brevity)
21 });
```

As the Java code shows, the `iLocMgr` object scans for (undirected advertised) Bluetooth signals every 501 milliseconds, which is the fastest rate that Estimote BLE location beacons permit. Figure 5.10 shows the map that users of HTT see as they navigate the room during Note Creation and Retrieval tasks. This map is updated using the new location of the user on every call of `onPositionUpdate`. The `locationPosition` parameter of this method enables an (x, y) co-ordinate to be extracted for REST call parameters to be constructed. A typical coordinate detected by the system might look like $(1.7517321107948618, 9.637726037712733)$, for example.

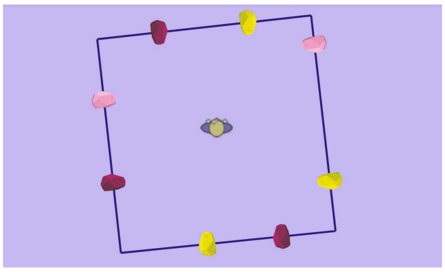


Figure 5.10: Implementation: Map displaying user's current location.

Note Creation

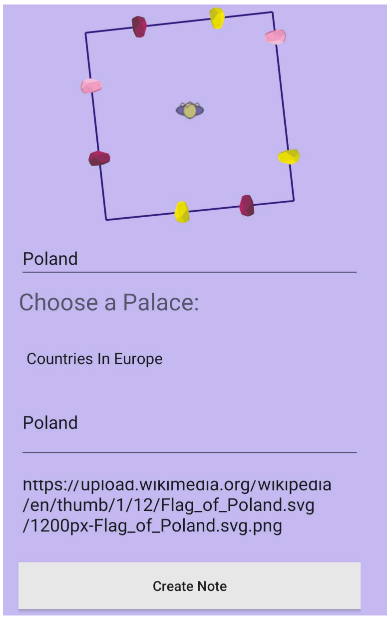


Figure 5.11: Creating a new note entitled "Poland" in palace "Countries in Europe".

Once a palace is created and can be navigated, the location values calculated from the BLE broadcasts discussed above can be associated with a note to be stored in the palace. In order to add a new note, a user must select a palace for the note to belong to before entering a title, description and URL of an online image associated with the item to be remembered.

As the user navigates around the physical space, the bird's-eye view map is updated in real-time to reflect the location where the device has been calculated to be (Figure 5.11). Users can use the colour and layout of the beacons around them in order to work out whether this detected location is accurate before creating the note. Inspired by the findings of Craik and Lockhart [1972], users must not only enter the name of the item to be encoded but also a description of what the item is (e.g. a description of its physical appearance or some non-visible property) as well as a URL of an image that suitably represents it. In doing this, they are processing the item to be remembered in a deeper way, contextualising it with a name, description and image before anchoring the item to a physical location in the room.

Image search engines such as *DuckDuckGo* or *Bing Images* can be used to search for a suitable image. The *Picasso* library efficiently loads and resizes the image from its URL to fit the dimensions of the container when the user taps the "Check Image" button before creating a note. Once a user is happy with the encoding of the item, they can tap "Create Note" to add the note to the palace.

Note Retrieval

Palaces with at least one note can be used in "train" mode, whereby a user of HTT will navigate the physical space and revisit the same places they visited when creating notes. A typical (x, y) location co-ordinate of the user's current detected location will be to 16 decimal places for both x and y. The implication of this high precision in detected location values is that it is nearly impossible for a user to revisit the exact same co-ordinate in the space, so there must be a way for a radius of *sensitivity* to be factored into the application when retrieving notes. Algorithm 1 outlines the steps followed when retrieving notes given an (x, y) of the user's current position, a radius of sensitivity and a chosen palace.

Algorithm 1: Note retrieval logic.

Input: (x, y): Co-ordinate of user's current position.
Input: r: Radius for location sensitivity.
Input: p: Chosen palace.
Output: *resp*: Response JSON - either a retrieved note or error message.

Extract input arguments
Connect to database
Let $|\mathcal{N}_p|$ be the number of notes in palace p
Let (x_i, y_i) be the (x, y) co-ordinate of note i in palace p
Set $\mathcal{A} = \{(x_i, y_i) | i = 1, 2, ..., |\mathcal{N}_p|\}$
Set $(c_x, c_y) = \arg\min_{(x_i, y_i)} f(x_i, y_i) = \sqrt{(x_i - x)^2 + (y_i - y)^2}$ for all $(x_i, y_i) \in \mathcal{A}$
if $(c_x - x)^2 + (c_y - y)^2 \leq r^2$ **then**
    Set *resp* to JSON containing note at (c_x, c_y)
else
    Set *resp* to JSON containing "outside range" error
end
Return *resp*

When Algorithm 1 is translated into Python code as below, the parameters from the REST call can be extracted and used in calculations to return the note that is closest to the user's currently-detected location. The use of `cdist` from the `scipy` library allows fast and efficient calculation of the Euclidean distance between the user's current location and the set of all other locations of notes in the current palace being used to train with the HTT application.

```
from scipy.spatial.distance import cdist

def closest_point(point, points):
    return points[cdist([point], points).argmin()]

@app.route('/nearestnote/<palace_id>', methods=['GET'])
def nearest_note(palace_id):
    args = request.args
    xpos = float(args['xpos'])
    ypos = float(args['ypos'])
    radius = float(args['rad'])
    // ...
    cur_loc = (xpos, ypos)
    closest_loc = closest_point(cur_loc, all_locs)
    within_rad = pow(closest_loc[0] - cur_loc[0],2) +
    pow(closest_loc[1] - cur_loc[1],2) <= pow(radius,2)
    // ...
```

Although the `closest_point` function is one line of code, it has several sub-steps to calculate the closest (x, y) co-ordinate in a set to another (x, y) co-ordinate. These can be summarised as:

1. `cdist([point], points)`- Calculate the Euclidean distance between `point` (the user's current (x, y) location) and `points` (the set of all (x, y) location co-ordinates stored with notes under the current selected palace).
2. `argmin()` - Return the index of the co-ordinate in `points` producing the minimum `cdist` value (the index of the closest point).
3. `points[cdist([point], points).argmin()]` - Return the value at the index of `points` producing a minimum `cdist` value (the (x, y) co-ordinate of the point in `points` closest to the user's current location).
4. If this returned location value is within the specified radius, it can be used as a parameter in an SQL query to the database to find the details of the note with the location calculated as closest to the user's current location. If not, a suitable error message can be displayed on the screen informing the user that no note exists at (or near) their current location.

The retrieval logic is triggered when a user walks to the location they believe a note to be stored under the current palace and they tap the "Check" button shown in Figure 5.12. Once the location of the closest note has been determined and its details have been looked-up in the database, its title, details and image (loaded from a URL) are displayed to the user in the application. It is then the user's responsibility to provide a response indicating whether they correctly recalled the note. This is a way of providing an element of elaborative rehearsal and demonstrating the "*testing effect*" first discussed in Chapter 2 (c.f. Greene [1987], Roediger and Butler [2010]). By asking the user for feedback on whether they remembered the item correctly, the application is effectively testing the user whilst they practice. Buttons (✔ and ✖) to record the user's response to the note are tapped in order to mark the note as remembered or not, updating its status.

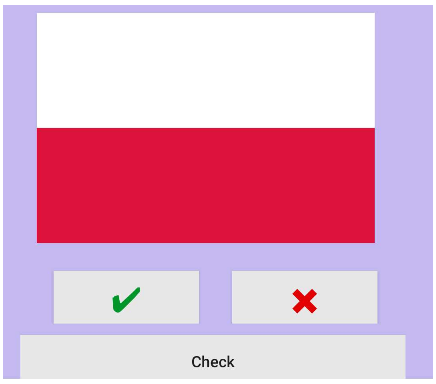


Figure 5.12: Implementation: Retrieving a note and updating its status in the palace.

Progress Tracking

Once a user has added notes to a palace, they can view the notes that are still to be marked as "remembered" using the Progress Tracking screen (Figure 5.13).

Figure 5.13: Implementation: Details of progress of remembering items in an example palace "Countries in Europe".

In section 2.3.2, deliberate practice was introduced. This aims to overcome the problem of practising a skill becoming monotonous and automated over time, meaning a person no longer improves beyond a certain level. By assessing the work that is needed to improve at a certain skill, one can practice it at a higher level [Lehmann and Ericsson, 1997, Davids, 2000].

No existing technical solutions that were discussed in Chapter 2 include any functionality to track items that a user has or has not remembered whilst practising the MoL technique. The progress tracking screen displays the list of notes that are still to be marked as remembered during a training session with that particular palace (Figure 5.13). By clicking on any of the notes listed as "still to go", users can see the location where this note is in the palace in order to focus on visiting that area in the next training session. It is hoped that by highlighting to users which areas of the palace are still to be covered, they can improve their use of the technique.

5.5 Technical Challenges

Having examined the rationale for choices of language and platform, assessed the software management practices that were adopted and looked at implementation details of key system functionality, it is important to highlight some of the technical challenges faced during development. Some of these challenges were predictable by the nature of the system design, whereas others were unforeseen.

Location Radius Sensitivity

The high precision of detected location co-ordinates and potential error offsets in the calculated location of the device warranted the implementation of an appropriately-sized radius of *sensitivity* in which a note can be retrieved whilst using the HTT application in a given room. As such, there needed to be some optimisation of the sensitivity radius when retrieving a note upon a user revisiting the physical location the note is anchored to. Figure 5.14 (b) shows that if this radius was too large, the number of potential notes within radius increases compared to (a), meaning that it is possible that a note located a considerable distance away from the device can be retrieved. The notion of anchoring a note to a distinct location in the room is then not as granular. Conversely, if the radius is too small it becomes too difficult to return to the exact location that note was stored. A series of values for the radius had to be experimented with before deciding on a suitable value.

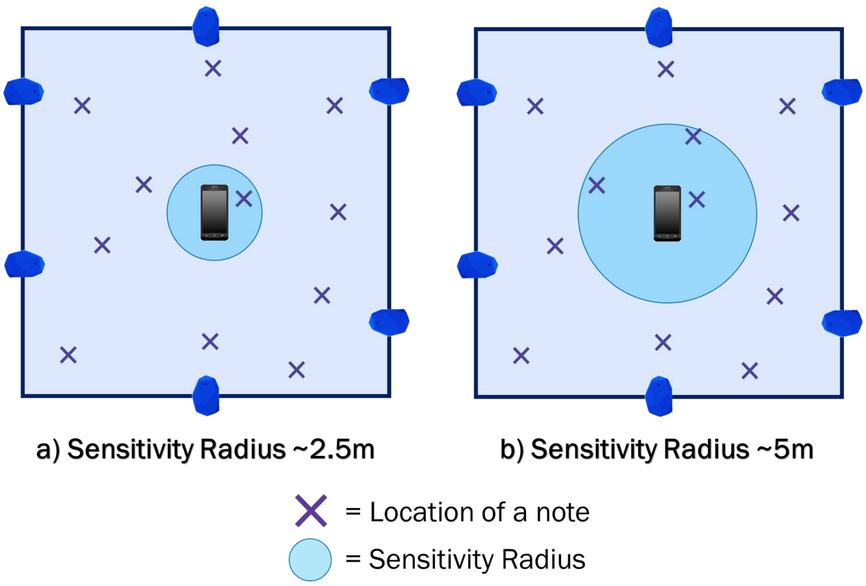


Figure 5.14: Location radius sensitivity: The effect of changing the sensitivity radius.

Position Update Latency

The BLE beacons broadcast undirected advertisements every 200 milliseconds[20] and the device scans for these signals every 501 milliseconds. That said, there is also an added latency of scan results being passed from the Android BLE chip, to the Android BLE driver, to the Android BLE operating system services and then eventually to the HTT application itself. Scanning might be more frequent when the application is in the

[20] `https://developer.estimote.com/how-beacons-work/`

foreground rather than the background for this reason. As such, there is a little bit of latency (a few seconds) between a user changing their position and the updates being fed to the application. This latency will be different depending on the version of the SDK, the Android device's operating system and the device's hardware specifications. For this reason, the latest version of the Estimote SDK was used, along with a new Android phone running Android 9.0 (*Pie*) to take advantage of optimisations. Despite a large amount of computational work being done to keep track of a user's location, the battery usage of the device is not adversely affected, ensuring that requirement NF1.3 is met.

REST Call Latency

Recall that an intermediary REST service is required in order for the HTT mobile application to interface indirectly with the database remotely via REST calls. The advantages of this approach have already been discussed at length (provision of multi-user support, resiliency etc.), but the major disadvantage of this approach is that there is extra latency. Firstly, an HTTP request is made from the device to the remote service, then the service makes an SQL query, handles the response and sends an HTTP response back to the application. Depending on network speeds, this can mean that the queries and updates to the database can take longer than if the database was local to the device. Unfortunately, this is a necessary trade-off.

As requests to the database have extra latency, they must be threaded carefully in the application logic to optimise response times. Android imposes restrictions on the functionality that can be executed on the UI thread (responsible for drawing and updating the current screen). As such, any REST calls need to be executed on a separate thread. This also can introduce UI race conditions whereby varying orders of execution produce different outcomes. To combat this, *Volley* was used to execute REST requests and handle responses as efficiently as possible. This is a library provided by Google that abstracts the execution of network requests and handles complexities such as caching responses.

Motion-based versus Ad-Hoc Note Retrieval

Early on in the implementation stages, the idea of a *motion-based* note retrieval was experimented with (Figure 5.15 (a)). This approach of note retrieval would entail opportunistically-attempting to retrieve a note every time a new update in the user's position was detected by the listener attached to the Bluetooth scanner in the application (instead of waiting for a user to query for a nearby note using the application). This approach would mean that a user simply needed to move position and then the application's UI would update automatically to view the details of the nearest note without the user needing to trigger any action using the application. This approach would be ideal but has its own shortcomings. A system-triggered REST call to retrieve the nearest note on every position update would mean (in its current state) a call is made every 501 milliseconds. The time required to calculate a new location from the signals, make a call to the web server with the new location as parameters, determine if a note is nearby, retrieve a response from the remote web-server and then update the device's UI accordingly is far greater than 501 milliseconds. As such, with this approach (even on a fast network) a queue of unserviced requests would rapidly build-up and mean that this approach is infeasible.

The above shortcomings meant that an *ad-hoc* note retrieval approach was instead adopted (Figure 5.15 (b)). This means that a REST call to check for nearby notes is only made by tapping the "Check" button on the application's UI. Requests therefore never build-up as rapidly and can be quickly serviced such that the UI can display up-to-date information about the details of nearby notes.

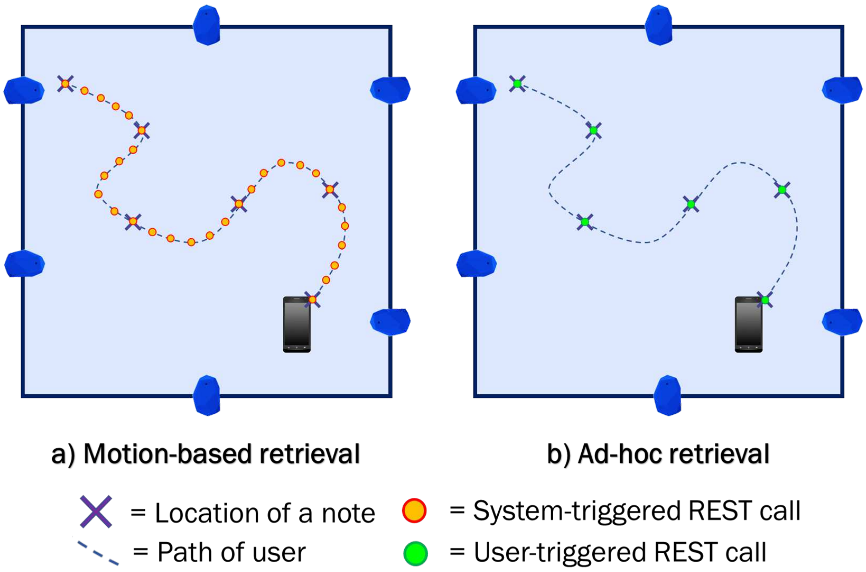


Figure 5.15: Motion-based versus Ad-Hoc retrieval: The difference between the approaches.

5.6 System Testing

During the implementation of the HTT system, it was crucial to carry out thorough system testing to ensure the system was performing in accordance with its requirements specification and ensuring it could behave as expected under normal operating conditions. (Appendix F has full Testing Evidence). After the requirements specification was formalised, a *test plan* could be built that incorporated all of the expected functionality of the system (Figure 5.16). Given the time and resource constraints of the project, it is inevitable that not all system subcomponents could be tested in detail both in isolation and as a whole. As such, an appropriate level of testing needed to be applied. Overall, three main stages of testing were carried out.

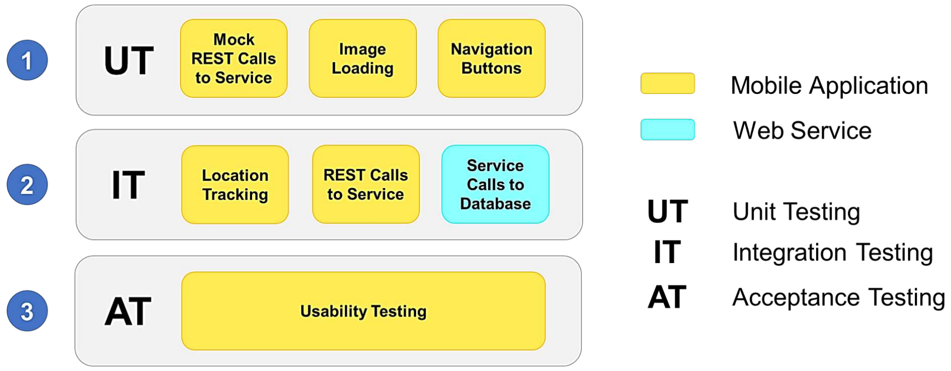


Figure 5.16: "Hold That Thought": Test Plan showing the 3 main stages of system testing.

As Figure 5.16 shows, initial unit testing revolved entirely around getting the navigation buttons of the mobile application functional and handling mocked calls to the web service to handle success and failure responses. Ideally, the web service would also have some unit tests applied to it to test REST endpoints in isolation from the database using a framework such as *Pytest* for Flask[21], but this was decided against due to time constraints. As the main role of the service is to act as an intermediary for the database, it was more important to focus on the web service during integration testing. See Appendix F.1 for full Unit Testing evidence.

Once unit testing was complete, the web server's REST API was integration tested using *Postman*[22] (Figure 5.17). HTTP requests can be made from the Postman client and responses can be viewed in the same window to diagnose errors. For further support and diagnosis, the application logs of the remote web service were accessible on Heroku. This part of the integration testing stage ensured a connection could be made between the web server and database and any HTTP clients. See Appendix F.2 for full Integration Testing evidence.

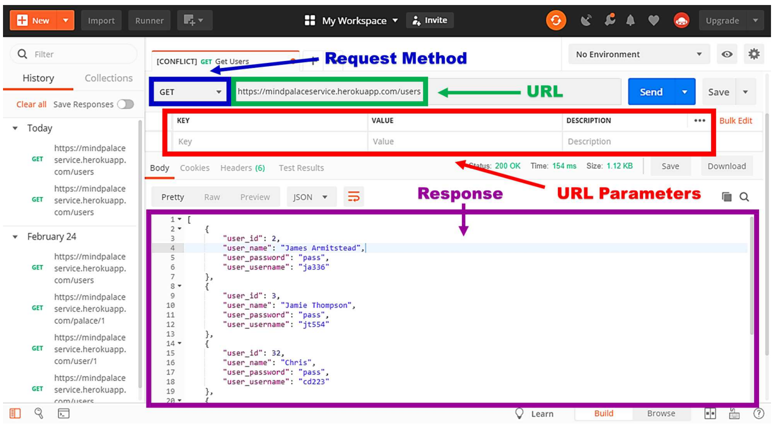


Figure 5.17: Postman: A powerful REST API client for testing web services.

[21]http://flask.pocoo.org/docs/1.0/testing/
[22]https://www.getpostman.com/

After the integration tests on the REST API were complete, the HTT application was then integration tested by connecting it to the remote web server and running instrumentation tests using the *Espresso*[23] testing framework, which tested the full data flow from front-end to back-end and ensured the Android UI could act as a suitable HTTP client for the backend. *Instrumentation tests* are executed on physical devices or emulators to make use of libraries such as AndroidX[24] and allow realistic automated behavioural testing on a physical device. As seen from Figure 5.18, the Espresso test suite could be executed from within Android Studio (all tests passed). This tested many subcomponents as a whole, from signing up, signing in, creating a palace and adding notes to it, and so on. The most notable and time-consuming tests to complete involved the location tracking feature. The complex interaction between the HTT application and Bluetooth beacons required careful data selection on a suitable sensitivity radius in order to retrieve notes.

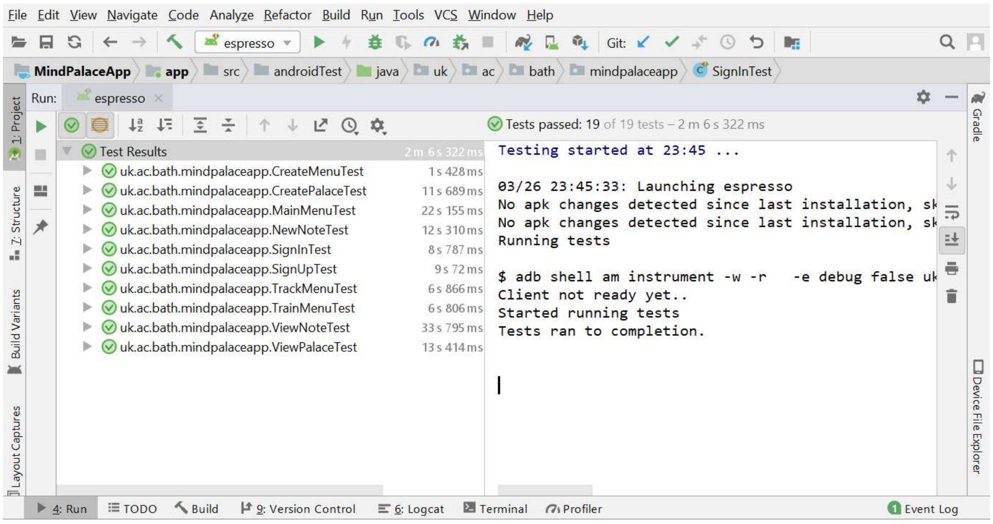


Figure 5.18: Espresso Tests viewed in Android Studio: All front-to-back tests passing.

The third and final stage of testing involved getting users to use the application in order to evaluate its usability and make changes in response to their feedback. Evidence of this is provided in the next chapter as it forms a sensible part of the HTT system's evaluation.

After unit, integration and acceptance testing was complete, it was possible to have confidence in the HTT system performing correctly under *normal* operating conditions. Had there been more time, further tests would have been created to ensure the application was robust to abnormal input data. That said, for the purpose of creating a prototype for experimental evaluation, this would have been beyond the original remit of the project.

[23] `https://developer.android.com/training/testing/ui-testing/espresso-testing.html`
[24] `https://developer.android.com/training/testing/unit-testing/instrumented-unit-tests`

5.7 Delivery of Requirements

From the details presented about the implementation above, it is time to reflect on the extent to which the requirements outlined in Chapter 3 have been met. Table 5.1 shows the number of functional MoSCoW requirements met in the implementation. It is clear that the prioritisation scheme adopted for requirements has influenced the system's implementation as all MH and SH requirements have been completed which allows the system to be readily evaluated in an empirical way in the next chapter after meeting its core requirements.

Table 5.1: Breakdown of delivery of functional requirements for the HTT system.

Priority	Total	Delivered
Must Have (MH)	22	22
Should Have (SH)	9	9
Could Have (CH)	5	1
Won't Have (WH)	2	0

Notably, some of the CH requirements were not met, which is either due to time constraints or an executive decision that they are not feasible to implement in each case. For example, F2.9[25] refers to allowing a user to add custom objects to a bird's-eye map of the palace to aid navigation. This idea would be helpful to help replicate the layout of the physical space being used as a palace, but it would require a large overhaul of the Note Creation and Retrieval logic (as well as back-end changes to implement custom map storage) and it is not a feature which is altogether necessary to complete before experimental studies to begin.

F4.9 was not implemented and so other media such as animations, video or audio are not currently able to be associated with a given note. As discussed previously, supporting other media types might encourage the bizarre imagery effect which is known to enhance recall in certain cases [Burns, 1996]. That said, this would also require a large change to existing logic which could cause delays which might negatively impact the design of the experiment. As such, image and text-based notes are prioritised, as they are most commonly supported in existing systems which implement the MoL technique.

Finally, another novel suggestion which was not implemented was a rewards scheme, whereby users attempt to reach targets (numbers of notes successfully recalled) for improvement. Whilst this is a common form of gamification technique, there is research in the domain of Persuasive Technology to suggest rewards schemes only target specific types of users and may be counter-productive to others [Orji et al., 2013]. As such, the simple progress tracking technique is adopted. The aforementioned CH requirements not being implemented leaves some scope for further research in this area, should the HTT application prove an effective method for assisting the traditional MoL technique.

Table 5.2 shows the number of non-functional MoSCoW requirements met. As with the functional requirements, all of the MH and SH non-functional requirements are

[25] Found alongside other formal requirements in Appendix B

met, with a couple of notable CH requirements not being implemented. These CH requirements include NF1.8 which refers to allowing customisation of colour schemes and personalisation features such as user profiles. Whilst these features would have made for a more complete application, they are not critical to assessing the effectiveness of the system. Finally, NF1.9 outlines the ability of users to create content off-line using the application. In light of the application's implementation, it will require an active Bluetooth and network connection at all times. As such, it is nonsensical to consider support for content creation off-line.

Table 5.2: Breakdown of delivery of non-functional requirements for the HTT system.

Priority	Total	Delivered
Must Have (MH)	10	10
Should Have (SH)	6	6
Could Have (CH)	2	0
Won't Have (WH)	2	0

5.8 Accordance with Design

It is also pertinent to assess the extent to which the system design conceived in Chapter 4 has been adopted. By adhering to the design criteria laid out in that chapter, and using a technology stack which reflects these considerations, the implementation of HTT successfully implements a location-based approach to creating Mind Palaces in physical spaces. The application permits users to:

1. Create many "palaces" (sets of items to remember) in the same room.
2. Add notes (text and an accompanying online image) to their palace by walking around the room.
3. Retrieve notes by revisiting the locations they were added.
4. Record whether they have remembered the information correctly.
5. Track how many notes in a palace they have remembered (and the locations of the notes that are still to go).

In other words, the design considerations and UI prototyping of the HTT application in chapter 4 has closely informed its implementation, and as such, there is high accordance with the design, both conceptually and visually via its user interface.

5.9 Chapter Summary

This chapter has summarised the key implementation details of the HTT system - the architecture and rationale for language, IDE and platform choices. The following chapters will evaluate the project by means of usability testing and experiments and discuss the findings from each activity.

Chapter 6
Evaluation

6.1 Introduction

Now that implementation details have been discussed, there will follow a multi-stage evaluation of the HTT system's implementation from a usability perspective before collecting experimental data from its usage to memorise information. This chapter describes the process by which the usability and experimental testing was designed and conducted.

6.2 Usability Testing

Once a working implementation of the HTT system was fully-functional, it was crucial to evaluate its usability before any experiment could take place. The usability evaluation took the form of two stages - a demonstration and feedback survey followed by a formal think-aloud protocol study with 5 participants. The feedback from both of these usability evaluation stages was then implemented in the mobile application so that the application was deemed usable to a suitable standard before experimental data could be collected.

6.2.1 System Demonstration Feedback Survey

At the time of the demonstration of progress, a functional version of the HTT system was complete. In order to get a consensus of opinion on the application's implementation at this stage, it was decided that an online demonstration survey could be distributed to better understand the response of potential users to the application that had been designed. Users were given a briefing about the project's research question and rationale before being presented with a set of slides that explained the Mind Palace technique and the proposed solution in more detail. Finally, a video was played which showed the working application in action, being used to create and recall a list of musical instruments (Figure 6.1).

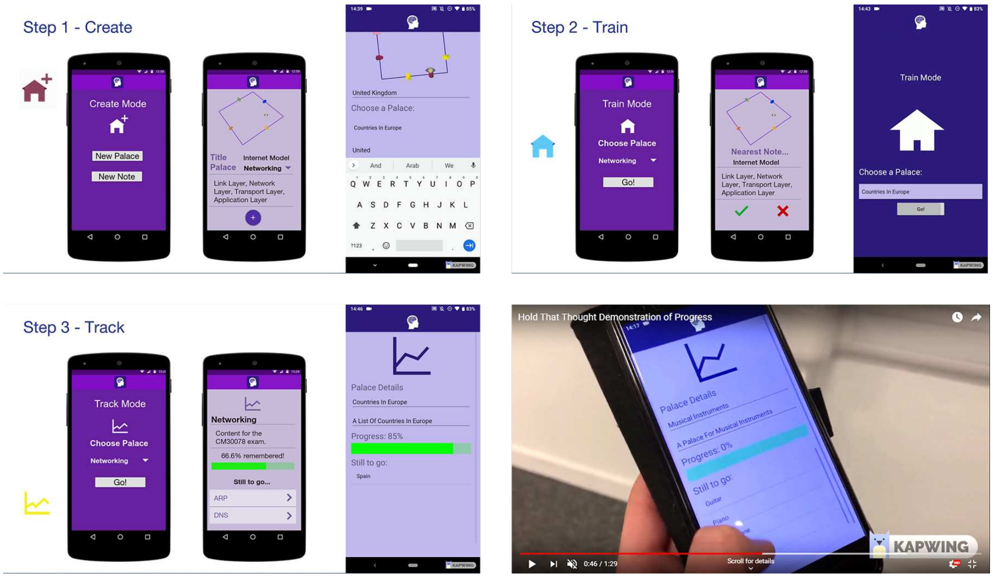


Figure 6.1: Slides and video presented to users to explain the application.

From the 24 responses gathered, a series of outcomes can be drawn about what users did and did not like, as well as their suggestions for improvement. (Full results can be found in Appendix G.1).

Positive Feedback

Most users were impressed by the project's novelty and uniqueness as a means of bringing the Method of Loci technique to life in an interactive and engaging style by tracking a user's location. Users especially commented on the application's clean and minimalist design and ability to encourage the user to explore their physical surroundings with real-time feedback on their detected location. It was said that the application was 'intuitive' if a user was already familiar with the Method of Loci technique. Tracking progress was a particular feature that gained a positive reception as users expressed that they wished to see some way of knowing if the technique was effective and allow frequent testing and reflection on which items needed more focus in order to remember them. Users also complimented the separation of menus to divide system functionality and the ability to associate each note with an image. In support of the research of Rosello [2017] into the effectiveness of using the same physical location to store different sets of information, users also appreciated the ability to create several palaces in the same place.

Alongside the praise that HTT received from users after the slides and demonstration video, there were some crucial comments and suggestions made to improve the application.

Constructive Feedback

A very common constructive point regarded the method of adding images to notes - requiring a URL instead of supporting native upload within the application caused controversy. Multiple users believed the copying and pasting of a URL was too cumbersome and complex, as it meant users needed to navigate away from the application in order to find a suitable URL before returning to the application to paste it into the appropriate box. This comment was certainly fair and was considered high priority as a way of making the HTT application more usable. This was therefore taken forward and the process of adding an image to notes was simplified.

Users did spot that the MoL technique has some limitations, as it does rely on users being able to visualise information which is difficult for content such as deep theoretical knowledge. That said, as discovered in Chapter 2, this is what makes the technique so powerful. When one has encoded an item in this way, they will have processed it deeply and therefore it will be more memorable. This initial difficulty to encode items is an inherent part of the technique which makes it challenging and could explain why many users are not sure at first if the technique could work for them. One user remarked that in order to remedy the problem of a lack of availability of a suitable physical space to a user, a VR mode could be added to minimise movement. Whilst this is a novel idea, it is beyond the project's remit as HTT seeks to investigate the use of physical spaces as palaces, much like *NeverMind, HoloMoL* and *Loci Spheres* [Yamada et al., 2017*a*,*b*, Rosello et al., 2016, Rosello, 2017, Wieland et al., 2017]. Recall, physical palaces were chosen over virtual ones in the first place based on the concerns that exploring a virtual environment does not activate the hippocampus as effectively as physical navigation of a space and hence is not as effective in episodic memory formation [Taube et al., 2013].

Corroborating requirement F2.9, one user suggested adding support for customisation of the bird's-eye map by allowing users to add virtual objects such as tables or desks to replicate the physical layout of the room. This could allow for deeper processing of the physical space chosen as a palace by coordinating the digital representation of the space with the real location. One could certainly investigate this as a viable optimisation of the HTT system, but for now, it is too time-consuming a modification to entertain before experiments take place. If resources such as time to complete the project were not finite, this would be an interesting avenue to explore. A single user also suggested that users could be able to share palaces. Whilst it is a potential 'nice' feature, this is something outlined in requirement F2.10 as being beyond the remit of the project.

Some comments were made about the flexibility of size and shape of rooms that can be used as palaces with this current approach. It is indeed a valid limitation of the system. If a room is of an unconventional size or shape such that there are not enough beacons to cover the area or signals are occluded, then the current implementation is not effective. Also, the use of a fixed sensitivity radius and fixed size room does indeed limit the number of notes that can be stored in a palace under the current implementation. This is not a concern for the purpose of planned experiments with the HTT system as a large-enough room will be available for these, but it is definitely a consideration to make the application more flexible in the future and less restricted by the dimensions of the physical space.

From a general usability perspective, users would also appreciate a clearer labelling of system and menu icon functionality, perhaps including a step-by-step breakdown of the tasks involved in adding and retrieving notes. This is a point of feedback that will be treated as high priority due to its criticality - participants in the experiment need to be able to use the HTT application confidently without having their performance hampered by an interface that is difficult to use or understand.

Fortunately, despite the constructive criticism received it does appear that as a result of the demonstration, 91.7% of respondents would be open to the idea of trying out the application in their own time if experiments showed a benefit in using it over the traditional MoL technique and/or other memorisation practices (Figure 6.2). This is strong evidence that the target user group are open to embracing technology as a potential solution to assisting them in memorising information should it prove effective at doing so. Users commented that they would find the application especially helpful during studying, especially as their phone was something easily-accessible to them.

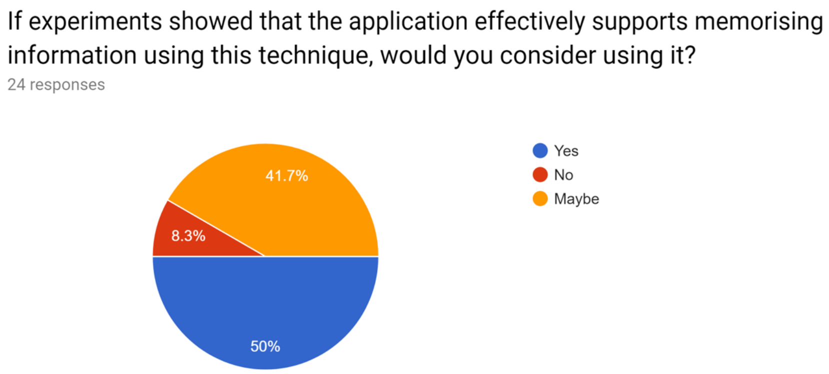


Figure 6.2: Demo Survey: If experiments showed that the application effectively supports memorising information using this technique, would you consider using it?

The demonstration survey stage of the evaluation was certainly a good way of obtaining a wider consensus view of the application's implementation but critically this was not sufficient to spot all usability issues in the application itself. As such, a more controlled and detailed approach was needed. It was decided that a Think Aloud study would permit this.

6.2.2 Think Aloud (TA) Protocol Study

The second stage of usability evaluation involved 5 participants who volunteered to test the HTT application for usability issues via a Think Aloud study (Figure 6.3).

Figure 6.3: Usability study: 5 participants complete 9 tasks using the HTT application.

With this approach, after a demonstration, a user is given a set of tasks to perform using the system with some level of probing used if assistance is required from the researcher [Preece et al., 2015]. Olmsted-Hawala et al. [2010] compared 3 different levels of probing in the Think Aloud protocol for effectiveness:

- **Levels 1 and 2** - Minimal probing during tasks (e.g. "okay", "what next?" or "keep talking").
- **Level 3** - Detailed probing (e.g. "why did you click there?")

Their experiments concluded that more detailed (level 3) probing (called "*coaching*") led to more positive reviews of the product being evaluated than levels 1 and 2. On the face of it, this sounds a positive outcome, but actually, this result means that the probing distracts users more from following the steps they otherwise would, influencing their thought processes and masking potential usability issues that would otherwise be uncovered by levels 1 and 2 probing. For this reason, level 1 and 2 probing was adopted during the study.

This stage exposed more 'small-grained' design issues than the demonstration feedback survey above was able to raise because each user could access the application at their own pace and see more of its functionality. Initially, the 5 volunteers provided their consent to participate via an online form (Appendix G.2). Once this was complete, a room on the University of Bath campus (1 West 2.101) was used to conduct a controlled usability study. Each participant had an individual 20-minute slot to observe a 5-minute demonstration before performing nine short tasks in their own time, whilst simultaneously explaining their thought processes in a "think aloud" fashion. Participants were briefed about the purpose of the study (Appendix G.3) before being presented the same demonstration and being given the chance to ask questions if they were unsure on any part of the application before starting the study. To ensure validity, participants were disallowed from entering the room before the previous participant had finished, and no communication could take place between participants between each run of the study. After completing the 9 tasks, participants were debriefed and asked if they had any further questions or comments on the application, usability-related or otherwise (Appendix G.6).

W. Turner et al. [2006] state that approximately 5 participants is optimal for finding around 80%[1] of usability issues with a system under scrutiny. The first participant is able to find around one-third of usability issues before the second raises some repeated ones as well as a few more. Then, the third, fourth and fifth find similar problems but may find new issues with less frequency [Lewis, 2006, Alroobaea and Mayhew, 2014]. This was certainly the case during the study involving the HTT application as even with 5 participants, consistency in responses and suggested improvements could be observed.

Summary and Outcomes

The Think Aloud study was very successful in the sense that users could complete many tasks with little or no prompting after being shown how to use the application, whilst also raising some crucial constructive feedback and highlighting usability issues that the survey simply could not. In general, the constructive feedback received was all feasible to implement and in some cases matched the comments made on the demonstration survey. Users were asked to sign up, sign in, create a palace, fill it with a few notes, retrieve these notes and track their progress before deleting the palace and their account (Appendix G.4).

Fortunately, many tasks required no prompting at all for any participant when asked to perform them after witnessing the demonstration (e.g TA1, TA2, TA3, TA7, TA8 and TA9[2]). These tasks included signing up, signing in, creating and deleting a palace. With each of these tasks, users commented on their ease and simplicity so there were no resulting changes to the implementation that were required. On the other hand, the Think Aloud study also raised some important usability issues during the below tasks:

- **TA1: Sign Up** - P3 commented on making the function of each of the 4 icons on the main menu clearer, which backs up the comments on the use of labelling in the application made in the above survey. As such, this will be addressed to ensure participants of the experiment do not get confused over their function.
- **TA4: Create Note** - On completing this task, P3 commented that an information screen would have been helpful to give a step-by-step breakdown on how to add a note in case a user was to get stuck performing each of the sub-steps, especially as this task is the most complex of all system components. P3 said the task was “very intuitive once you know how to do it at first”. P4 also originally selected the wrong submenu for this task. The labelling and instructions idea was also raised in the demonstration survey so these will both be addressed as an issue with high priority. P5 also asked if there was a need to press the Check Image button every time. This will be removed to avoid confusion and the image will load automatically when selected. Image selection will be simplified as a result of this task’s feedback and the responses to the demonstration survey. The current use of a textbox to copy and paste URLs and a Check Image button is too confusing (bottom right, Figure 6.4).

[1] `https://www.nngroup.com/articles/how-many-test-users/`
[2] Detailed in Appendix G.4.

- **TA5: Track Progress (Before Training)** - P1 selected the wrong submenu initially, which will be resolved by clearer labelling.

- **TA6: Train using Palace (Retrieve Notes)** - P2, P3 and P4 all struggled when the screen first loaded as the Check button was out of sight and the text fields looked as though they needed text entry but weren't focusable or editable (left, Figure 6.4). This caused a long pause in the task with these participants before they finally scrolled to the Check button and resumed the task successfully. Making the Check button clearer and only displaying the tick and cross buttons when a note is loaded was an improvement suggested by P3 and P4. P2 also commented that the error message displayed when a note was checked for but out of range (bottom right, Figure 6.5) was too confusing and didn't diagnose the error clearly enough. As a result, this error message will be changed with high priority.

- **TA6: Track Progress (After Session)** - P4 wished to have a number of items remembered (e.g. 4 out of 5) instead of just a progress bar. Also, when marking all notes as remembered, they commented that the 'Still to go' list should not be displayed with an empty list (top right, Figure 6.4), but that the message should change to reflect the fact that all notes have been remembered. This will be implemented to avoid confusion.

- **Additional Comments** - P2 reiterated the need to change the ambiguous fields and button placement on the screen when retrieving notes. They also suggested the ability to add objects to the bird's-eye map. Whilst this would be a novel extension to the application, it is not of high priority to implement this before the experiment stage as it does not make the application less usable. P4 and P5 also expressed interest in an integrated web browser to simplify the process of image selection when creating a note. This was implemented in order to address this feedback and similar comments made about the complexity of using URLs from the demonstration survey above. Finally, both P4 and P5 wished to have a back button added to each submenu and functionality screen instead of relying on the inbuilt Android back button. As this is a simple and quick change, it was also implemented.

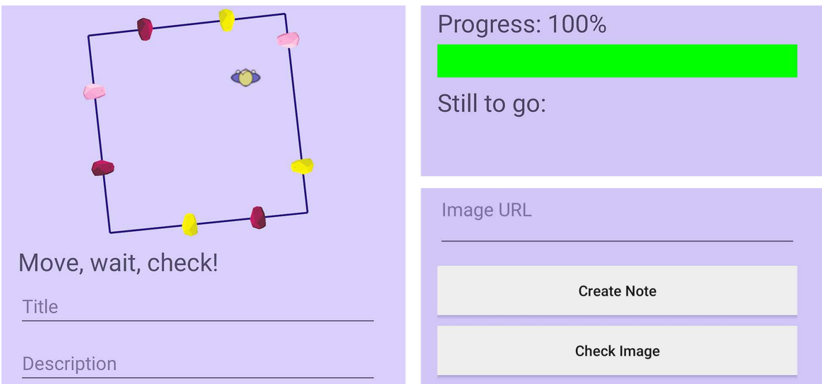


Figure 6.4: Usability study: Issues flagged during the study

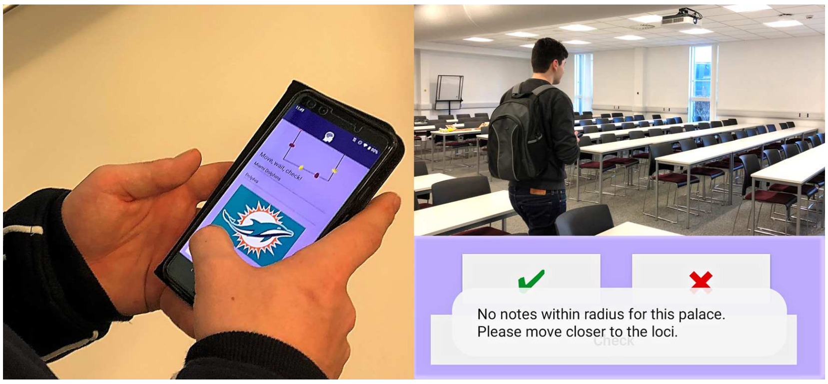


Figure 6.5: Usability study: A participant adding a note and then retrieving it.

Overall, this method of usability evaluation was successful in the sense that multiple users identified potential usability issues that might have otherwise prevented participants of the experiments from using the HTT application effectively which would adversely affect the empirical findings. Whilst it was challenging to provide suitable levels of probing during periods of silence where users could not see an obvious next step, it was useful to observe their natural thought processes instead of interrupting and asking them invasive questions such as "what is it about this function that isn't obvious?" until the task was over. The next stage will explore how the issues raised in the demonstration survey and the TA study were addressed in the system implementation.

6.2.3 Incorporating User Feedback

Based on the system demonstration survey and think-aloud protocol results above, a series of improvements were incorporated into the application to ensure the features tested above were more usable before the experiment stage. As many of the suggested improvements from both stages were implemented as possible, but a higher priority was given to tasks which prevented the participants of the Think Aloud study from performing their tasks effectively. Any suggested improvements that were still left unimplemented were considered either as low priority or not crucial enough to warrant the time they would require to implement. The main focus was on creating a usable application to the greatest extent whilst being able to dedicate time on planning experimental design for the next stage of the project. The implemented improvements to the application can be grouped into 2 categories: *Clarity of Functionality and System Status* and *Simplifying Note Creation and Retrieval*. (Screenshots of the application after these improvements can be seen in Appendix E.1).

Clarity of Functionality and System Status

A set of improvements were made which aimed to address usability issues related to ambiguity or lack of clarity in the application. These are subdivided into issues which do not make application functionality clear enough, as well as usability issues that do not inform the user about system status effectively. The below changes were made:

- **Icon Labelling:** The main menu is labelled to indicate the part of the application that each icon button leads to (left, Figure 6.6). This change resulted from the feedback from the demonstration survey and TA study.
- **Back Button:** Each 'non-landing' screen (i.e. all bar the sign in and main menu screens) is equipped with a back button in the toolbar, for use instead of relying on the native Android one. This change resulted from the feedback from the TA study.
- **Information dialogues:** Each 'non-landing' screen (i.e. all bar the sign in and main menu screens) is equipped with an info button in the toolbar, for when the user is unsure what the current screen is for or how to perform certain operations. This change resulted from the feedback from the demonstration survey and TA study.
- **Handling Edge Cases:** When a palace is empty (i.e. contains no notes) then the system now lets the user know before they consider selecting it in order to train or view their progress. Also, when a user has remembered all notes, the tracking screen shows a suitable message instead of an empty 'still to go' list as before (right, Figure 6.6). This change resulted from the feedback from the TA study.

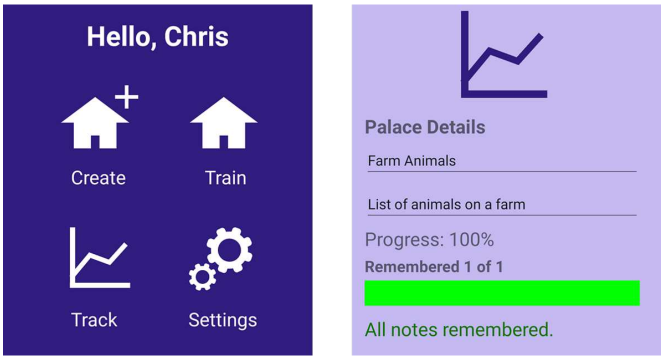


Figure 6.6: Usability study improvements: Making menus and system status clearer.

Simplifying Note Creation and Retrieval

Many respondents of the demonstration survey and the participants of the TA study understandably commented on the complexity of adding an image to a note using the application. Although participants of the TA study faced no major challenge in completing this task once they were shown how to do it, the task needed to be simplified to prevent a user navigating away from the application and needing to copy a URL which could potentially require a large amount of cognitive effort by the user instead of allowing them to focus on processing the item to be encoded (stored) using the application. Table 6.1 summarises the difference before and after changes to the implementation were made to simplify note creation.

Table 6.1: Original and simplified note creation.

Original Note Creation	Simplified Note Creation
1. Enter title and description. 2. Choose palace. 3. Leave the HTT application and navigate to DuckDuckGo. 4. Type in search term and select a suitable image. 5. Click ‘View File’ and copy the current URL. 6. Return to HTT and paste into the textbox. 7. (Optional) Click ‘Check Image’ to see if image loads correctly. 8. Click ‘Create Note’.	1. Enter title and description. 2. Choose palace. 3. Click ‘Choose Image’ and select suitable result from browser (search term auto-filled). 4. Click ‘View File’ and click ‘Select Image’. 5. Click ‘Create Note’.

As Figure 6.7 shows, a built-in web browser prevents the need to leave the HTT application when adding an image. The title of the note is used by default as a search parameter for the image search when the user clicks ‘Choose Image’ which in many cases will save users from typing the information out twice. An information dialogue is now available to the user should they struggle with remembering the required steps. On selecting an image, it is automatically loaded into the preview pane on the Create Note screen and hence the previous Check Image button has been removed.

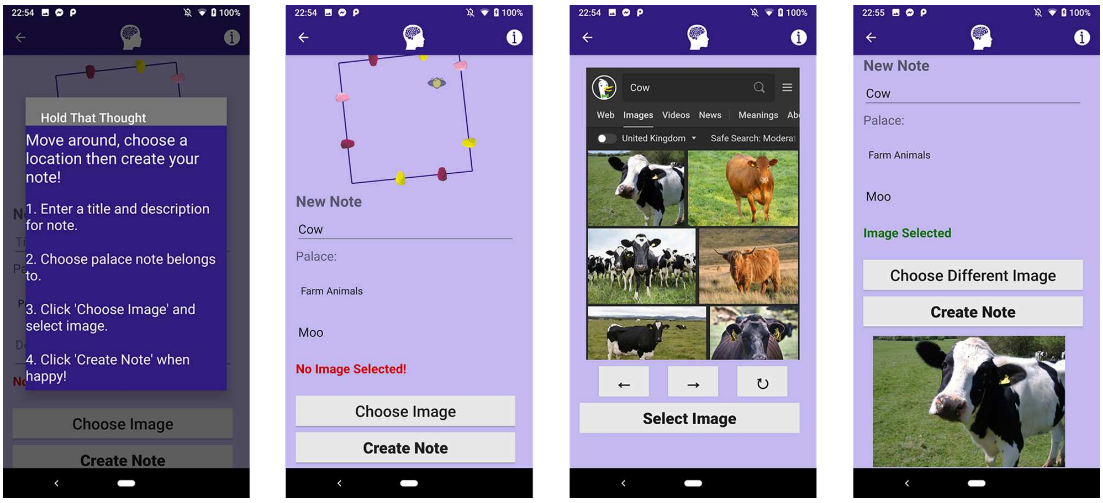


Figure 6.7: Usability study improvements: Integrating image search during note creation.

Figure 6.8 illustrates the improved note retrieval screen, changed in response to comments about:

- **Ambiguous non-editable fields:** These fields have been entirely replaced by labels which do not give the illusion that they can be edited.

- **Button overload:** The check button has been moved to the top of the screen and tick and cross buttons to record whether a note has been remembered are displayed only when a note is found.
- **Difficult error messages:** The complex error message flagged up in the TA study which used the word ‘loci’ has since been replaced by a clearer note telling users that no note exists at the location they are currently at.

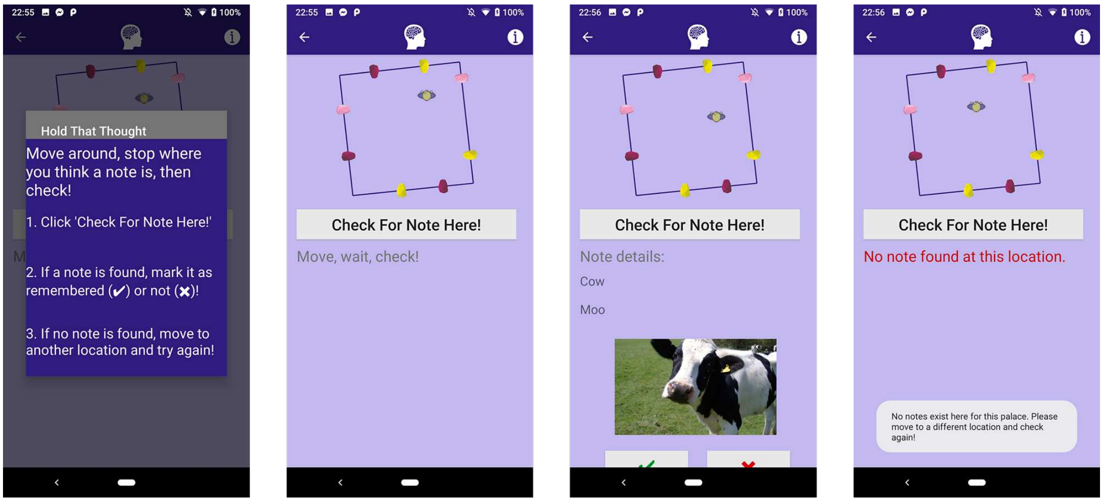


Figure 6.8: Usability study improvements: Friendlier note retrieval experience.

The simplifications to note creation and retrieval should make the processes less challenging and more intuitive to users, meaning they can focus their attention on remembering the items at hand.

6.2.4 Returning to Users

After improvements were implemented, the same group of 5 participants of the Think Aloud protocol study were asked to view the application for a second time in order to determine if they were satisfied with the changes that had been implemented in response to their initial feedback. Thankfully, all 5 participants were very satisfied with the changes that had been implemented. Admittedly, the favoured approach to re-evaluate HTT’s usability in light of new changes would be to run another full formal usability study with a new set of users to avoid any form of bias or training effect from the first TA study. However, due to time constraints, it was sufficient to simply consult the original users to see if they were satisfied.

As a second form of verification that usability issues had been addressed, a final video[3] (Figure 6.9) of the system in action was distributed amongst the same pool of participants as the original demonstration feedback survey (Section 6.2.1). Comments were positive on the whole, with many users being glad to see their suggested changes being

[3]Viewable here: `https://youtu.be/RwE5stBEOIA`.

implemented (e.g. inbuilt browser for image selection). On top of the positive feedback, it was also suggested that experimentation should take place which compares the use of a mobile-based approach such as HTT against an AR approach using a Head-Mounted-Display for practising the MoL technique in physical spaces. Another suggested possible extension would be to experiment with replacing Bluetooth beacons with GPS technology to enable users to roam over greater distances.

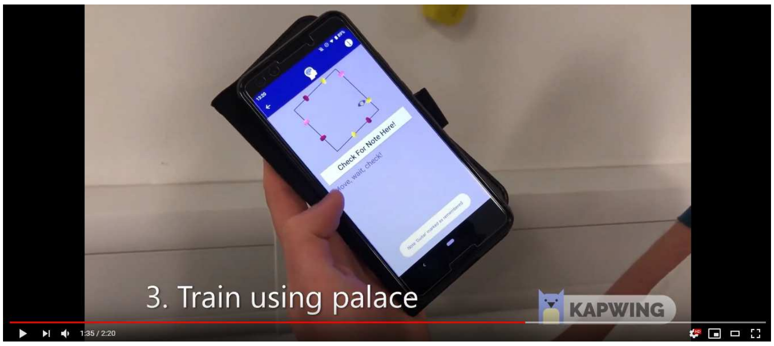


Figure 6.9: Final video presented to users after incorporating initial feedback.

This successful second check, combined with the approval of the same set of users from the TA study formed a ‘green-light’ to indicate that the HTT system was usable to an acceptable standard and the experimental testing phase could begin.

6.3 Experimental Testing

As demonstrated by the rich selection of literature explored in Chapter 2, experiments are central to the majority of cognitive psychology research on memory and the Method of Loci technique. Carrying out controlled experiments and observing the effects of changes in variables can assist us in investigating the validity of a well-defined hypothesis [Lazar, 2017]. As such, once a working implementation of the HTT system was implemented and evaluated for usability issues, it was important to evaluate it by means of a controlled experiment to observe the effects of its use.

6.3.1 Experiment Overview, Scope and Contributions

The experiment’s primary focus was to compare the efficacy of the HTT application against the traditional Mind Palace technique and assess perceptions of the mobile application as well as the cognitive effort required to use it compared to traditional techniques. The experiment was carried out in a controlled laboratory setting (as opposed to a field study) in order to reduce the influence of as many confounding variables as possible and keep the environment that the experiments were performed in as consistent as possible between participants [Shneiderman et al., 2016].

Recent existing systems which assist users with the MoL technique (e.g. *NeverMind* [Rosello, 2017] and *Loci Spheres* [Wieland et al., 2017]) measured the recall accuracy of participants directly after using the system, as well as 7 days after the original experiment in order to assess longer-term recall of information. As such, the experiment involving HTT was modelled on these investigations and adopted the same recall testing periods. That being said, there is no known existing experiment which *directly* compares a proposed system which supports the MoL technique in physical spaces against the *classical* technique itself, in addition to a control group. Rosello [2017] compares recall accuracies of participants using NeverMind against a simple paper-based task (control group), whilst Wieland et al. [2017] compares the recall accuracies of participants using the Loci Spheres application with 3 different designs in a form of A-B-C testing. Yamada et al. [2017*a*,*b*] also assessed the use of their HoloMoL system in a unique way - by observing user behaviour with the system and exploring how participants place items in the physical space. For this reason, the experiment described below involving HTT is the first known experiment with a system utilising physical spaces as mind palaces which assesses efficacy against the *traditional* technique, and the first of its kind to compare measures of cognitive workload between technology-based methods and traditional techniques.

In response to the experimental scoping and intended contributions described above, it was important to formalise a set of well-defined aims and research questions that can be answered by the findings of the experiment. These are as follows:

A.1 Measure the recall accuracies of participants using the HTT application against the traditional MoL technique and a control group instructed to use no technique or technology in particular.

A.2 Compare the cognitive workload of users performing a typical memorisation task with the HTT application against the traditional MoL technique and a control group.

A.3 Understand how enjoyability and difficulty measures vary between the 3 methods of memorisation.

A.4 Obtain feedback from participants about their opinions of the HTT application and its usability.

The following research questions were decided upon in order to articulate the above experiment aims:

R.1 How does recall accuracy compare over short and extended periods of time after 1 practice session with the HTT application compared to the traditional MoL technique and a control group?

R.2 What effect does practising using the HTT application have on cognitive load compared to the traditional MoL technique and a control group?

R.3 What effect does use of the HTT application have on enjoyment and difficulty ratings of participants compared to the traditional MoL technique and a control group?

R.4 How will participants rate the usability of the HTT system for memorising information?

6.3.2 Ethics

As the experiment being conducted relied on the participation of humans, careful consideration of research ethics was required. Appendix I contains a comprehensive set of answers to the 13-point Ethics check-list created by Dr Leon Watts of the Department of Computer Science at the University of Bath.

6.3.3 Methodology and Design

Between-groups design

The experiment adopted a between-groups design whereby 3 groups represented the 3 different methods of memorisation under scrutiny described in Table 6.2. As well as comparing the HTT application against the traditional MoL technique, it was important to factor in the performance of a control group where no specified technique or technology was used. This enabled the efficacy of the MoL technique to be more closely and aptly compared with the use of the HTT application. A between-groups design was adopted in order to ensure all participants were exposed to the same content when memorising words, and for obvious reasons, a single participant could not use more than one of the methods in Table 6.2 on the same list of words as they would experience an order bias. As such, to avoid order bias and potential training effect issues inherent of a within-groups study, every participant only used one of the 3 methods outlined in the table.

Table 6.2: Breakdown of participant groups in the main experiment ($N = 30$).

Group	Participants	Description
HTT	10	Participants using the HTT mobile application.
MoL	10	Participants practising the traditional MoL technique.
Control	10	Participants using any technique of their choice (no instructed technique).

Participant demographic and selection

The 30 participants (26 male, 4 female, median age 22-24) were all students of either the University of Bath (28) or University of Southampton (2) across the degree subjects of Computer Science (25), Mathematics (1), Physics (1), Engineering (1), Accounting and Finance (1) and Business Management (1). The choice of $N = 30$ was to enable participants to fill 3 groups of size 10. This was in order to compare the group using the HTT application against the group practising the traditional MoL technique and in turn against a control group with no instructed technique or technological assistance.

Participants were all aged 18 years or above to ensure they could provide consent. A copy of the participant consent form can be seen in Appendix J.1. Ideally, participants from a range of age groups would participate to enable results to hold external validity across age groups, but the selection pool available for this project was limited to current university students. However, this is not a catastrophic limitation of the study as the HTT application in its current guise seeks to assist users who are likely to rely on memorisation techniques to study for examinations. Further research might look into the effects of using the HTT application across different age groups.

Each participant was randomly assigned to one of the 3 groups described in Table 6.2 using a Microsoft Excel spreadsheet to avoid bias in assignment to each of the groups and reduce the chance of participants volunteering themselves for a group which they preferred, which might affect later enjoyment and difficulty ratings.

Measuring cognitive workload - NASA TLX Index

In order to investigate R.2, a measure or quantity is required in order to indicate cognitive workload before and after the memorisation task. The NASA Task-Load Index (TLX) is an empirically-tested measure by which one can assess an individual's cognitive workload at a given moment in time, broken down into 6 categories as specified in Hart [2006]:

- **Mental Demand**: How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex?
- **Physical Demand**: How much physical activity was required? Was the task easy or demanding, slack or strenuous?
- **Temporal Demand**: How much time pressure did you feel due to the pace at which the tasks or task elements occurred? Was the pace slow or rapid?
- **Performance**: How successful were you in performing the task? How satisfied were you with your performance?
- **Effort**: How hard did you have to work (mentally and physically) to accomplish your level of performance?
- **Frustration**: How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?

As mentioned in Chapter 2, lab studies investigating the traditional MoL technique have reported a high initial cognitive demand when items are encoded using the method [Bower, 1970, Kemp et al., 1985]. However, the effect of using technology to support the MoL technique on cognitive workload has not been reported in studies thus far. As such, the NASA TLX scale forms a well-grounded metric by which to answer this research question. Whilst traditionally the scores of each of the 6 scales are weighted to form a total TLX score based on the perceived importance of each factor by the researcher, Hart [2006] recommends using the "raw" TLX scores instead, which encompasses all 6 factors of cognitive workload in equal measure to produce a non-weighted TLX value. In the experiment with HTT, raw TLX scores were measured before and after the memorisation task in order to ascertain the shift in workload caused by the memorisation task and account for individual differences in benchmark TLX scores before the task has begun (Figure 6.10). The meaning of each of the 6 factors was explained to each of the 30 participants before they filled out each scale. See Appendix

J.3 for the TLX sheet handed to participants.

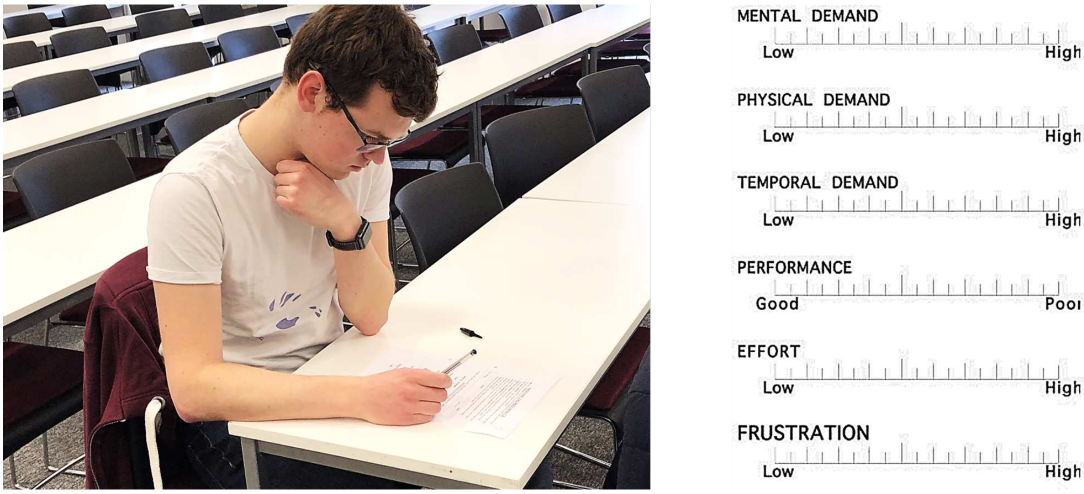


Figure 6.10: NASA TLX: A participant (left) fills in each of the ratings on the TLX sheet (right) before and after the memorisation task.

Measuring enjoyment, difficulty and usability - Experience survey

In order to investigate R.3 and R.4, a set of measures or quantities is required in order to indicate enjoyment, difficulty and usability. The Likert scale is a widely-adopted and empirically-tested technique for rating agreement with a given statement along a 5-point scale [Cairns, 2019]. The System Usability Scale (SUS) is another widely-adopted technique that uses the Likert scale as a way of responding to 10 statements about the usability of a system with a score of 1 representing ‘Strongly Disagree’ and 5 representing ‘Strongly Agree’. It is often referred to as a “quick and dirty” metric for assessing the usability of a system [Brooke, 2013]. Statements are positive or negative, arranged in an alternating fashion. From the Likert ratings of these 10 statements, a score can be calculated which acts as an indicator for system usability.

After the experiment was completed, an online survey included questions which captured participants’ experience and opinions of the memorisation task. All 30 participants indicated the difficulty and enjoyability of the memorisation task according to a 5 point Likert scale. Then, the 10 participants of the HTT group in particular also filled out 10 Likert ratings to give the application a SUS score. See Appendix J.9 and J.10 for the 2 different experience surveys completed by participants of the HTT and MoL or Control groups respectively.

Providing careful distraction - Victoria Stroop Task

The Stroop task was created by Stroop [1935] to investigate interference in reaction times and it is still adopted in many psychology experiments to this day [Mitrushina et al., 1999]. The task involves identifying the colour of a shape or word on a display. The effect noticed by Stroop was that when a word is displayed in a different colour from the one it represents (e.g. "red" displayed in yellow text), the reaction times are slower than when there is a match between text colour and what the word represents. A Victoria Stroop task (Figure 6.11) is a minor modification of this task, which displays 3 cards to participants in the following order for them to identify the colour of each item in turn:

1. Coloured dots (blue, green, red, yellow)
2. General words (blue, green, red, yellow)
3. Colour words (displayed in a *non-corresponding* colour)

Whilst this may seem unrelated to memory, it serves as an effective cognitive distraction from the memorisation task as it requires the careful attention of the participant to complete. By completing this task, participants' minds are temporarily distracted from the words to be remembered. As such, after the memorisation task was complete, a Victoria Stroop task was carried out on all 30 participants using PEBL[4]. This enabled a gap between encoding and recall, which prevented participants from committing all words from the memorisation into working memory and then repeating these when tested.

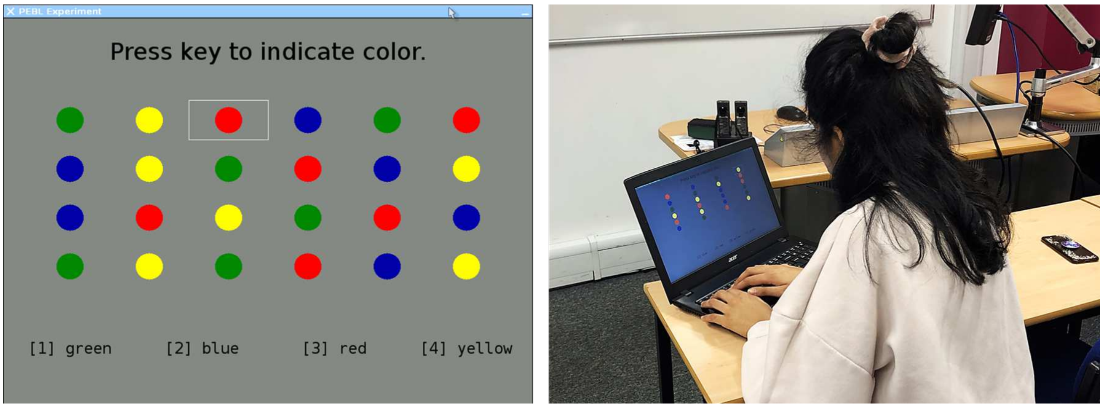


Figure 6.11: The Victoria Stroop task, viewed within PEBL (left), completed by a participant (right).

Testing for Recall

In order to investigate R.1, a method was required in order to indicate % recall accuracy. After the memorisation task was complete, the post-task TLX score had been gathered and the Victoria Stroop task had been carried out, an online word recall form was given to all participants (Appendix J.8), for them to take as long as they required (within reason) to freely-recall and type out as many of the 10 words from the memorisation task as they could remember (in any order). A list of 10 words was chosen as this is the number used in experiments with the NeverMind system [Rosello, 2017] and the maximum feasible number of notes in a room of 1 West 2.101's size in order to create a meaningful route between them and navigate in a reasonable time. The accuracy was

[4]Psychology Experiment Building Language: `http://pebl.sourceforge.net/`

manually computed as a percentage by comparing the participant's guesses to the list of words.

Each participant was told that they could not have their data contribute towards the study unless they completed a "survey" that would be emailed to them 1 week after completion of the original experiment. At that point, they were not given detail on what the "survey" would be. In fact, it was the same word recall form, which was emailed 1 week later and gave participants the chance to spend as long as they required to recall as many words as they could remember (in any order). In this way, recall data could be collected after 5 minutes and 7 days as in other experiments with systems technologies the MoL technique [Rosello, 2017, Wieland et al., 2017].

Independent Variables

- Method of Memorisation - HTT, MoL and Control.

Dependent Variables

- Raw TLX Score (before and after memorisation task)
- Recall Accuracy (after 5 minutes and 7 days).
- Enjoyment - Likert scale (1-5).
- Difficulty - Likert scale (1-5).
- System Usability Scale (SUS) Score - **HTT only**.

Realism versus control - Environmental set-up

The nature of running such a tightly-controlled laboratory study is that there is a certain loss of realism in experimental conditions [Lazar, 2017]. As discussed in Section 4.6, it would be ideal to give participants of the experiment the flexibility to set the BLE beacons up in a physical space of their choice and practice the Mind Palace technique (e.g. in their homes) to observe the application's efficacy. This would be interesting to run as a potential field study in the future, but for the purposes of evaluating the HTT application's effectiveness, there would be too many confounding variables which would not be controlled and hence could mediate the results. For example, the range of room sizes and layout may affect beacon sensitivity by differing amounts and hence cause a discrepancy in the accuracy of the location tracking feature. As such, 1W 2.101 on University of Bath's campus was used for experimentation with the 10 participants of the HTT group (Figure 6.12). However, this is not a large loss of experimental validity as the environment chosen for a palace does not need to be totally familiar to the subject for improvements in recall to be observed [Crovitz, 1971].

Another point of flexibility in the technique is that in general, an individual can choose how and where in the palace to encode the information to be remembered, as well as what order these items can appear. For the purposes of this experiment (in order to keep the timing equal across all 3 groups), participants of the HTT group navigated the room in a pre-defined order (Figure 6.12) to retrieve notes that had already been created. Otherwise, if participants created the content using the application as well as retrieving it, they would require more time than the MoL and Control groups. This is another clear trade-off between flexibility (realism) and experimental control (consistent timings between groups). By creating the content and retrieving it, HTT participants would process the items to be remembered at a deeper level and hence would be more likely to remember it than if they had just retrieved the item created by someone else [Craik and Lockhart, 1972]. (See Appendix J.11 for the instruction sheet used in the experiment with the HTT group). However, this loss of realism for the sake of control is ameliorated by the findings of existing experiments - Perrault et al. [2015] observed that participants of their experiment did not have to create the content themselves to show enhanced recall. It is for this reason that the experiment involving the HTT application used pre-created notes and instructed participants to retrieve these by following a pre-determined path to navigate the physical space.

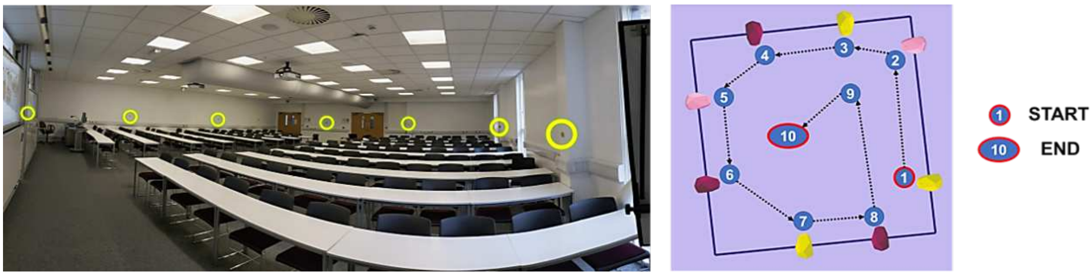


Figure 6.12: HTT Experimental Setup: Beacon placement in 1W 2.101 (left) and route between notes (right).

Even in a laboratory environment, the technique can only be controlled to a certain extent. Whilst the total time spent navigating the environment can be controlled, the *time spent per locus* cannot. In other words, the time spent at each point in the palace (room) which contains a note. This is a necessary trade-off that needs to be made in order to allow users to practice the technique at their own pace.

6.3.4 Threats to Validity

When designing the experiment, it was important to consider a range of threats to validity that, if not addressed, could reduce the internal and external validity of the experiment. Threats are mostly reduced by controlling confounding variables [Lazar, 2017], but consideration of issues such as fatigue, ambiguity, social desirability bias, selection bias and participant communication was required.

Confounding Variables

As the experiment took place in a laboratory environment, a series of variables remained under control in order to ensure participants experienced the same task and no unfair advantage was presented to any particular person.

- **Number of words:** For all 3 groups, there were exactly 10 words to be remembered.
- **List of words:** The same list of 10 words was used for all 3 groups (*flame, museum, tongue, rumour, trust, muck, pause, cave, thirst, bike*).
- **Order of words:** The same word order was used for all 3 groups.
- **Word imageability:** Imageability is the level of difficulty associated with associating a given word with a form of mental imagery [Paivio et al., 1968]. The list of words contained 5 high imageability and 5 low imageability words from the experiment of Kroneisen and Makerud [2017] to ensure the list contained an equal number of each type of word. These words were randomly generated from a Microsoft Excel spreadsheet.
- **Encoding time allowance:** Participants of all 3 groups were given 6 minutes to memorise the list using their assigned technique or technology.
- **Recall test gap (5 mins):** Participants of all 3 groups had to perform the Victoria Stroop task and fill out a NASA TLX sheet before being tested for recall for the first time.
- **Recall test gap (1 week):** Participants of all 3 groups were given a 1-week gap before being tested for recall on the words from the experiment for a second time.
- **Android device (HTT only):** Participants in the HTT group all used the same device (Google Pixel 3) to perform experiments to mitigate for potential time discrepancies due to using differently-sized devices or devices with better specifications (able to run the application more smoothly).
- **Laptop device:** Participants of all 3 groups all used the same laptop device (Acer Aspire E 15) to perform the Victoria Stroop task and fill in surveys to mitigate for potential time discrepancies due to using laptop devices with better specifications (able to run the application more smoothly).
- **Briefing and de-briefing:** All participants across each of the 3 groups were given the same briefing and de-briefing scripts before and after the experiment.
- **Instruction sheet (per group):** All participants within a given group were given the same instruction sheet to remember words.
- **Stopwatch:** The same stopwatch was used to record the timings in the memorisation tasks across all 3 groups.
- **Demonstration and examples:** All participants within the HTT group were given the same demonstration of the application. All participants of the MoL group were given the same toy examples to explain the technique. All participants of the control group were given no example of a technique.
- **Experiment location (HTT only):** All participants within the HTT group used the application in the same room (1 West 2.101 at University of Bath).
- **Note placement (HTT only):** All participants within the HTT group had items stored in the same places in the room and all followed the same route to retrieve all 10 items.

Fatigue

The experiment required mental attention and effort at all times for a 10 to 15 minute period, lasting approximately half of the allocated time for the experiment. Participants were told at the start that they may take a break at any time during the experiment, but not between the start of the memorisation task and the test for recall, as this time must be kept as constant as possible without allowing any discrepancies in different time gaps between encoding and recall.

Ambiguity of Instructions

To ensure each participant was given an equal amount of information before attempting each task and mitigate the chance of any unfair advantages, each group had its own instruction script (see Appendix J.4, J.5 and J.6). Before each task was attempted, participants were asked whether they have any questions or comments on what was being asked of them to put their mind at ease and clarify any ambiguities. In the Pilot Study (section 6.3.7), these scripts were used and refined to ensure participants understood the tasks with minimal ambiguity or misunderstanding.

Social-Desirability Bias

This issue is related to participants expressing opinions influenced by what they believe to be the 'social norm' to be, instead of providing honest answers. This was a potential threat to validity in the post-study survey, which is why all responses to the survey were made anonymous and it was reiterated to participants that their honesty was the most valuable asset, even if this included constructive criticism of the project or study itself.

Selection and Self-Selection Bias

Whilst the participant selection pool was limited to students of the University of Bath and University of Southampton, no bias influenced who was selected for the experiment. An advertisement of the study was sent via email to a wide pool of students from a variety of subjects and cohorts and participants were recruited on a first-come-first-served basis by selecting an appropriate time slot on a Doodle Calendar. No extrinsic (e.g. monetary) motivation was offered to participants to take part in the experiment, so all 30 participants were intrinsically-motivated to complete the tasks. Participants were not made aware of which group they would be allocated to prior to the experiment session, so the experiment did not suffer from self-selection bias towards a favoured method of memorisation.

Participant Communication

As participants were tested on their recall of a specific list of words, they were asked not to communicate with any other participant of the experiment to reduce the influence on results. Each experiment was carried out on a 1-to-1 basis - the researcher and participant were the only ones present in the room at a time. By not overlapping experiments with each other, this provided maximum control over the environment and especially communication whilst the participant was present in the room. A potential weakness in the online recall test after 7 days was the fact that participants could no longer be controlled once they had left the room. Results of individual participants' performance were made available on request after all participants had completed the experiment, including both recall tests after 5 minutes and 7 days.

6.3.5 Procedure

In this section, we will outline the general procedure followed by all 3 groups: HTT, MoL and Control. To avoid needless repetition, the common procedure will be described, until it branches at the point of the memorisation task before rejoining until the experiment's completion. In other words, the experimental procedure was as consistent as possible between groups, with the only difference being how memorisation was performed. (For full instruction sheets used with the HTT, MoL and Control groups, see Appendix J.4, J.5 and J.6 respectively).

The experiment was conducted over the course of 1 week, with another week allocated to collecting 7-day responses to the word recall form. Every participant had a unique slot so that no two experiments overlapped.

1. **Briefing**: Before the experiment began, all participants signed a consent form (Appendix J.1) whilst being briefed on the purpose and design of the experiment (Appendix J.2).

2. **Pre-Task TLX Rating**: An initial NASA TLX sheet was filled out (Appendix J.3) to provide a benchmark score representing their cognitive workload before the memorisation task. They were asked: *"In this current moment, how do you feel?"*. Any comments or questions were encouraged, to help participants understand the purpose and meaning of the ratings.

3. **Memorisation Task**: Participants were given 6 minutes to memorise 10 unrelated low and high imageability words (*flame, museum, tongue, rumour, trust, muck, pause, cave, thirst, bike*) selected at random from the set used in the experiment of Kroneisen and Makerud [2017] (Figure 6.13). Table 6.3 shows the difference between how the memorisation task was carried out between the 3 groups.

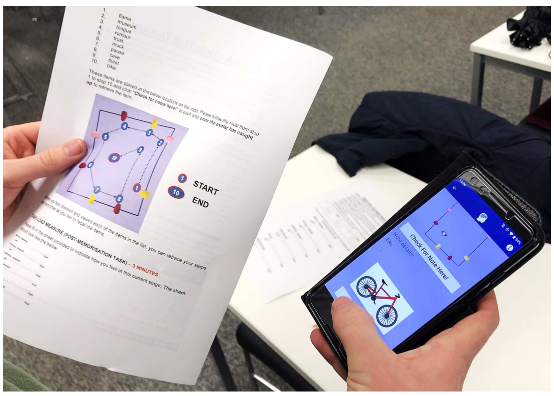


Figure 6.13: A participant uses the HTT application to retrieve the word "Bike".

Table 6.3: Difference in the memorisation task across each of the 3 groups.

Group	Task Description
HTT	A description of the task and demonstration of the application retrieving notes was carried out using dummy data (a shopping list with items *Apple* and *Banana*). Participants were asked if they had questions before being handed the Google Pixel 3 phone and instruction sheet containing the list of words and numbered map with the route to follow. A 6-minute timer was set to allow participants time to navigate the 10 stops on the pre-determined route, retrieve all notes and commit these to memory. Participants were told to follow the route in order, but that they could follow any route after visiting all stops if they had time remaining and wished to revisit a stop. Participants were also told that they could finish in less than 6 minutes if they were comfortable doing so.
MoL	A description of the task and explanation of the MoL technique was given using a toy example (a shopping list with items *Apple* and *Banana*). Participants were asked if they had questions and told they could not use any external artefacts such as a phone or a pen to help them with the technique before being handed the instruction sheet with the list of words. A 6-minute timer was set to allow participants time to create a mental palace, visualise items at distinct places and mentally-navigate their palace to commit these to memory. Participants were told that they could follow the route in any order and that they could finish in less than 6 minutes if they were comfortable doing so.
Control	A description of the task was given with no specific technology or technique instructed. Participants were asked if they had questions and told they could not use any external artefacts such as a phone or a pen to help them before being handed the instruction sheet with the list of words. A 6-minute timer was set to allow participants time to commit these to memory. Participants were told that they could memorise the words in any order and that they could finish in less than 6 minutes if they were comfortable doing so.

After the 6 minutes were complete, the list of words (and mobile phone in the case of the HTT group) was confiscated.

4. **Post-Task TLX Rating**: A second NASA TLX sheet was filled out (Appendix J.3) to provide a post-task score representing their cognitive workload after the memorisation task. They were asked: *"In this current moment, how do you feel?"*. Any comments or questions were again encouraged, though all participants were comfortable filling this out for a second time.

5. **Victoria Stroop Task (VST)**: Participants carried out the VST using the PEBL software on the laptop provided. They were asked to complete the task as quickly and accurately as possible, under the guise that this was another part of the experiment where performance was assessed. No time limit was imposed.

6. **Word Recall (5 mins)**: The word recall form (Appendix J.8) was filled out by participants, with no time limit imposed on the task.

7. **Post-Study Experience Survey**: The experience survey (Appendices J.9 and J.10) was filled out by participants according to the group they were in, with no time limit imposed on the task. This survey included HTT participants rating the application according to the SUS described previously. All groups also rated the memorisation task for its enjoyability and difficulty. Qualitative data was also gathered, which included asking participants of the MoL and Control groups how they approached the memorisation task, to verify the techniques used.

8. **De-briefing**: All participants were debriefed after completing all tasks using a script (Appendix J.7). This included asking participants to ensure they completed a "follow-up survey" which would be sent out 1 week after their slot.

9. **Word Recall (7 days)**: After 1 week, participants were emailed a link to the identical word recall form (Appendix J.8) to test their recall of the words from the memorisation task.

6.3.6 Hypotheses

After discussing the experimental design and research questions, it is important to present the formulated experimental hypotheses which predicted the outcome of the experiment and attempted to answer the research questions introduced in Section 6.3.1.

Experimental Hypotheses

EH.1 Participants' recall accuracy % after 5 minutes and 7 days will be lower for the Control group than participants of the HTT and MoL groups.

EH.2 Participants of the HTT group will experience less of an increase TLX Score than participants of the MoL and Control groups respectively.

EH.3 Participants using the HTT application will find the memorisation task more enjoyable and less difficult than the MoL and Control groups respectively.

EH.4 Participants using the HTT application will find the application usable to a good standard (Mean SUS Score of greater than 68).

EH.1 was predicted because by examining the findings of experiments with existing systems supporting the MoL technique (e.g. Rosello [2017]), there is little or no difference in recall accuracies between the system and control group after 5 minutes and a significant difference after 7 days. EH.2 predicted that the TLX scores across all groups would increase between Pre-Task and Post-Task measures. However, the HTT group should notice that the application handles some of the initial cognitive effort that is required of the traditional MoL technique [Kemp et al., 1985] and Control group. Hence, the Δ in TLX scores should be lower. For this reason, combined with the feedback of the demonstration survey (Section 6.2.1) and successful TA study (Section 6.2.2), EH.3 and EH.4 predicted that HTT participants would rate the application as having good usability and the task as being less difficult and more enjoyable than other groups.

Null Hypotheses

As a result of the above Experimental Hypotheses, a series of Null Hypotheses accompany the experiment that predict no significant statistical difference between groups or repeated measures.

NH.1 There will be no significant difference in recall accuracy % between all 3 groups after 5 minutes and 7 days.

NH.2 There will be no significant difference in the Pre-Task and Post-Task TLX Scores across all 3 groups.

NH.3 There will be no significant difference in difficulty and enjoyability ratings across all 3 groups.

6.3.7 Pilot Study

A pilot study ($N = 3$) for each of the 3 conditions was carried out in order to assess whether the tasks were feasible in the set time period and whether the instructions given to participants needed further clarification, before running the full study with 30 participants. After the pilot study was complete, the design described above was adopted. No major issues were found with any of the 3 groups' tasks in the pilot study, though the following findings were made through unstructured conversations, which in some cases required minor adjustments to the experimental design:

- Reduce the time limit in the memorisation task to 6 minutes (originally 8 minutes).
- Reduce the forecast completion time of the experiment to 40 minutes (originally 1 hour).
- Capture qualitative data on participants positive and negative comments towards the experiment in the survey.
- Add a demonstration phase for the HTT group to allow them to become familiar *before* starting the task.
- Add printed numbers on pieces of paper next to each of the stops on the route for the HTT group (e.g. centre-bottom of Figure 6.14).
- Explain the function of the BLE beacons before the demonstration to HTT participants.

Figure 6.14: Participants of the HTT group retrieving notes to commit to memory.

6.4 Chapter Summary

This chapter has seen the implementation of the HTT application undergo multiple stages of usability evaluation and changes in response to user feedback. It has also laid the foundations for the detailed design of an experiment which assesses the HTT application's efficacy compared to the traditional MoL technique and a control group. Not only does the experiment consider recall accuracy, but also levels of enjoyment and difficulty as well as the effects on cognitive workload. In this sense, the experiment evaluates the HTT application from multiple angles in a way that studies involving existing solutions do not. The next chapter will detail and analyse the results of the aforementioned experiment as well as discussing its strengths and limitations. Chapter 8 will then reflect on the entire project's contributions and avenues for future work.

Chapter 7

Results and Discussion

7.1 Introduction

In chapter 6, details of the main experiment to evaluate the efficacy of HTT were discussed. This chapter will present the results of this study, including the main findings to help answer each of the research questions put forward in the previous chapter. (Full raw and statistical data from the experiment can be seen in Appendix J.12 and J.13 respectively).

7.2 Analysis of Results

After the 30 participants had completed the experiment and filled in their recall data 7 days later, results were analysed using IBM SPSS with Field [2017] and Cairns [2019] as a reference. The experiment relied on the use of a non-parametric independent variable (method of memorisation) with a sample size of 10 per group so parametric statistical tests such as the t test and one-way ANOVA are not suitable for analysis [Field, 2017]. Instead, *non-parametric* tests such as Kruskal-Wallis and Wilcoxon Signed Rank are more suitable for analysing data from the HTT experiment, similar to existing experiments with technology supporting the MoL such as Loci Spheres [Wieland et al., 2017]. There is also no need to analyse metrics such as Cronbach's alpha [Cronbach, 1951] on the raw data, as the methods adopted (Likert ratings, accuracy % and TLX scores) are all well-established methods and scales without the need for further reliability tests. Results are marked with subscript H for the HTT group, M for MoL, and C for the Control group. Statistical significance is two-tailed in all cases, as repeated measures may show positive or negative changes (e.g. recall %, TLX score), with a significance value of $p < 0.05$. Kruskal-Wallis metrics had the Bonferroni correction[1] applied.

Before analysing data directly pertinent to the experimental hypotheses outlined in the previous chapter, we will take a brief look at some baseline metrics which could have impacted or mediated later results. Based on the results of the post-study experience surveys (Appendix J.9 and J.10), Figure 7.1 shows that participants of all groups rated the instructions they were given during the experiment as clear ($M_H = 4.70, M_M = 4.50, M_C = 4.50$) and memorisation techniques as useful in equal measure across groups ($M_H = 4.10, M_M = 3.90, M_C = 4.20$).

[1] An adjustment of p values by dividing by the number of comparisons made. Applied when many statistical tests take place at the same time on the same dataset.

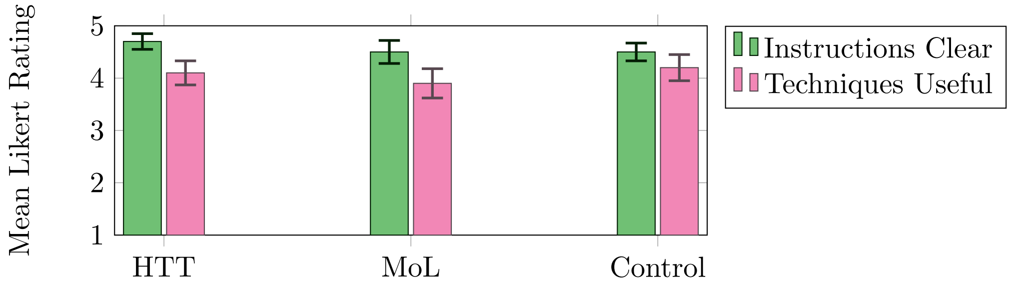


Figure 7.1: Instruction clarity and technique usefulness across all 3 groups.

By collecting metrics such as the perception of instruction clarity and baseline opinions on using memory techniques, one can use this data to analyse other metrics collected. For example, had there been a large variance in instruction clarity metrics between participants of the 3 groups, that may have been a mediating factor for any difference in difficulty ratings discovered in the experience survey. Also, had there been a large variance in baseline opinions towards memory techniques' usefulness, that could have mediated the results of the enjoyability ratings also collected in the experience survey. Thankfully, Likert ratings of instruction clarity and technique usefulness were consistent across all groups, meaning that mediating factors such as these can be ruled out as having a significant impact later on enjoyability and difficulty ratings.

7.2.1 Significant Qualitative Data

All participants successfully completed all tasks, with no major issues reported regarding the ambiguity of instructions. The most time-consuming point of assistance and explanation came during the initial NASA TLX sheet to help participants understand its contents and purpose. Whilst some participants might have thought a long explanation was not necessary, it was important to ensure all participants had an equal understanding before rating their cognitive workload to prevent inaccuracies in data. The post-study experience surveys captured a variety of valuable qualitative data about what participants liked and disliked about the experience.

Positive Feedback and Observations

Several participants across all groups made positive comments on the experiment's organisation: *"Very easy to participate in"*, *"It was structured well and had nice variety"*, *"Relaxed environment, short and little paperwork"*. Most of the participants using the HTT application commented on its novelty and were surprised at how effective moving around the room was as a strategy for remembering the list: *"It was interesting to see that when I tried to remember the words, I visualised myself walking around the room in the order I had learnt them"*. This suggests that even without previous knowledge of the technique or how to recall items, the application makes it intuitive that in order to recall words, a retracing of steps is the most effective strategy. Whilst midway-through carrying out the memorisation task, one of the HTT participants remarked: *"I like how I can simply look at a wall and tell you which item I saw there!"*. Location tracking was a popular feature amongst HTT participants, with several asking how the technology worked and one participant even remarking *"I could do with some of these at home!"*. Whilst somewhat said in jest, this does suggest a warmth towards initial use of the application with a low barrier for entry. There were also valuable comments on usefulness and applicability of the application to participants' lives: *"I can actually see this research being useful in my life"*. This solidifies the theory that students studying for examinations would have a vested interest in the project's outcomes.

The physical effort required to navigate the room (something predicted as a point of negative feedback) was not commented on by any of the 10 participants of the HTT group, suggesting that participants are not phased by the idea of physically navigating spaces in order to memorise a list of items. Upon asking participants to fill out the word recall form for a second time after 7 days, several commented that they had forgotten the follow-up survey was coming, which is a good reassurance that the gap between short term recall and long term recall assessment is long enough for participants to provide useful data. For the MoL group, most of the positive experiment feedback manifested itself in surprise at the effectiveness of the technique by those who had not practised it before: *"Idea was novel to me"*, *"Really interesting learning a new technique"*, *"I might adopt it in the future"*. As there was no instructed technique given to those in the Control group, most positive comments actually focused on the experiments' efficiency and use of the Victoria Stroop task: *"The colour game was fun"*, *"Clear, concise and intelligent to give time after memorisation task"*.

Negative Feedback and Observations

In terms of negative qualitative feedback, HTT participants noticed a technical bug experienced by the application when detecting their position in the centre of the room to retrieve note number 9 and 10 on the route (*thirst* and *bike*). It is a known technical limitation of using the BLE beacons that the performance of the location tracking system is not as optimal when users approach locations in the centre of the room. It takes longer for the positioning to calculate an updated location in this circumstance as signals are triangulated from more BLE beacons and there is no single dominant signal unlike if a participant stood next to a particular beacon. Being in the centre of the room requires the participant to hold the phone completely still at chest-height until their detected location can be computed and displayed. Of course, without being aware of this, natural intuition of the participants was to immediately move the phone to trigger a movement of the on-screen avatar which restarted the whole process. This was understandably a point of frustration for some HTT participants. One of the HTT participants even remarked that if the accuracy of the tracking system could be improved, *"the application would make an even greater learning tool"*.

Across all groups, there was a general negative consensus towards the inclusion of the Victoria Stroop (VS) task as a form of decoy task as participants did not like the feeling of being duped after learning they did not need to put so much effort into the task. Whilst understandable as a response, this was completely necessary to provide time between encoding and recall. Several participants of the MoL and Control groups even requested that the VS task be customised to make the task easier, which was an indication that a few participants were under the impression that the PEBL software (discussed in the previous chapter) was custom-built. On the contrary, it was designed to be difficult to ensure participants do not complete the task without devoting full attention to it.

Non-HTT Use of Techniques

In the MoL and Control groups, participants were asked to detail their approach to the memorisation task in the experience survey, as this could not be directly observed and verified unlike the use of the HTT application. Interestingly, 8 out of 10 people in the MoL group chose their current house to create their palace. This reinforced the idea that people tend to choose locations they know very well in order to reduce the cognitive load in navigating them. Many participants in this group used the bizarre imagery effect [Burns, 1996] to encode items in an otherwise ordinary environment: *"I put down a ball of fire ... walked past a miniature building ... turned into my room with the entrance of a cave"*. Notably, many within the group also tried to associate the item with the place it was stored as a form of semantic association (c.f. Cohen [1990]): *"I placed flame in the living room fireplace, and tongue and rumour in the kitchen because that's where I most often talk to people"*.

The Control group were given no instructed technique and hence techniques used were varied. The most effective techniques (ones producing the highest recall accuracy after 7 days) used elements of what makes the MoL technique so effective. These included story-telling (strongly-linking each word with another) and creating bizarre sentences from the words. Less effective techniques from the Control group included basic rote repetition and chunking the list into smaller chunks. This discrepancy between the effectiveness of techniques supports Craik and Lockhart [1972]. Those in the control group who processed the words at a deeper level (connecting them with a story perhaps) performed better than those who adopted verbatim repetition.

7.2.2 Testing EH.1: Recall Accuracy

After the memorisation task was complete, the 30 participants across all groups were tested on their recall accuracy of the 10 items in the memorisation task in 2 intervals: once after 5 minutes and for a second time after 7 days had passed using the same recall form (Appendix J.8). This design was also adopted by Rosello [2017] and Wieland et al. [2017], so there was a level of confidence in its ability to produce meaningful results. Interestingly, in the case of Wieland et al. [2017], not all participants answered the follow-up recall test after 7 days which may have skewed their results. Thankfully in the experiment involving HTT, all 30 participants filled out the follow-up test as they had been told their original contributions could not be counted unless they did so. To re-iterate the previous chapter, the accuracy of recall *order* was not assessed, though this is a topic which will be revisited later in the analysis. The paradigm of delayed free recall (DFR) was used in the guise of the Victoria Stroop task, which attempted to provide a gap long enough to empty the short term memory of participants before they are tested for recall [Aldridge and Farrell, 1977].

Table 7.1 shows the statistical data on each group's recall accuracy % after 5 minutes and 7 days, which is plotted in Figure 7.2. After 5 minutes, there was very little difference in recall accuracy % across the 3 groups ($M_H = 95.0, M_M = 100.0, M_C = 89.0$). A Kruskal-Wallis test on this first set of recall data shows no significant statistical difference between all 3 conditions ($H = 3.577, df = 2, p < 0.167$). Interestingly, the MoL group outperformed the other 2 groups by remembering all words in the list, with the Control group having the lowest mean accuracy after 5 minutes.

After 7 days there appears to be a more pronounced difference between the recall accuracies of each group. Again, the MoL group have the highest mean accuracy %, but this is closely followed by the HTT group, with the Control group showing the largest drop in recall accuracy after 7 days had passed ($M_H = 74.0, M_M = 84.0, M_C = 55.0$). However, another Kruskal-Wallis test on this second set of recall data again shows no significant statistical difference between all 3 conditions ($H = 3.397, df = 2, p < 0.183$). This means that we cannot confidently reject null hypothesis NH.1 as $p > 0.05$. This may be due to the relatively small sample size (10 per group) causing a lack of statistical significance. Whilst there are clear indications that after 5 minutes and 7 days, both HTT and MoL participants perform better than the Control group which supports EH.1, this difference is not enough to reject NH.1.

As recall data was collected twice (related samples), 3 Wilcoxon Signed Rank tests were carried out to compare the statistical significance of the difference between recall data after 5 minutes and 7 days *within* each group. All 3 tests showed a significant difference between repeated measures across all groups ($z_H = -2.536, z_M = -2.226, z_C = -2.555$ with $p_H < 0.011, p_M < 0.026, p_C < 0.011$). This allows us to reject the null hypothesis that the difference in mean recall *within* each group between 5 minutes and 7 days is random.

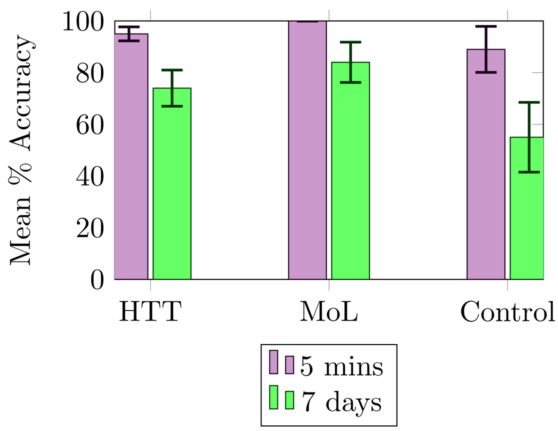


Figure 7.2: Mean Recall Accuracy % ± SE across all groups after 5 minutes and 7 days.

Table 7.1: Statistical data for recall accuracy % across all 3 groups.

Task		5 mins	7 days
HTT	M	95.0	74.0
	SD	8.5	22.2
	SE	2.7	7.0
MoL	M	100.0	84.0
	SD	0.0	24.6
	SE	0.0	7.8
Control	M	89.0	55.0
	SD	28.1	42.8
	SE	8.9	13.5

Once crucial factor which might mediate the above results is that the participants of the MoL group contained 4 participants who had used the technique before, compared to 1 participant with prior experience in the HTT and Control groups respectively (Figure 7.3). This is a potential weakness in the above findings, and occurs purely by chance as participants were allocated to a group using a random name generator in a

Microsoft Excel spreadsheet. In hindsight, it would have been more valuable to select 10 participants per group who had never used the MoL technique before. However, due to time and resource constraints, there was an imbalance of experience which may explain the superior performance of the MoL group.

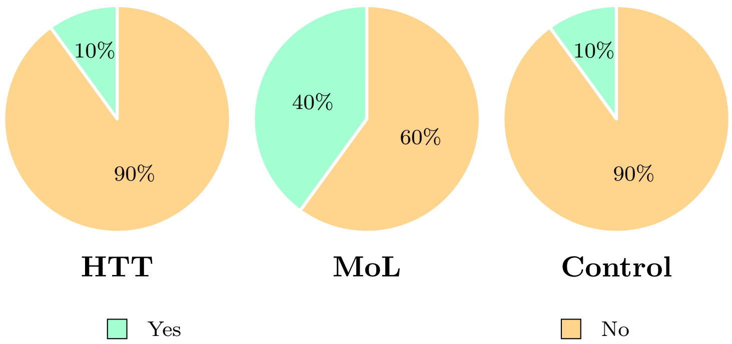


Figure 7.3: Experience with the MoL technique across all 3 groups.

In light of this analysis, further investigations on recall data were carried out after each group was filtered based on participants who had never used the MoL technique before. This meant that the sample sizes were imbalanced ($N_H = 9, N_M = 6, N_C = 9$) but the effect of unequal experience between groups could be observed. As Table 7.2 and Figure 7.4 show, the mean recall rates after 5 minutes are relatively unchanged after this modification ($M_H = 94.4, M_M = 100.0, M_C = 88.9$). The profound difference after balancing on MoL experience comes from examining the recall accuracies after 7 days. By considering only participants who have never practised the MoL technique before, the mean recall accuracies of the HTT and MoL groups are very similar, and there is a larger difference in mean accuracy between these 2 groups and the Control group ($M_H = 74.4, M_M = 76.7, M_C = 52.2$).

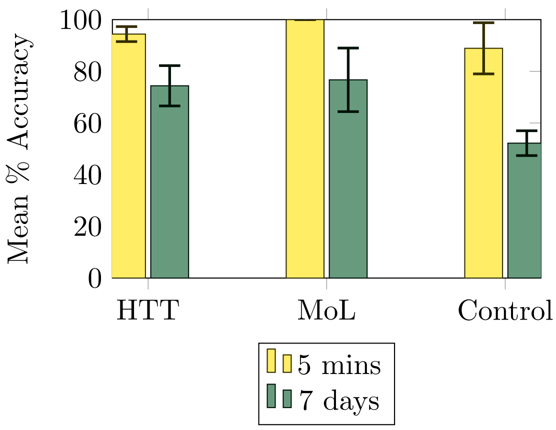


Figure 7.4: Mean Recall Accuracy % ± SE across all groups after 5 minutes and 7 days, balancing on MoL experience.

Table 7.2: Statistical data for recall accuracy % across all 3 groups, balancing on MoL experience.

Task		5 mins	7 days
HTT	M	94.4	74.4
	SD	8.8	23.5
	SE	2.9	7.8
MoL	M	100.0	76.7
	SD	0.00	30.1
	SE	0.00	12.3
Control	M	88.9	52.2
	SD	29.8	44.4
	SE	9.9	4.8

It is clear from these findings that NH.1 still cannot be rejected, but there is some evidence to suggest that recall rates are improved by using the HTT application compared to the Control group, and that performance of participants with no prior experience of the MoL is similarly effective when using HTT compared to the traditional technique. Further experiments are needed to confirm this speculation.

7.2.3 Testing EH.2: Cognitive Workload

Table 7.3 shows the statistical data on each group's Pre-Task and Post-Task TLX Scores before and after the memorisation task, which is plotted in Figure 7.5. This data shows that across all 3 groups, the memorisation task increased participants' cognitive workloads, which is to be expected as the task required a significant amount of mental effort to commit items to memory. The Pre-Task measures were collected as soon as the participants had signed their consent form, which is why the initial scores are relatively low ($M_H = 27.333, M_M = 21.833, M_C = 28.167$). It was important to take into consideration both of the scores, to account for the fact that there may be variance between each group's Pre-Task score. In hindsight, this was a good decision as the mean Pre-Task TLX score of MoL participants was noticeably lower than the other 2 groups. The most meaningful statistic is, therefore, Δ TLX.

It is clear from the graph that the increase in cognitive workload was significantly lower for HTT participants than the MoL or Control groups. This inference was confirmed by carrying out a Kruskal-Wallis test on the Δ TLX data, which showed a significant statistical difference between HTT group and the other 2 conditions ($H = 6.007, df = 2, p < 0.050$). This means that we can reject the null hypothesis NH.2, and conclude that there is convincing support in favour of EH.2 from the empirical data gathered. It would seem that by using the physical space as a mind palace and by guiding participants through the steps of the MoL technique, participants experienced a significantly lower increase in cognitive workload when memorising information using the HTT application than the other 2 conditions.

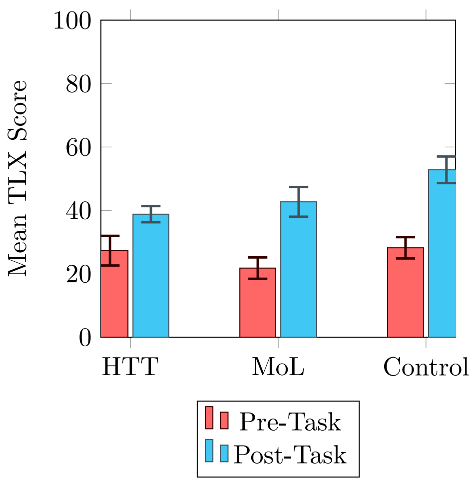


Figure 7.5: Mean Pre-Task and Post-Task TLX Score $\pm$ SE across all groups.

Table 7.3: Statistical data for NASA TLX Score across all 3 groups.

Task		Pre-Task	Post-Task	Δ TLX
HTT	M	27.333	38.833	+11.500
	SD	14.792	8.062	+10.793
	SE	4.678	2.550	+3.413
MoL	M	21.833	42.667	+20.833
	SD	10.627	14.828	+11.460
	SE	3.361	4.689	+3.624
Control	M	28.167	52.750	+24.583
	SD	10.612	13.258	+14.965
	SE	3.356	4.193	+4.732

As TLX data was collected twice (related samples), 3 Wilcoxon Signed Rank tests were carried out to compare the statistical significance of the difference between Pre-Task and Post-Task TLX scores *within* each group. All 3 tests showed a significant difference between repeated measures across all groups ($z_H = -2.807, z_M = -2.803, z_C = -2.805$ with $p_H < 0.005, p_M < 0.005, p_C < 0.005$). This allows us to reject the null hypothesis that the difference in mean TLX score *within* each group between Pre-Task and Post-Task measures is random. As such, we can be more confident in the support for EH.2.

7.2.4 Testing EH.3: Difficulty and Enjoyability

The third experimental hypothesis (EH.3) pertained to the Likert ratings of participants across each group towards the difficulty of completing the memorisation task and the feelings of enjoyment during it. Table 7.4 shows the statistical data on each group's enjoyability and difficulty ratings of the memorisation task, which is plotted in Figure 7.6. It was predicted that by giving participants a mobile application to practice the technique, the novelty of the technology and the reduced upfront cognitive effort would mean HTT enjoyability ratings were higher and difficulty ratings were lower than the other 2 groups.

In fact, mean Likert enjoyability ratings were consistently high across all groups ($M_H = 4.20, M_M = 4.40, M_C = 4.20$). A Kruskal-Wallis test on enjoyability data shows no significant statistical difference between all 3 conditions ($H = 0.110, df = 2, p < 0.800$). Most participants saw the memorisation task as a challenge of their ability, which perhaps encouraged a competitive approach which was experienced by participants of all groups. This attitude might have affected results, making the task enjoyable for each of the 3 groups in equal measure. Equally, difficulty ratings were consistent across all groups as well ($M_H = 2.50, M_M = 2.30, M_C = 2.40$) with a Kruskal-Wallis test on difficulty data showing no significant statistical difference between all 3 conditions ($H = 0.446, df = 2, p < 0.946$). It may be that as the number of items to remember grows, these ratings change as the increased cognitive workload induced by this change can be more effectively offloaded to the HTT application. For now, however, this is just conjecture. There is currently not enough data to reject null hypothesis NH.3 and as such, it must be retained.

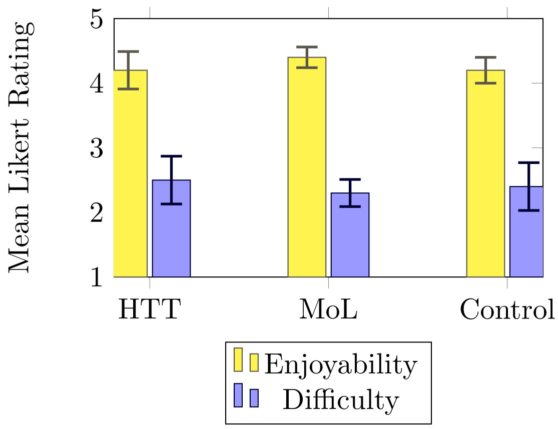


Figure 7.6: Mean Enjoyability and Difficulty ratings ± SE across all groups.

Table 7.4: Statistical data for difficulty and enjoyability ratings across all 3 groups.

Task		Difficulty	Enjoyability
HTT	M	2.50	4.20
	SD	1.18	0.92
	SE	0.37	0.29
MoL	M	2.30	4.40
	SD	0.67	0.52
	SE	0.21	0.16
Control	M	2.40	4.20
	SD	1.17	0.63
	SE	0.37	0.20

7.2.5 Testing EH.4: Usability

The final hypothesis we will examine considers system usability of the HTT application to complement the comprehensive evaluation presented in section 6.2. In the version of the post-study experience survey filled out by HTT participants (Appendix J.9), there contained an extra 10 usability statements for participants to rate levels of agreement with. In this sense, only 10 participants filled this out, as the remaining 20 did not use the application. Each set of 10 Likert ratings were totalled in a way that produces a score ranging between 0 and 100 corresponding to a "quick and dirty" usability metric to judge the system by [Brooke, 2013]. Table 7.5 shows the statistical data on HTT's SUS Score, which is plotted in Figure 7.7. As there were no repeated measures or other systems to compare this metric to, there were no tests by which to assess statistical significance and hence no accompanying null hypothesis for EH.4.

Overall, the 10 participants of the HTT group gave the system a mean SUS score of 77.8 (with $SD_H = 12.4$). It is generally accepted that a SUS score of 68 or above means a system can be categorised as "*Good*" and a score of 80 or above would place the system in the top 10% of systems in terms of usability [Laubheimer, 2018]. As such, the mean SUS score given to HTT can be considered good enough to provide convincing support for EH.4. Some immediate limitations in this metric include the fact that it is not relative to another system. Whilst this data does support EH.4, it would make a more convincing case had there been enough time to evaluate the SUS score of HTT against a similar existing system such as *NeverMind* [Rosello, 2017] or *Loci Spheres* [Wieland et al., 2017] to assess usability in a more rigid way and hence compare distributions of scores between systems. In the meantime, the SUS score is satisfactory and provides enough of a basis to support EH.4.

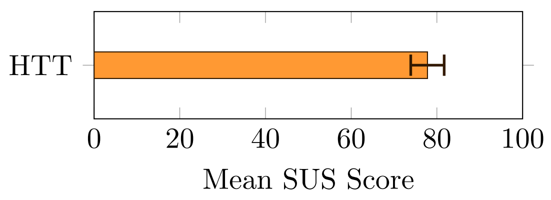


Figure 7.7: Mean SUS Score ± SE.

Table 7.5: Statistical data for HTT's SUS score.

Task		SUS Score
	M	77.8
HTT	SD	12.4
	SE	3.9

7.3 Limitations of the Study

Whilst the above study allowed a comprehensive analysis of the efficacy of HTT to be carried out, it is not without its limitations. This section will provide a critical assessment of the potential weaknesses in the study and how these could be remedied.

Participant selection

The selection of participants of median age 22-24 at the University of Bath and Southampton allowed controlling for education level and age, but it did also limit the experiment. The majority of students from Computer Science backgrounds in the HTT group are likely to be more technically proficient than the general public, making results less generalisable across subject disciplines. Ideally, a broader range of ages should also have been represented. Further studies are invited to compare the effects of using HTT with different age groups for greater external validity. Secondly, as section 7.2 concludes, results are far more likely to produce a statistically significant difference if future participants are selected based on the pre-requisite of having no prior experience with the MoL technique.

Realism of techniques

Encoding Specificity (c.f. Tulving and Thomson [1973]) is a core part of what makes the MoL technique so powerful - subjects freely create content at a place of their choice and then retrieve it. Due to a trade-off in keeping task completion time consistent between groups, HTT participants did not *create* notes according to what they were being asked to remember. Instead, they were asked to *retrieve* the notes, which is only half of the total MoL technique. The alternative would be to either have participants only *create* content and not retrieve it or to extend the total time limit for all groups and allow both creation *and* retrieval of content for HTT participants which might give other groups far too much time to complete the task. In this sense, the comparisons between groups' recall data above are somewhat asymmetric - the MoL and Control groups had far more flexibility over how to practice their techniques as they had the freedom to encode and create content in their own way. Ideally, to allow a maximum match in recall conditions for the HTT group 1 week after the experiment, participants should have been instructed to return to the room where the experiment took place, to trigger memories of the task. Also, it would be ideal to provide HTT participants more realism to practice the technique in an environment of their choice, by allowing them to set the beacons up in their homes for example. This would have been at the cost of less control over experimental conditions. Finally, a *serial order* was implicitly imposed on participants of the HTT group by defining a pre-defined route for each participant to follow. Other conditions did not have this restriction - they could recall the words in any order they wished. As such, participants of the HTT group might have felt a subconscious need to remember words in a specific order that was not imposed on the other 2 groups.

Experimental control and coverage

Participants could not be controlled from the moment they left the initial laboratory environment. Therefore, they were trusted not to communicate with each other and not to write down the words they could recall to assist them when tested again for recall after 7 days had passed. The threat of foul-play ultimately could not be controlled. This is why participants were not told the full details of the 7-day recall test until a week after the initial experiment.

As documented in previous chapters, the training feature of the HTT application is not the only part of system functionality. The application allows users to create content, retrieve it and mark the content as having been remembered or not, to track their progress. Whilst earlier usability studies revealed the progress tracking feature to be a popular piece of system functionality, there was not any scope or time to assess the impact it had on recall performance in this experiment. As such, future research is invited to empirically study the effects of tracking progress on recall accuracies and Likert ratings.

Assessment of performance and usability

Due to time constraints, recall was only tested after 1 session of the memorisation task. However, previous technologies supporting the Method of Loci technique have sometimes not shown a significant improvement in participants' recall accuracies until tested over longer periods [Fassbender and Heiden, 2006]. Indeed, Dresler et al. [2017] observed the effects of practising the traditional MoL technique over several months. As such, it could be a possibility that the efficacy of using the HTT system needs to be judged over the course of several months and indeed several sessions of use, instead of over a single week after 1 use.

On the subject of time, it would also be interesting to factor in performance metrics when considering recall data. Under the experiment's current design, participants have as long as they wish to recall the information as only accuracy is considered. By measuring performance metrics such as time, it would be interesting to research whether participants of the HTT group can recall information faster than other groups. Participants were also only tested on their free-recall ability. It is generally accepted that free recall differs from other retention test types such as *recognition* in the cognitive activity it requires [Loftus, 1971]. As such, varying the type of assessment between free recall and recognition may have some impact on results. Indeed, experiments with the *NeverMind* system [Rosello, 2017] employed recognition over recall.

In Section 2.2.2, the *serial position effect* was described, whereby participants are most likely to remember the initial (*primacy*) and final (*recency*) words in a list they are to recall [Glanzer and Cunitz, 1966]. To mitigate for this, an allowance could be made in future experiments by adding some words at the start and end of the list of words to be recalled which are *not* considered in accuracy calculations. The *word-length effect* is another effect that must be considered. Shorter words are easier to recall than longer words [Avons et al., 1994]. Notably, 70% of the words used in the experiment were 1 syllable, which may have made items easier to remember than longer words would have, influencing recall rates. Further experiments should investigate the use of HTT with words of varying lengths.

Another important factor which is likely to affect recall rates is the *number* of words used in the experiment. Technical and practical limitations (not having enough space or time to store many more than 10 items in the room being used) limited the number of words used in the HTT experiment. Should these limitations be overcome, then an investigation should follow which uses far more than 10 items to remember.

From a usability perspective, the evidence supporting EH.4 provides some convincing evidence of the good usability level of the HTT system but as discussed already, this metric is not entirely helpful without a basis for comparison with other existing systems supporting the MoL technique. Given more time, the use of A/B testing might be able to assess usability and efficacy between *technologies*, as well as just comparing between *techniques* as the current HTT experiment investigates.

7.4 Implications of Findings

Whilst there appears to be evidence suggesting the HTT application does indeed support memorisation using the Mind Palace technique and EH.1 does seem to be supported by recall data after 5 and 7 days, it cannot be said that use of HTT supersedes the ability of the traditional technique. Nor can we rule out the null hypothesis NH.1 as results are not statistically significant. With more time, there would, therefore, follow a larger scale experiment comparing the HTT application against the traditional technique to achieve statistically significant results.

Arguably the most significant finding of the experiment came when EH.2 was supported by experimental results. Use of the HTT application significantly relieves participants of a proportion of the cognitive workload required in memorisation using the MoL technique, especially compared to the control group. As such, we can confidently reject the null hypothesis NH.2. The investigation pertaining to EH.3 (enjoyability and difficulty ratings) revealed that there was no significant difference in ratings across all 3 experimental groups, which means we must retain the null hypothesis NH.3. Finally, the SUS score data collected from HTT participants in the post-study experience survey does indeed support EH.4. As this data is not being compared in its distribution against another system in question, we do not have a null hypothesis to reject or retain.

The results obtained, though limited in the ways discussed in Section 7.3, have several implications for the field of supporting the MoL with technology. Firstly, it appears that a system of HTT's nature is able to significantly reduce the cognitive effort involved in practising the MoL technique, whilst somewhat retaining the technique's effectiveness. It might turn out that this reduced cognitive effort is the *reason* for the HTT group's recall accuracy not being as high, as part of the power of the traditional technique is the forced deep processing of items to be remembered, requiring high cognitive efforts.

Despite needing further experiments to ascertain if a statistical significance exists in the recall accuracies of HTT participants against the traditional technique, there is some evidence to suggest it is just as effective when participants are balanced on their previous experience. It cannot be concluded that this technology is more effective than its traditional counterpart, but the reduced cognitive effort may well prove a significant finding of this experiment in medical domains such as supporting those suffering from brain injuries and Dementia. This is discussed in greater detail in the next chapter.

7.5 Chapter Summary

This chapter has summarised and analysed the results of the experiment first described in Chapter 6. Despite some of the constraints placed on the study (e.g. sample size, selection pool), we managed to successfully evaluate the level of support for all 4 of the experimental hypotheses. This range of analysis has laid a strong foundation for examining what qualities a system which supports the Method of Loci needs to have, as well as assessing the extent the HTT application demonstrates these. The next chapter will contain a thoughtful discussion of these findings in the wider context of the dissertation, as an assessment of how well it has met the objectives set out in the introductory chapter. We will also be taking a broader view of what these findings may lead to in the way of future work on supporting the Method of Loci with technology.

Chapter 8

Conclusions

8.1 Introduction

Having analysed the findings of the main experiment involving HTT, it is appropriate to reflect on the main contributions of this dissertation from a wider perspective. This chapter examines the achievements of the project in relation to its original objectives, draws attention to the project's limitations and prompts a discussion on what work is left open for future research in the domain of HCI and beyond.

8.2 Satisfying Objectives

In this dissertation, we have seen the genesis of "Hold That Thought" (HTT) - a location-based system that brings the ancient mnemonic technique of the Mind Palace to life via a mobile application and Bluetooth technology. We believe this system acts as a strong contribution to the field of memory enhancement and assistance using the Mind Palace technique. This section assesses the progress that has been made relative to the original aims and objectives.

In Chapter 1, the following objectives were set for the project:

- **O.1** Explore the psychological theories about human memory in order to understand why certain techniques are more effective than others when memorising information.
- **O.2** Investigate existing methods for assisting with memorisation and recall, as well as systems that attempt to support this.
- **O.3** Extend existing work which supports memorisation of information using the MoL technique such as Rosello et al. [2016] in order to create an effective mobile-based method for practising the technique.
- **O.4** Evaluate how users use the system, and whether spatial information helps them recall information more effectively than rote or non-spatial (passive) memorisation methods.
- **O.5** Investigate the usability of the system, and its effects on cognitive load, enjoyability and difficulty compared to practising the traditional MoL technique.

The salient aim of this project was to investigate how technology can support memory with particular focus on the Mind Palace technique, in order to assist with the long-term recall of information in a way that reduces the level of cognitive effort required by the traditional technique. Even in the modern age of digital amnesia, the Literature Review demonstrated that this research is still relevant in a variety of fields from the control of HCI applications [Perrault et al., 2015] to medical applications such as supporting the vulnerable suffering with Dementia [Piasek, 2015]. In order to scope the project more easily, the domain of examination revision was chosen for the HTT system due to memory techniques being popular for this purpose and an abundance of suitable participants being available for this domain, but its findings can act as an open invitation for further research in other domains.

This dissertation introduced the subject of memory by categorising each type and analysing which classical models are still relevant to this day in order to achieve objective **O.1**. It was decided that episodic memory would be the focus of this dissertation as it encapsulates the concept of long term, conscious memories [Tulving, 1972]. We discovered that by navigating a physical space, one might engage their hippocampus effectively so as to create episodic memories. Equally important was the exploration into theories such as Levels of Processing [Craik and Lockhart, 1972] and Encoding Specificity [Tulving and Thomson, 1973] as they are key ideas that can help explain why the MoL technique is so powerful. By processing items at a deeper level (e.g. considering their location in space) and by matching conditions between encoding and retrieval (e.g. retracing the same route where items were stored), episodic recall is greatly increased. There followed an examination of common mnemonics shown empirically to be effective, such as the Mind Palace, Pegword and Chunking techniques. This knowledge equipped us to examine existing systems which augment memorisation to meet objective **O.2**. The effective existing systems supporting the MoL technique seemed to all use physical spaces as palaces to reduce the cognitive effort required in navigating and constructing a mental model of the palace environment [Perrault et al., 2015, Rosello, 2017, Yamada et al., 2017*a*,*b*, Wieland et al., 2017].

In light of this research, the work of existing systems was extended in order to create the requirements and design for Hold That Thought (Figure 8.1).

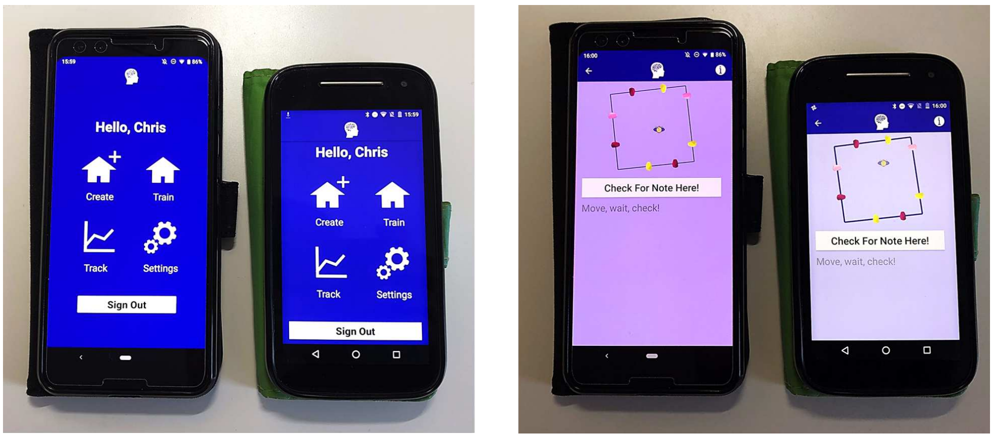


Figure 8.1: HTT on different devices: Google Pixel 3 running Android 9.0 (left hand side) and Moto E running Android 6.0 (right hand side).

The HTT application builds on existing systems such as *NeverMind*, *HoloMoL* and *Loci Spheres* to provide a location-based approach to creating palaces in physical spaces. This implementation satisfied objective **O.3**. The video of the final system described in Section 6.2.4 was also distributed to the creators of *NeverMind*, *HoloMoL*, *Loci Spheres* and *Physical Loci* (discussed in Chapter 2) to see if feedback could be attained from experts in the field. The response was overwhelmingly positive:

> "Your prototype looks great. I really like the idea of using indoor tracking because it allows walking through the loci physically. By comparison to our system, it thereby adds another stimulus which could further lower the initial threshold for learning the method."
>
> —*Jonathan Wieland, co-author of Loci Spheres [Wieland et al., 2017]*

> "You have advanced our work to the next step by actually implementing a fully-fledged system that can be used on a day-to-day basis. I really like your work."
>
> —*Mohammed Al-Sada, co-author of HoloMoL [Yamada et al., 2017a,b]*

Objectives **O.4** and **O.5** were achieved in the comprehensive usability and empirical evaluation described in Chapter 6. The application was met with praise for its novelty by potential users upon viewing a demonstration, which supported the initial prediction that students may find the application useful with their revision. With a key drawback of the traditional technique manifesting in its initially high cognitive workload [Bower, 1970, Kemp et al., 1985], it was important to lower the barrier for entry by designing a system which encourages users to practice the technique. Through the system demonstration survey and Think-Aloud study to observe how users interact with the system, improvements were made to the application to improve its usability. A controlled experiment indicated that use of HTT does improve recall compared to a control group and is similar in effectiveness to the traditional technique when participants are balanced on their previous experience of the MoL technique. However, the null hypothesis cannot be rejected at this stage. Quantitative investigations into enjoyment and difficulty still require further investigations as the null hypothesis could not be rejected after similar mean Likert ratings were collected across all groups.

Potentially the most significant finding of the experiment when meeting **O.5** surfaced when measuring the increase in cognitive workload caused by the experiment's memorisation task. There was a statistically significant difference between groups' Δ TLX scores with HTT participants showing a lower Δ TLX than other groups whilst still producing greater recall accuracies than the control group. Whilst this could be explained by the fact that HTT users only retrieved items instead of using the application to create content, this still suggests that the performance of users with the application can be almost as effective as the traditional technique purely by retrieving content already stored in a palace. This implies that HTT can support users in effectively memorising content with less of an upfront cognitive effort on the user themselves.

8.3 Summary of Contributions

As well as meeting all of the original project objectives, this dissertation contributes to existing research in the domain of using technology to support the MoL technique in the following ways. These are both contributions of the HTT system itself as well as the research this dissertation presents.

- A prototype location-based mobile application called "Hold That Thought" which permits users to create many palaces in a physical space of their choice. It is the first system of its kind which harnesses the potential of contextual computing to record where in the physical space a note is stored with the goal of retrieving this information the next time the location is visited. No known existing attempts to support the MoL in physical spaces have harnessed this technology, instead relying on the use of a Head-Mounted Display which requires unique fiducial markers [Yamada et al., 2017*a*,*b*] and in some cases does not fix content to spatial locations [Rosello, 2017]. HTT thereby adds another stimulus by which to engage the hippocampus for episodic memory formation.

- The first known system of its kind to facilitate tracking of users' performance in the spirit of Deliberate Practice. Whilst this could not be empirically tested due to time constraints, it is a key part of system functionality that may encourage the more effective practising of the technique by imposing a "testing effect" on users who can assess their current level of performance whilst using the system to improve long-term recall [Roediger and Butler, 2010].

- The first known empirical evaluation comparing recall accuracies of participants using a system utilising physical spaces as palaces against the traditional technique and a control group. Existing systems instead either compare multiple designs within the same application against each other [Wieland et al., 2017] or the system against a control group directly [Rosello, 2017].

- The first known empirical evaluation comparing measures of cognitive workload between technology-based methods and the traditional MoL technique. The result of this measure produced a statistically significant difference between HTT users and the other 2 groups, suggesting a system of its kind can indeed support effective recall whilst reducing the initial cognitive effort that makes the traditional technique so challenging [Bower, 1970, Kemp et al., 1985, Bellezza, 1996].

- The first known empirical evaluation comparing measures of difficulty and enjoyability ratings of participants performing a memorisation task using technology against more traditional memorisation strategies.

- A multi-faceted usability investigation of the HTT system. This included a video demonstration, a TA protocol study to observe users of the system, as well as the elicitation of expert opinions from the authors of successful existing systems supporting the MoL technique such as Yamada et al. [2017*a*,*b*] and Wieland et al. [2017].

- A thorough Literature Review which reviews the state of the art in our current understanding of memory and the common factors which increase the likelihood of episodic memory recall. This research also explores the difference between systems which use graphical environments and those which rely on the subject's physical surroundings when creating Mind Palaces.

This list is not exhaustive but represents the most significant contributions made by the HTT system and its research to the field's current understanding of how technology may support memorisation using the Method of Loci technique.

8.4 Limitations of the Project

Despite the success of the project in relation to its original objectives and the strong contributions it makes to the field, there exists a number of limitations in addition to the experimental limitations discussed in Section 7.3 that must be discussed.

As discussed in the negative feedback of the empirical study (Section 7.2.1), the current implementation of HTT suffers from minor inaccuracies in the detected location of the device when a user approaches the centre of the room. This technical limitation occurs due to BLE beacons taking longer periods to calculate an updated location as more signals are triangulated. This is not the case when a user approaches a specific beacon, as in this case, a specific beacon's signal will be more dominant than others which makes a user's position easier to determine. The best strategy for the system to detect a user in the centre of the room is to hold the phone still at chest-height for a longer time to allow for calculations to finish. As the interface does not currently inform users of this, their mental model dictates to them that they should move the phone, which is counter-productive.

A second important technical limitation of the current location-based approach HTT adopts is the limited scope it gives to store many items in a given room. Whilst the application correctly handles multiple palaces being created in the same physical environment (shown to be effective by Rosello [2017]), the physical size of the room being used is the upper bound on the number of notes which can be stored, as only one room may be set up with the BLE beacons and used at a time. Even though the experiment supported 10 words (to allow participants to walk along a meaningful route), many more can be stored in a given room but only one note is ever retrieved from a given location at a time. A better approach might be to scan for up to 4 notes when a user visits a specific location, as experimental studies have indicated that the MoL technique can still be as effective when storing up to 4 items at a specific locus [Crovitz, 1971]. Making this change might increase the number of words which can be stored in a physical space. An alternative to this might be to change the type of location tracking technology used, from Bluetooth to Wi-Fi or GPS (more detail discussed in Chapter 4) to support the creation of notes over greater distances than a single room.

The remaining significant limitations of the project pertain to its experimental design, which is already discussed in greater detail in section 7.3.

8.5 Future Work and Research

Having appreciated the contributions and limitations of the project, this section will take a look at potential avenues that future research which builds on the HTT system might take. Even though the development of HTT has met all of its original objectives, there are now many possibilities that the application and its empirical study has led to.

Increasing External Validity

Empirical evaluation of the HTT system recruited 30 university students (26 male, 4 female) of median age 22-24 without balancing on previous MoL experience. It is therefore difficult (even with statistically significant results such as the findings supporting EH.2) to generalise across different age ranges and the general population or base results on a level of prior experience. As such, future work should repeat the experiment with these adjustments in mind and a larger sample size, by recruiting participants from a larger age range and balancing on factors such as gender and previous MoL experience. This is especially valid given existing studies on recall suggest that females perform better when asked to recall episodic memories than males [Guillem and Mograss, 2005]. Another way of increasing confidence in external validity would be to increase the number of words used in experiments - a suggestion discussed in more detail in Section 7.3 along with other experimental limitations. Future work should aim to increase the external validity of the findings this dissertation presents.

Memory Enhancement for the Injured, Vulnerable and Impaired

Empirical findings supporting EH.2 were statistically significant, suggesting that the use of HTT lowers the cognitive workload induced on users compared to the traditional MoL technique and a control group whilst still being an effective memorisation method. These findings could have implications beyond the domain of students revising for upcoming examinations. For example, future work could assess the efficacy of HTT in medical applications such as assisting those with Dementia or Alzheimer's disease in training their episodic memory. It is estimated that these diseases will affect more than 75 million people worldwide by 2030 - a number which is expected to triple by 2050 [World Health Organization, 2015].

Existing technical solutions assisting Dementia use a variety of methods, ranging from Augmented Reality (AR) [Lamounier et al., 2018] to lifelogging technology (discussed in Section 2.4.2) [Chen and Okumura, 2018]. Perhaps more surprisingly, regular training using spatial techniques can also create neurons in the hippocampus, which can reduce risk of memory loss, post-traumatic stress disorder, depression, Dementia and Schizophrenia [Gilbertson et al., 2002, Chen et al., 2010]. Several studies are also starting to harness the power of the MoL technique in particular for memory enhancement to help patients suffering from the early stages of Alzheimer's to recognise names of the faces they see [Morel et al., 2015, Bormans et al., 2016]. A big factor in making the MoL technique more accessible to the vulnerable for them to reap its benefits is to reduce the level of cognitive load the technique requires.

As the empirical results of the study indicate, use of technology which uses a stimulus such as the subject's current location to retrieve images of items they wish to remember may prove as an effective memorisation aid *without* requiring the level of cognitive load that the traditional technique demands. Future work should, therefore, investigate the use of HTT for these purposes. If HTT is successful in this domain, it could potentially assist millions of people with memory impairments such as Dementia, Multiple Sclerosis, Parkinson's disease and brain injuries.

Comparison Between Modalities and Systems

When investigating EH.4 as part of objective **O.5**, it was discussed that a stronger method of empirically testing usability would be to do pairwise comparisons with other existing systems to compare how HTT ranks amongst these in terms of usability. These existing systems include *NeverMind*, *Loci Spheres* and *HoloMoL* [Rosello, 2017, Wieland et al., 2017, Yamada et al., 2017*a*,*b*]. With more time and resources (e.g. the Head Mounted Display technology that some of these systems require), suitable A/B testing could have taken place. The empirical study put forward in this dissertation has shown the HTT system to be comparable in effectiveness to the traditional MoL technique with less of a cognitive workload induced on the subject. However, as this is the first known study to investigate efficacy explicitly against the traditional technique and measure cognitive workload, there is no basis for comparison on these metrics from other systems supporting the MoL technique. Future research is invited to investigate the pairwise comparisons between HTT and other systems' efficacy and impact on cognitive workload. This would allow direct comparison between systems that use virtual environments and those that use physical spaces, as well as revealing where HTT's use of location as a stimulus ranks it amongst existing solutions.

Empirical Investigations of Progress Tracking

It is generally accepted that for better retention of content to be recalled over longer durations such as material for an examination, there should be some element of testing integrated into the learning phase [Roediger and Butler, 2010, Wiklund-Hornqvist et al., 2014]. The testing effect and the concept of deliberate practice (Section 2.3.2) motivated the development of the progress tracking functionality of HTT to allow users to monitor their progress in remembering items using the application. However, as stated previously, the empirical investigations were scoped to only focus on the *training* feature so that the recall accuracy of participants could be directly compared. With more time, an investigation into the effects of this progress tracking feature would be carried out in a between-groups A/B testing experiment. This experimental design has already been adopted by similar systems in the field - it was adopted by Loci Spheres when comparing several versions of the design of their system [Wieland et al., 2017]. Future research should investigate the effects of integrating progress tracking into HTT on the recall accuracies of participants over time.

Improving Realism and Flexibility

Another avenue for future work might be to relax experimental conditions and carry out a field study with the system to increase realism and external validity. Giving potential users the opportunity to set the beacons up in the rooms of their own homes to observe how they interact with the system might improve realism in return for the loss of control over experimental conditions.

Another suggestion to extend the current application for improved realism and flexibility might be to allow users to modify the on-screen map of the room to match the layout of the room they are currently in by adding objects such as furniture (Figure 8.2). There could also exist control buttons to move the on-screen avatar around the map for practising the MoL technique at times when users cannot access the physical space used for their palace.

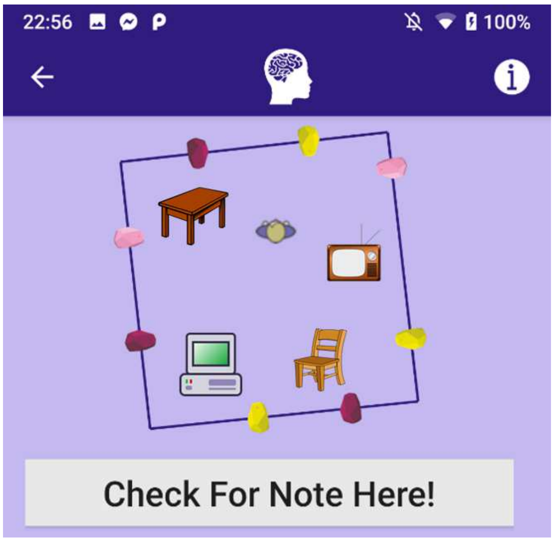


Figure 8.2: Vision of a future version of HTT.

Another avenue for greater flexibility might be to integrate support for new loci media types. Currently, only text and image-based notes are supported using the application. Future research is invited to add support for animations, audio and video to observe if this change makes any difference to efficacy, enjoyment and difficulty measures.

The applications of this new location-based approach to the Method of Loci is suitable in a number of domains. Not only could it assist the vulnerable as discussed above, but also depending on the location, it might be possible to use the MoL technique with HTT to learn a language. By filling the room used as a palace with objects that represent the word in the foreign language, a subject could navigate the room and learn the words by moving from object to object and retrieving the associated notes using the application. Future work is invited to use HTT and evaluate its efficacy in learning the vocabulary of a foreign language.

Micro to Macro: Changing Location Tracking Technology

Designing a system supporting the Method of Loci which relies on location tracking technology has introduced an extra physical stimulus that users of the application can use to practice the MoL technique without needing to know full details of the original technique. Just by navigating a physical space whilst using the application, users can build a mental model of where items they wish to remember are stored in their palace. However, a notable barrier to making HTT a general purpose application for the wider population is its current dependency on BLE beacons. The adoption of BLE beacons was a design choice made to ensure small changes in users' positions could be accurately detected by the location tracking system. The alternative to this might be to adopt a design which instead relies on GPS tracking technology in order to compare the reception of users to both designs. Transitioning from BLE beacons to GPS technology would mean that users' palaces are far more widespread in geographical location than the current approach allows for. This change might either prove popular, allowing users to create palaces 'on the go' whilst they commute to work, or unpopular as it requires scaling larger distances to store the items they wish to remember. Future research is invited to compare the two approaches.

Longer term effects

As mentioned in Chapter 7, time constraints limited the experiment to examine the impact of using the application on recall accuracy after 1 session. This approach can provide useful insights into immediate effects but does not account for factors such as learning curves as a user becomes familiar using the system at their own pace. It might turn out that the true benefits of the use of the HTT application are not observed until they are studied over longer periods of time to account for the learning curve. This has been the case with other systems supporting the Method of Loci [Fassbender and Heiden, 2006] and is therefore not a wild suggestion. Future research is invited to investigate the efficacy of the application over longer periods of time.

Integration of different techniques

HTT was designed from the start to assist users in practising the Mind Palace technique, but the requirements elicitation and empirical evaluation stages of this dissertation have highlighted just how diverse the range of mnemonics used by students are when committing information to memory. Other techniques such as Chunking or the Pegword method may suit different users who find the MoL technique too cumbersome to practice. As such, future versions of the HTT application might seek to integrate support for assisting with wider ranges of memory techniques.

8.6 Closing Remarks

Overall this dissertation sought to investigate if and how technology can assist users in memorising information by adopting the Mind Palace technique and reducing the level of cognitive effort it requires. From the rich literature review of psychological theories and existing systems, the HTT application has been designed to successfully support users in engaging their hippocampus to create episodic memories. The prototype has been thoroughly evaluated and analysed from both a usability and experimental perspective.

Whilst this dissertation has focussed on the domain of students practising the MoL technique for exam revision, it is clear that this research could lead to further research in other domains such as supporting those with Dementia. The findings of the empirical study suggest that HTT requires less cognitive effort compared to the traditional MoL technique and control group, whilst being an equally effective memorisation method for those unfamiliar with the traditional technique. In this sense, HTT successfully lowers the barrier for entry for inexperienced subjects practising the MoL technique. Even in the modern age of ubiquitous devices and digital amnesia, there is still scope and a need for technology to assist and not replace the human memory. As contextual computing systems such as indoor location tracking become more popular, it opens up more avenues for applications such as Hold That Thought to assist users in many more domains.

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Appendix A
Requirements Elicitation

A.1 User Survey and Results

Memory Techniques Dissertation Survey

Responses: 47

Source: `https://goo.gl/forms/mRy7Ri5vIer0I3bg1`

This survey concerns techniques used when memorising information.

The data from responses gathered will be used to help inform the requirements and design sections of my final year dissertation for the accreditation of BSc Computer Science at the University of Bath.

The survey should take a maximum of 5 minutes to complete unless you wish to elaborate on your answers to provide a more detailed (and helpful!) response.

All responses are anonymous, however, there is the chance to leave your email at the bottom in case you do not mind being contacted to explain your answers further.

About You

Q.1 **What is your gender?**

- Male (59.6%)
- Female (40.4%)
- Prefer not to say (0.0%)
- Other (0.0%)

Q.2 **What age bracket do you fall within?**

- 18-22 years old (93.6%)
- 23-29 years old (4.3%)
- 30-39 years old (0.0%)
- 40+ years old (2.1%)

Q.3 **What is your occupation?**

- Student (78.7%)
- Developer (4.3%)
- Teacher (2.1%)
- Accountant (2.1%)

- Team Leader (2.1%)
- Systems Engineer (2.1%)
- Marketing and Advertising Client Manager (2.1%)
- Software Engineer (2.1%)
- Estate Agent (2.1%)
- Media Technician (2.1%)

Q.4 **If the answer to the above was "Student", then please state your degree subject.**

- Computer Science (straight CS or joint honours with maths/business) (31.9%)
- Not a student (19.1%)
- Psychology (6.4%)
- Natural Sciences (4.3%)
- Economics (2.1%)
- Building Surveying (2.1%)
- Accounting and Finance (2.1%)
- Medicine (2.1%)
- Estate Agent (2.1%)
- Sports Science (2.1%)
- Mathematics (2.1%)
- Politics with Economics (2.1%)
- Geophysics (2.1%)
- Biomedical Sciences (2.1%)
- Business Management (2.1%)
- Linguistics and Deaf Studies (2.1%)
- Student (2.1%)
- Physics (2.1%)
- Mechanical Engineering (2.1%)
- Biomedical Sciences (2.1%)
- Literature (2.1%)
- Electrical and Electronic Engineering with Management (2.1%)

Q.5 **What type of phone do you most regularly use?**

- Android (e.g. Samsung) (44.7%)
- iOS (e.g iPhone) (55.3%)
- Windows (0.0%)
- Other (0.0%)

Memory Techniques

The below questions focus on Memory Techniques. Think about your usage of these techniques. A helpful description of those mentioned is as follows:

Mind Palace: Creating an imaginary location in your mind where you can store information. The most common type of memory palace involves making a journey through a place you know well, like a building or town.

Chunking: Taking individual pieces of information (chunks) and grouping them into larger units (e.g. remembering the first letter of every word in a phrase).

Pegword: Create a short rhyme such as (one=sun, two=shoe). Then, using these words as pegs, you create a visual image of each of the words you wish to remember. If we wish to remember "apple, orange" we can picture the sun melting an apple followed by a shoe crushing an orange.

Q.6 **For each of the following memory techniques, please answer with the most applicable option based on your awareness/usage of each.**
Mind Palace:

- Unaware (17.0%)
- Aware but never used (55.3%)
- Aware - used once or twice (21.3%)
- Aware - used often (whenever needed) (6.4%)

Chunking:

- Unaware (27.7%)
- Aware but never used (19.1%)
- Aware - used once or twice (25.5%)
- Aware - used often (whenever needed) (27.7%)

Pegword:

- Unaware (57.4%)
- Aware but never used (27.7%)
- Aware - used once or twice (17.0%)
- Aware - used often (whenever needed) (4.3%)

Q.7 **If you have used any others, please describe them below. (If not applicable, please answer "N/A")**

- N/A
- Writing down the thing I want to remember more than once
- Memorising mind maps by branch colour (to memorise relationships between different hierarchies of things)
- Basically the same as pegword but without the rhyming, the words you are trying to remember are the main focus of the story.
- Flashcards
- Repetition
- Restructuring information into new formats (similar to chunking, but includes e.g. making recordings)
- Creating lists and trying to remember every element in the list. In order to make sure I don't forget anything, I also try to remember how many elements exist in the list.
- I often use acronyms to remember certain aspects of a disease profile
- Repetition in reading or speaking to myself and others
- Acronyms for words like because
- Rehearsal
- Repetition (Flashcards or like when you used to do spelling in primary school, just doing it over and over)
- Not rhymes but just random stories/facts that are useful and amusing that make it easier to remember.
- Writing out the information. Covering it and trying to write it out again.

Q.8 **If you have used any of the above techniques (or others), in what situation was this / were they used?**

- Exam revision (78.7%)
- Speeches (14.9%)
- Presentations (44.7%)
- Memory competitions (4.3%)
- Shopping lists (14.9%)
- Not used any (21.3%)
- Daily TODOs mostly (2.1%)

Q.9 **Please explain how you use these techniques in these situations. (If not applicable, please answer "N/A")**

- N/A
- Read lecture notes, then summarise them by writing them on paper. After writing down the notes I'll read over them and maybe highlight important bits with a highlighter.
- Mind palace for presentations, essays and speeches, I use a different room in my house for the different points/paragraphs. Pegword more for specific case studies (first used it for my geography GCSE case studies!), revising lists. Chunking doesn't work as well for me as the others.
- When trying to learn chemical multi-step processes mainly.
- I sit down and write out what I need to memorise, pick a method based on the structure of the data and then sit and learn it. I practice in my head over a few days.
- Grouping larger sections of a presentation.
- Chunking used when memorising a list of things, used an acronym to remember. Used mind palace technique similarly before, try to remember it as a story in my head.
- Breaking down all required information into a large chunk of text and applying the aforementioned techniques.
- For exam revision, I had to remember a list of around 15 sections of a model. Used memory palace technique, so I would enter my (then) house, and in each room, something was happening (funny/scary/anything emotive) that reminded me of one. of the sections. This was about 2 years ago so I can't remember it well, but I can still see faint images in my head of what was happening. Think I used a variant of pegword for a shopping list once to try it out but was pretty pointless since I could just use my phone!
- Used for memorising lecture content for exams.
- Writing out lecture notes for exams, going over slides before a speech or presentation.
- Walking to uni.
- In year 8 we were asked to memorize as many stanzas of Horatius as we could, so I went through it on my way to school and can still remember the place I learned a particular stanza. I often group topics for exam revision, or use existing structures such as the layout on CGP revision books.
- I use "chunking" and "mind palace" for exam revision as they help me memorise large quantities of information effectively.
- Have only ever used chunking. chunks are separated into topics and each topic has a few paragraphs to remember separately. Then when I see the topic name or think of the topic name I am reminded of the paragraphs.
- Imagine my house, put information in different rooms.

- Associate keywords with locations or relevant actions.
- I go through the lecture slides or my own notes, digesting them into decidable bits. Chunking is great for specific bits of presentations or actual activities.
- Just very simply, memorise the list if I need to remember multiple things.
- I break information into chunks such as symptoms, risk factors, treatments then create an acronym to prompt me such as CRAB for Hypercalcemia symptoms.
- Go over readings lists or words until it felt more natural and easier to do.
- Reinforcing by repetition.
- Memorise large pieces of information in preparation for an exam.
- Using mental imagery to remember names and dates of studies
- When revising I use study cards to break down into chunks and then the whole set of cards is the information that I need for the whole topic.
- Print out slides, write them out and try to write it again. For presentations, I practise saying it out loud after I've written out.
- If I have to write without a prompt this is useful.
- For remembering/memorising large chunks of text, I use keywords/the first word in a phrase to remember the sentences.
- I don't frequently use these memory techniques for revision these days – I tend to rely on flashcards – but we were encouraged to use them occasionally in school.
- Just taking myself on a journey in exams.
- I would often use a form of chunking to help remember facts for science-based exams.

Q.10 **Where did you primarily first learn these techniques?**

- Online (articles, YouTube) (10.6%)
- Book (2.1%)
- Word of mouth (family, friends) (42.6%)
- Not used any (19.1%)
- School (2.1%)
- Studies in psychology (2.1%)
- Chunking - falls in line with what I normally do - unaware it was a technique (2.1%)
- TV episode (2.1%)
- As I was trying to memorise things growing up (2.1%)
- Just picked it up over time and in school, we're taught it (2.1%)
- PE lessons (2.1%)
- Lectures (2.1%)
- TV and college (2.1%)
- School (2.1%)
- Just did it naturally (2.1%)
- Films (2.1%)

Q.11 **Have you ever used mobile phone or computer applications for revision or memory/brain training?**

- Yes (48.9%)
- No (51.1%)

Q.12 **If yes, please give as much detail as possible (name of the application, how it was used). If no, then please respond "N/A".**

- N/A
- Nintendo DS: Brain training, Apps: memory training.
- DVLA driving exam revision software. Can't remember how it worked...
- Quizlet - creates memory cards and tests you on them
- Flashcard apps in short Q&A format for exam revision/definitions
- Word/Excel
- Reading lecture content, listening to dictated notes, practising timings (similar to chunking, but with activities. Sometimes referred to as fragmentation in the literature.)
- Peak Brain training because it was fun
- Mnemosyne, used to revise flashcards in the first and second year of university. Duolingo, for learning German at university on my phone and computer.
- Evernote as it uses the cloud, thus allowing me to make notes in lectures and revise on the go on my phone.
- Notes App on iOS for revision, driving theory test apps
- memrise - language learning. pretty much just flashcard app packaged up with nice visuals and modes
- I get lecture slides up or rehearse speeches/presentations.
- Flashcards, language apps, brain training apps
- An accounting app to practise whether something should be credited or debited for double entry bookkeeping.
- Duolingo and a flashcard app that I've forgotten the name of
- The main source of my revision would come from online media, this came in the form of YouTube videos and podcasts.

Q.13 **If there existed an effective mobile application to assist in memorising information using the Mind Palace technique, to what extent would you find this helpful?**

1 = Very Unhelpful
5 = Very Helpful

- 1 (4.3%)
- 2 (14.9%)
- 3 (36.2%)
- 4 (38.3%)
- 5 (6.4%)

Q.14 **If you have any further comments on the survey topics or otherwise, please leave them below.**

- Not sure how helpful I'd find it. I would need to try it out first to see if it's useful to me.
- An application for Pegword would probably be more useful. Put in the list you need to remember and words would be generated from the first letters or something - like solving a word wheel.
- I'd recommend looking at Huys et. al 2015 "Interplay of Approximate Planning Strategies". Has some interesting stuff on stochastic memoisation techniques used by humans when learning to solve new problems, involves memorising chunks.

- Mind palace doesn't seem like it'd be very helpful but I'm open to trying new things out.
- If the application was user-friendly like headspace with videos or animations would be good
- While I've not really made use of the mind palace technique myself, I'd be interested to see how a phone app could aid this technique.

Q.15 **If you do not mind any follow-up questions being asked, then please leave your email below. (All responses are anonymous unless you consent to providing an email).**

Responses hidden for anonymity reasons.

A.2 Interview Transcript

The below transcript is paraphrased from an interview with a final year Computer Science student at the University of Bath who uses mnemonic techniques with their revision, including the Mind Palace. The following questions were asked in order to understand the viewpoint of a typical student when attempting the Mind Palace technique.

Q.1 **What techniques do you use to commit information to memory and why? Do you think these are effective memory aids?**
"I am not aware of the technical terms for the ones I have used but they are probably most similar to the Memory Palace.

The one I used most recently was for an exam where an essay required me to remember a list of items/words. I usually pick out keywords in each sentence in order to compose a list of keywords from each sentence to remember the structure of the essay. With a list of words, I would start to create a story. So if the first word was "apple", I would picture an apple in a wacky situation, such as one with arms and legs that is sat in the sun, or something equally as funny. If the next word was "shark", I would then think of something like a giant inflatable shark jumping out of the water and eating the apple. Each word would then act as a new action in the story. When it came to the exam, I could write out my list of words which would then prompt me for the next sentence in the essay. As it has been a few weeks without practice, I can't quite remember the exact list, but I can still remember the story.

The other technique I use commonly is closer to the memory palace where, for example, I might imagine my house in order to remember a list of 10 of Nielsen's heuristics where each heuristic is in a different place. These techniques are very effective for me. I visualise the word and then make a mapping back to the encoded items."

Q.2 **What are your opinions on using the Method of Loci / Mind Palace to remember information? Can you think of any advantages or disadvantages to its use?**

"I am convinced of the Mind Palace's effectiveness. For my most recent exam, I used it to remember a list of around 20 words. I know that memory champions use the technique to remember staggering numbers of words in a list or card types in a deck, so it is very advantageous for remembering that type of information. When I first use the technique to create a palace, I generally only need one run-through in order to remember the entire list for about 10 minutes, so it is quite effective even with a small number of trials.

The main disadvantage, in my opinion, is the cognitive effort involved in creating the initial list. A recent example for me was the phrase "difficult to research" needing to be encoded. For that to be encoded, I had to come up with a suitable image in order to remember that phrase which was quite abstract. For that, I had to visualise a scientist attempting to do research whilst something was attacking him. If the information is ordered, it helps to tell a story with the information so that each event has a natural sequence.

When using a physical place for a mind palace, I did struggle using the same location for multiple palaces because it made it harder to distinguish items in palaces. I would need to use several different *familiar* locations."

Q.3 **What type of information to be remembered would make you want to use the Mind Palace in your revision? (For example, categorical, diagrammatic, etc.)**
"I have always used the Mind Palace technique with lists of words rather than image-based or visual information. I think that for visual information it might be difficult to remember verbatim in a palace as there wouldn't be any kind of processing involved when the item is encoded. Perhaps it would only work if the chart, graph or diagram became animated or metamorphosised in some way to make it memorable."

Q.4 **The Mind Palace technique can use either real or imaginary palaces and can involve exploring these physically or mentally when using the technique. Have you tried both approaches? If so, which do you find less challenging and more effective?**
"Whenever I have practised the Mind Palace technique before it has always been a mental journey through a familiar place. I would be curious to see if the physical navigation of a palace made any difference to me or not. I tend to use my house for an unordered set of items, whereas for an ordered set of items I would imagine a story. It is therefore difficult to compare the two approaches as I use both."

Q.5 **Could you describe in detail the process you follow when *encoding* items in your chosen palace? Please include rationale on what you choose as the palace and why, the way you encode information at each locus etc.**
"My general approach would be to take a map of topics or a list of words that I need to remember and figure out whether the map or list needs to be in a particular order or not. After this, I will look at each word and come up with something scary, colourful, bizarre or funny to imagine it by. I also like to have sounds at each locus. Having a character in a story talking is useful to make them vivid."

Q.6 **Could you describe in detail the process you follow when *retrieving* items in your chosen palace? Please include rationale on the route you may choose and why, the way you transform information from its encoded form back into meaningful information etc.**
"For example, with the house palace I had, I would walk into a room and see someone firing a missile saying something. From what they said, I would remember the item as they mentioned the item in their speech. This method is easy to encode loci but harder to remember what the item was itself as there is no processing of the item, it is just mentioned in the speech. Recalling an item in the house is done by visiting each of the rooms as I tend to have a 1 to 1 mapping between rooms and items to distinguish items more easily. From there I would question why I visited that particular room, which usually results in the item being recalled."

Q.7 **How do you usually verify that you have remembered all items in the palace you have created?**
"I don't usually have any kind of checklist. I usually maintain a 1 to 1 mapping between rooms and items so if I visit a room and can't remember it, that triggers a mental note to myself that I need to revisit and potentially encode that item in a better way. I haven't tried tracking items I struggle to remember after each pass, but I would be interested to try.

With the story-based approach, as one event leads to another due to the ordering, it is fairly easy to spot when an item has been missed because part of the story is missing. With the Mind Palace approach, however, it is even easier as the room itself is empty."

Q.8 **What distinctive features of a loci makes you choose it as a place to store information?**
"Making items strange, colourful, scary, or funny helps to make it distinct. I also tend to try and relate the item being encoded back to the room - so if I was memorising an item in the kitchen, I might visualise Gordon Ramsay (the well-known chef) doing something to the item to remember more easily that the item was in the kitchen."

Q.9 **How regularly and for how long do you practice the technique in order to start noticing results and benefits in enhanced recall?**
"I generally start around 2 weeks or so before my exam. When I start I map out the list of words and follow the process I described earlier. It usually takes about 5 to 10 minutes to come up with an average sized set of encoded items and place them in a palace. I usually take a few iterations in case certain items aren't working very well so I can change their encodings. If the item isn't interesting or memorable, for example, then I would change how I imagine it. I try not to remember many lists for a given exam as I find this might confuse me."

Q.10 **What makes a "good" memory palace in your opinion? Here "good" is used to mean characteristics of a palace whose items are easily remembered.**
"Usually, familiarity is the major factor. Being able to spend less time struggling

to remember the palace and more time focusing on the items being remembered is key."

Q.11 **What are your thoughts on a mobile application designed to support memorisation using the Mind Palace technique? Have you ever known another application attempt this?**
"I haven't noticed or seen any applications that use the Mind Palace technique. Because of that, I am intrigued to see how you might go about designing and implementing it. I would find it difficult to comment, but all I usually have is my story in my head and the list of items to remember."

Q.12 **What features would you like an application like this to have in order to support you in making and practising palaces?**
"When visiting an application I would like to see the encoded item rather than the original word or phrase itself. That's what you are trying to remember here, rather than the word itself. When you view the image, you then map that back to the item. The app would ideally support that.

My typical process usually involves physically writing down the topic - for example, representational reasoning, then noting down the encoded image description next to it. If I could have a way to name the item being remembered and have a description or image of what it is represented by then that would be ideal."

Q.13 **Are there times when you would feel like feedback on which items you cannot remember correctly in your palace would be helpful? If yes, how should this be presented?**
"I think that tracking progress over time might not necessarily be too helpful from a memorisation perspective, except perhaps as a motivator. It is only really necessary to keep a note of what you didn't remember on the last run-through of the palace as either you remember it or you don't. Sometimes palaces need changing in light of this information. I would need to try out a feature to see if tracking the information was effective."

Q.14 **Would you consider participating in any future user studies to help evaluate my application?**
"Yes, of course!"

Q.15 **If the conclusion of my experiments suggest that technology can indeed effectively assist the mind palace technique, would you hypothetically consider using this application with future revision?**
"Yes, I would definitely."

Appendix B

Requirements Specification

Source Key

The source of the below requirements will be denoted by the following key:

- **LTS** - Literature Review
- **US** - User Survey
- **I** - Interviews
- **A** - Author (Christopher J. Davies)

B.1 Functional Requirements

General

F1.1 Users *must* be able to sign into the application using a username and password.
Source: A.

F1.2 There *should* be an option to sign up for the application using a name, username and password.
Source: A.

F1.3 The application *could* sign into the application automatically on every new sign up.
Source: A.

F1.4 Users *should* be able to delete their account at any time which erases all their data.
Source: A.

F1.5 Users *should* be able to access their account and log in via any Android device running the application.
Source: US.

F1.6 The system *must* handle the case of incorrect credentials being used as a login attempt by denying access to the application.
Source: A.

F1.7 The system *must* be functional in physical spaces of at least classroom size.
Source: LTS - [Perrault et al., 2015, Yamada et al., 2017*a*,*b*, Rosello et al., 2016, Rosello, 2017, Wieland et al., 2017].

Palace Creation

F2.1 A user *must* be able to create a "palace" (a logically-connected set of items to be remembered).
Source: LTS - [Perrault et al., 2015, Yamada et al., 2017*a*,*b*, Rosello et al., 2016, Rosello, 2017, Wieland et al., 2017].

F2.2 A palace *must* be given a title and description, associated with a user.
Source: LTS.

F2.3 The application *should* allow multiple palaces to be created.
Source: LTS - [Perrault et al., 2015, Yamada et al., 2017*a*,*b*, Rosello et al., 2016, Rosello, 2017, Wieland et al., 2017].

F2.4 Users *should* be able to delete their palace at any time which erases all notes created under this palace.
Source: A.

F2.5 Users *should* be able to create a palace within 2 clicks from the home screen.
Source: A.

F2.6 Multiple users *should* be able to create a palace with the same title, description and notes without updates to the content of one user's palace interfering with the other.
Source: A.

F2.7 The system *must* provide meaningful feedback to confirm palace creation.
Source: A.

F2.8 The system *must* allow a user to browse a list of all palaces they have created.
Source: A.

F2.9 The system *could* allow a user to add custom objects to a bird's-eye map of the palace to aid navigation.
Source: A.

F2.10 The system *won't* allow multiple users to share the same palace.
Source: A.

Palace Navigation

F3.1 The system *must* be able to listen for changes in user position.
Source: LTS - [Harand et al., 2012, Mueller et al., 2012, Perrault et al., 2015, Yamada et al., 2017*a*,*b*, Rosello et al., 2016, Rosello, 2017, Wieland et al., 2017].

F3.2 The system *must* update the user interface to reflect a change in position, tracking the user's movements.
Source: LTS.

F3.3 The system *must* interface with location-tracking technology in order to determine a user's position.
Source: A.

F3.4 The system *won't* require any physical fiducial markers besides sensors used to detect location.
Source: LTS - [Perrault et al., 2015, Yamada et al., 2017*a*,*b*, Rosello et al., 2016, Rosello, 2017, Wieland et al., 2017].

Note Creation

F4.1 A user *must* be able to create a "note" (an atomic piece of information to be remembered).
Source: LTS - [Perrault et al., 2015, Yamada et al., 2017*a*,*b*, Rosello et al., 2016, Rosello, 2017, Wieland et al., 2017].

F4.2 A note *must* be given a title and description, associated with a palace.
Source: LTS.

F4.3 A user *must* be able to create multiple "notes" associated with a given palace.
Source: LTS - [Perrault et al., 2015, Yamada et al., 2017*a*,*b*, Rosello et al., 2016, Rosello, 2017, Wieland et al., 2017].

F4.4 Users *should* be able to create a note within 2 clicks from the home screen.
Source: A.

F4.5 A note *must* be associated with the location of the user's device when the note was originally created.
Source: LTS - [Eichenbaum et al., 1999, Eichenbaum, 2000, Cain et al., 2006].

F4.6 A note *should* be associated with a chosen image, either from a user's local storage or via a URL.
Source: LTS.

F4.7 The application *must* store a "status" field associated with a given note to indicate if the user has remembered that piece of information the last time it was retrieved during training (default value set to false).
Source: LTS.

F4.8 The system *must* provide meaningful feedback to confirm note creation.
Source: A.

F4.9 The system *could* allow other media such as animations, video or audio to be associated with a given note.
Source: I, LTS - [McDaniel and Einstein, 1986, Burns, 1996].

Note Retrieval

F5.1 The system *must* factor in a suitable radius around location captured when retrieving notes to allow for error offsets in determining a user's location.
Source: A.

F5.2 The system *must* handle the scenario when no note is detected in a given location.
Source: A.

F5.3 The system *must* display details about a given note (title, description, image) when the user revisits the location it was created.
Source: LTS - [Schacter and Tulving, 1994, Harand et al., 2012, Mueller et al., 2012].

Progress Tracking

F6.1 The system *must* ask the user a Yes/No question to determine whether the note was remembered accurately when in training mode.
Source: LTS.

F6.2 The system *must* show the user their progress (number of notes accurately remembered) when they view one of their palaces in the application.
Source: LTS.

F6.3 The system *must* show the user which notes are not currently "remembered" (based on the user's feedback provided the last time this note appeared in the application).
Source: LTS.

F6.4 The system *could* allow users to view a history of their progress, indicating whether they see an improvement over multiple sessions of using the application.
Source: A.

F6.5 The system *could* implement a rewards scheme, whereby users attempt to reach targets for improvement.
Source: LTS - [Goshevski et al., 2017].

B.2 Non-Functional Requirements

Software Quality and Maintenance

NF1.1 The application *must* be able to run on Android smart phones running Android 5.1 and above.
Source: US.

NF1.2 The application *must* be easy to use, reliable and robust, ensuring smooth operation.
Source: US.

NF1.3 The application *should* not consume a lot of battery.
Source: A.

NF1.4 The application *should* be able to run on cheaper mobile phones.
Source: A.

NF1.5 The application *should* be able to scale for different mobile phone screen resolutions.
Source: A.

NF1.6 The application *should* adhere to the design standards of the Android operating system.
Source: A.

NF1.7 The application *must* adopt a consistent colour scheme and design across all functionality, especially between note creation and retrieval.
Source: LTS - Tulving and Thomson [1973].

NF1.8 The application *could* allow customisation of colour schemes and allow personalisation such as user profiles.
Source: US.

NF1.9 The application *could* allow users to create content off-line.
Source: A.

NF1.10 The application *must* ask users permission to turn on Bluetooth scanning and have an active network connection.
Source: A.

NF1.11 The application source code *should* be backed up in several places, hosted privately and version-controlled using Git tools.
Source: A.

Data Storage and Hardware Interaction

The system must have a robust way to store and retrieve data a user creates when using the application.

NF2.1 A mobile phone *must* be able to run the application and interface with necessary hardware for tracking a user's location.
Source: A.

NF2.2 Data created using the application *must* be stored and accessed remotely to allow a user to be able to run the application on different Android mobile devices.
Source: A.

NF2.3 The application *should* allow different users to have separate accounts on the application, allowing multi-user support.
Source: US.

NF2.4 The application *must* retrieve data from the remote storage in 5 seconds or less.
Source: A.

NF2.5 The application *must* update a user's position on the interface within 15 seconds of them moving to another location.
Source: A.

Security

The system will only store names of certain users - a username and password may be used to differentiate users, but users will be made aware that this data is not encrypted.

NF3.1 Personal data *won't* be collected without explicit consent of users.
Source: A.

NF3.2 The application *won't* perform any encryption on any passwords or other data stored.
Source: A.

User Evaluation

Certain requirements are needed to allow a meaningful user study to be carried out.

NF4.1 A user evaluation *must* identify whether users of HTT show better recall of information than the traditional MoL technique and control groups.
Source: LTS - [Perrault et al., 2015, Yamada et al., 2017*a*,*b*, Rosello et al., 2016, Rosello, 2017, Wieland et al., 2017].

NF4.2 The application *must* be able to store enough notes per path to make for a meaningful user study.
Source: LTS - [Perrault et al., 2015, Yamada et al., 2017*a*,*b*, Rosello et al., 2016, Rosello, 2017, Wieland et al., 2017].

Appendix C

Design Evidence

C.1 Iteration 1 - Initial Sketched Mockup

Figure C.1: Sign in

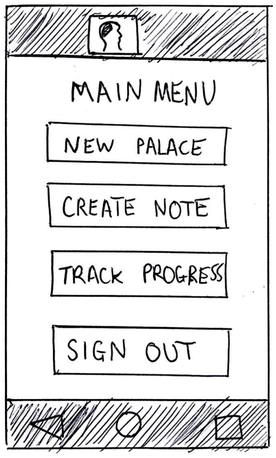


Figure C.2: Main menu

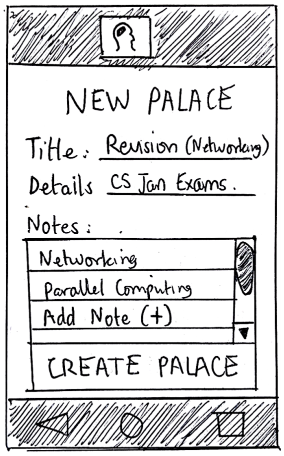


Figure C.3: Create Palace

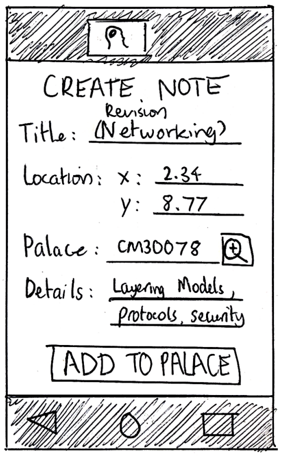


Figure C.4: Create Note

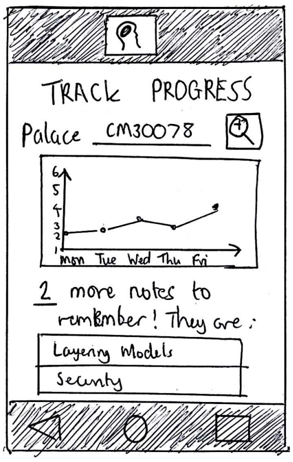


Figure C.5: Progress

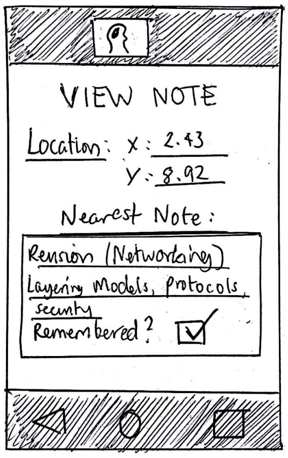


Figure C.6: View Note

C.2 Iteration 2 - Balsamiq Wireframe

Figure C.7: Sign In

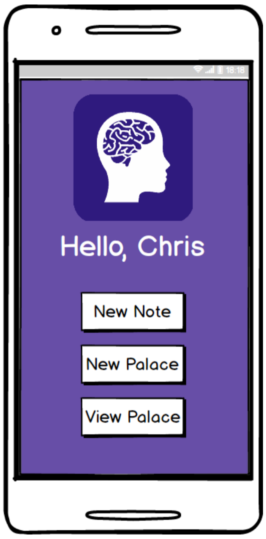


Figure C.8: Main Menu

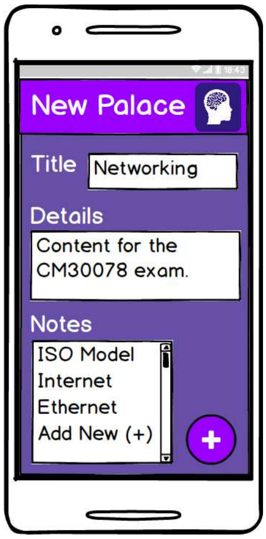


Figure C.9: Create Palace

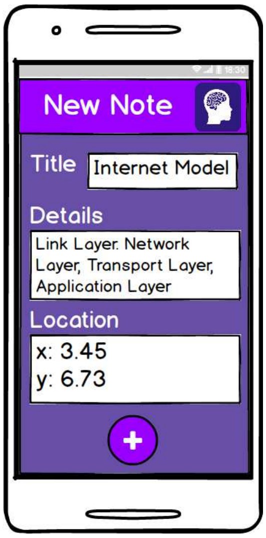


Figure C.10: Create Note

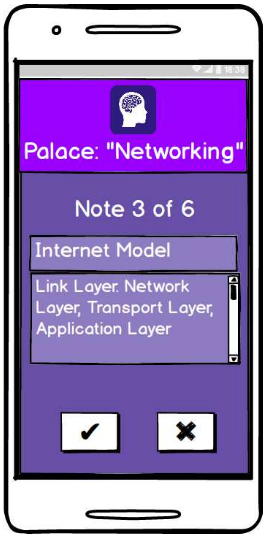


Figure C.11: View Note

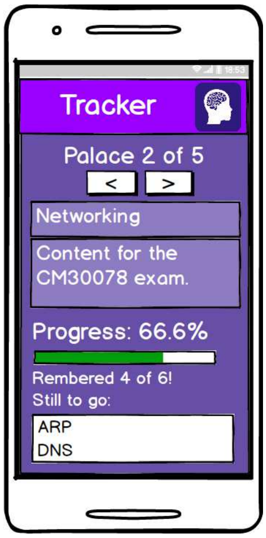


Figure C.12: Progress

C.3 Iteration 3 - Proto.io Wireframe

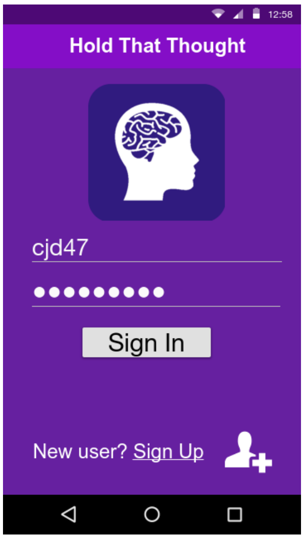


Figure C.13: Sign In

Figure C.14: Sign Up

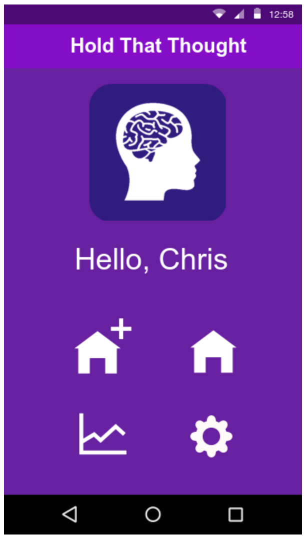


Figure C.15: Main Menu

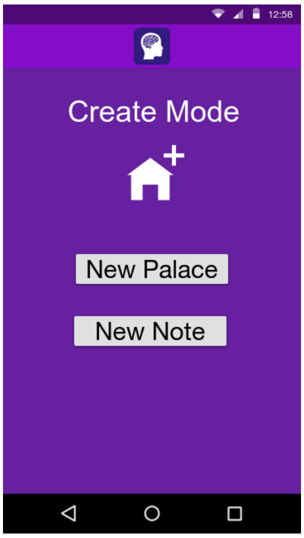


Figure C.16: Create Menu

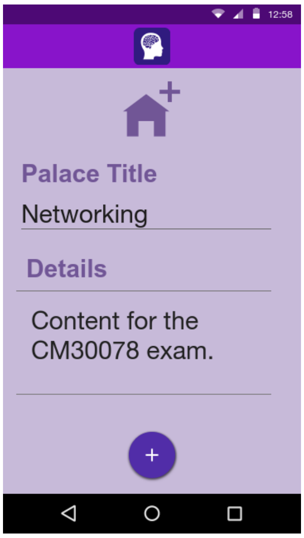


Figure C.17: New Palace

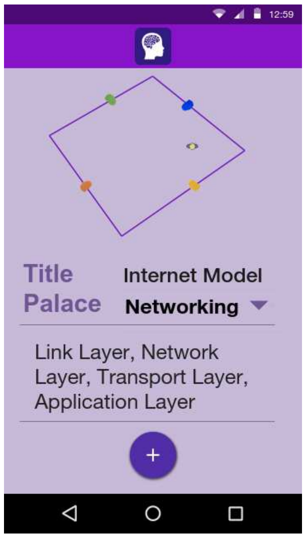


Figure C.18: Create Note

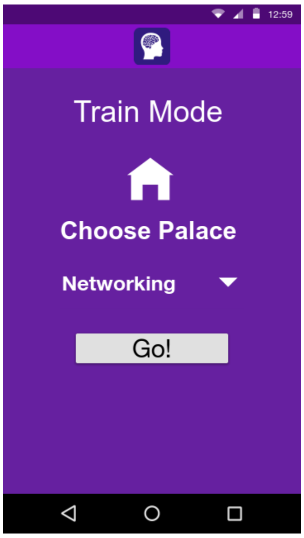


Figure C.19: Train Menu

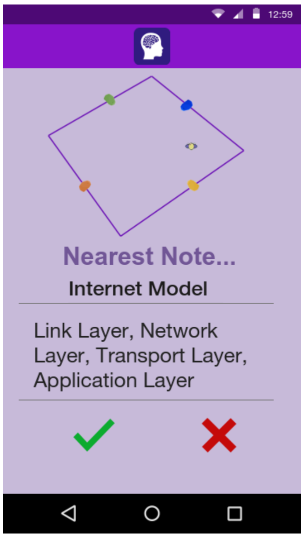


Figure C.20: View Note

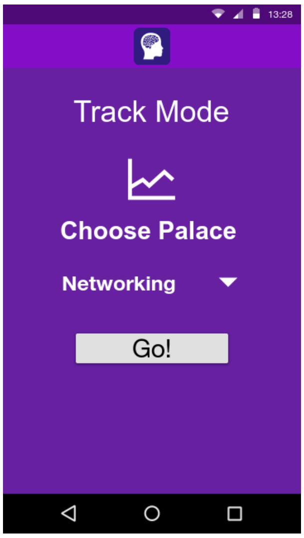


Figure C.21: Track Menu

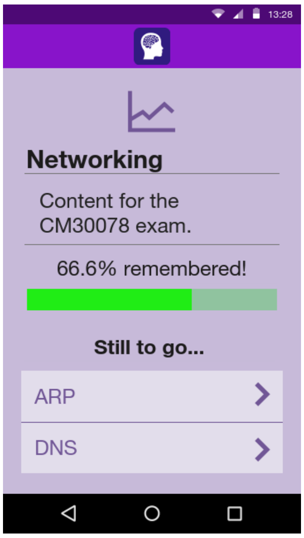


Figure C.22: Track Progress

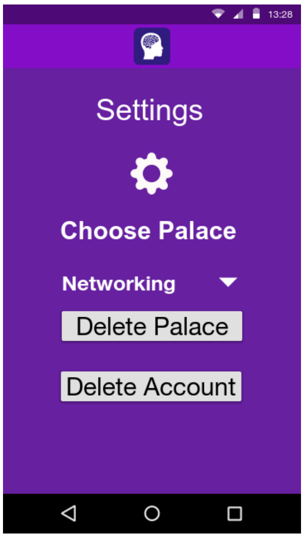


Figure C.23: Settings

Appendix D
Design Feedback

"Hold That Thought": UI Design Feedback

Responses: 8

Source: `https://goo.gl/forms/gfdXZlNoSra29DJB3`

Techniques (mnemonics) such as the Method of Loci / "Mind Palace" have been shown to enhance information recall over simple rote learning techniques.

For my dissertation, I will be creating an Android mobile application for memorising information using the Mind Palace technique.

Research question: "Can technology effectively assist users with practising the Method of Loci technique to memorise information?"

SUMMARY:

- The application will use Bluetooth technology to track users' locations in a room.
- Users will be able to:
  - create many different palaces in the same room.
  - add notes (text and an accompanying online image) to their palace by walking around the room.
  - "retrieve" notes by revisiting the locations they were added.
  - record whether they have remembered the information correctly.
  - track how many notes in a palace they have remembered.

SURVEY STEPS:

1. DESIGNS - View the wireframe design here: `https://drive.google.com/open?id=1XrJO8SOmYnlQSiEDakzBiYxLBeZttY0l`
2. QUESTIONS - Fill out below questions.

The data from responses gathered will be used to help inform the evaluation sections of my final year dissertation for the accreditation of BSc Computer Science at the University of Bath.

All responses are anonymous.

Design 1 Feedback

Q.1 **What do you like about the design and why?**

- It is nice and simple, not too complex - the purpose of screens are clear from their name.
- It seems to use native Android components such as lists and buttons.
- Ability to track my progress.
- Can create more than one palace.
- Screens are pretty consistent.
- Not too complex - styles are consistent.
- Seeing which notes are still to go in a palace is a nice touch.

Q.2 **What do you not like about the design and why?**

- N/A
- Graph seems a bit too detailed for a mobile application.
- Why do I need to search by name for a palace? Can I use a list instead?
- Not personalised enough.
- Inconsistency in terms - both "new" and "create" used. Which term means what?

Q.3 **Is anything unclear? If so, what improvements could be made?**

- N/A
- Can the tracking screen just show the latest results instead of progress over time?
- The interface is quite cluttered with a lot of text and no icon-based buttons.
- I would like to be able to select palaces from a list instead of searching by name.
- Shouldn't note content be shown above its location when a note is retrieved?
- It would be nice to add some personalisation to screens such as displaying the name of who is logged in.

Design 2 Feedback

Q.1 **What do you like about the design and why?**

- The added personalised message on log-in.
- Swapping a graph of progress for a simpler progress bar.
- Use of icons for buttons in most cases.
- Title and description of notes and palaces at the top of creation screens.
- The colour scheme is aesthetically pleasing.

- Screens are more consistent than before.
- Moving text to the toolbar.

Q.2 **What do you not like about the design and why?**

- N/A
- I don't think co-ordinates for location are particularly useful.
- Not clear from note creation screen which palace the note is added to.
- Scrolling one by one through palaces to track progress could get laborious.

Q.3 **Is anything unclear? If so, what improvements could be made?**

- It would be nice to separate palace and note creation screens.
- Currently all functionality is displayed in one main menu. Can this be separated into menus for creation, tracking and training if these are separate features?
- Use a visualised map instead of textual co-ordinates as locations.
- Make note creation and retrieval screens more consistent in design.
- Instead of navigating back and forth sequentially through palaces using back and forward buttons, I would prefer to select the palace beforehand.

Design 3 Feedback

Q.1 **What do you like about the design and why?**

- Looks very professional!
- Menu structure - icons are a nice addition.
- Map feature to see my current location on the map.
- Location tracking! Much nicer to see a person on a map than numbers as coordinates.
- UI looks less cluttered now.
- Ability to delete palaces if a mistake is made in one.
- Selecting a palace from a list instead of searching.

Q.2 **What do you not like about the design and why?**

- N/A
- What does clicking on the notes "still to go" take me to? Can I see more details including where the note is stored?
- Colour scheme should match the logo a bit more.

Q.3 **Is anything unclear? If so, what improvements could be made?**

- N/A
- Allow users to add an image via URL or camera roll.
- Add a screen to view the note's location from the progress tracking screen.
- Match the colour scheme more closely to the logo colours.

Appendix E

Implementation Evidence

E.1 HTT (Android) Mobile Application

Screenshots of the final mobile application. Demo: `https://youtu.be/RwE5stBE0IA`

Figure E.1: Splash screen.

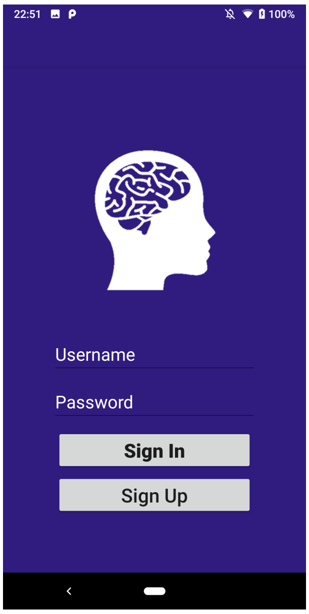


Figure E.2: Sign in.

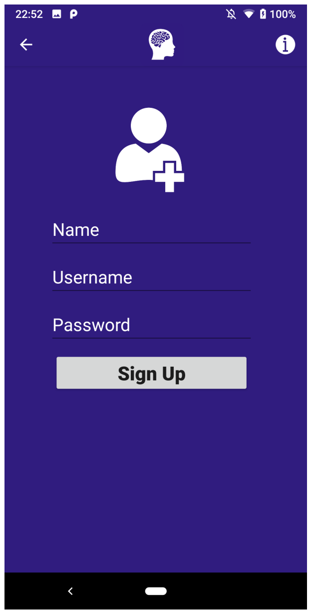


Figure E.3: Sign up.

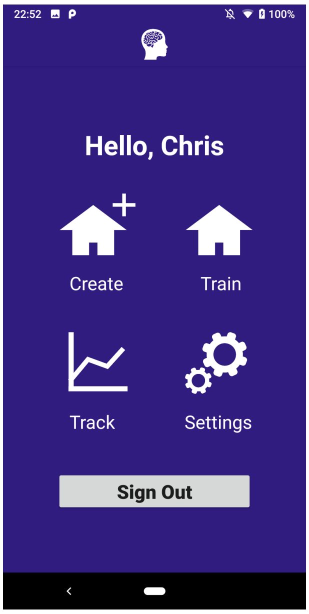


Figure E.4: Main menu.

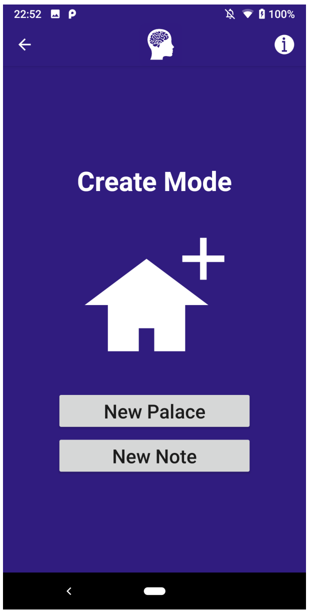


Figure E.5: Create menu.

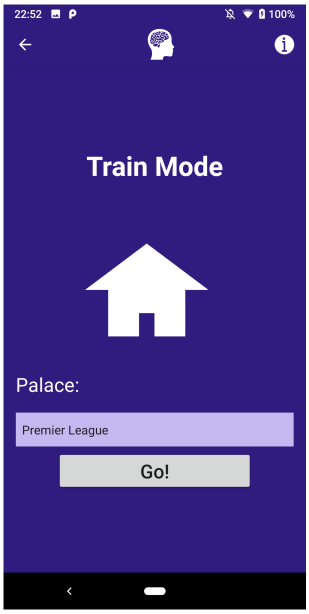


Figure E.6: Train menu.

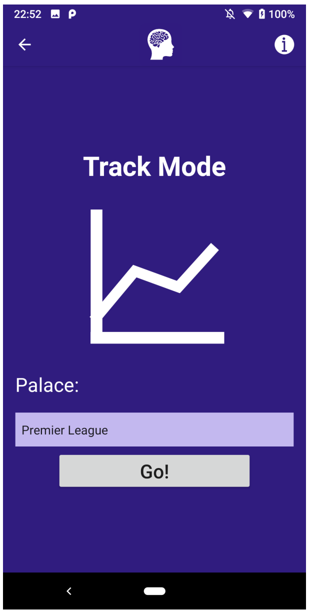


Figure E.7: Track menu.

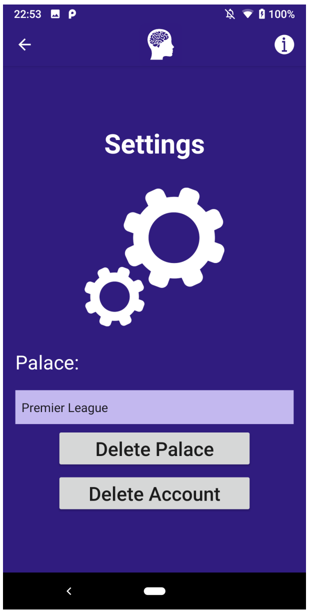


Figure E.8: Settings.

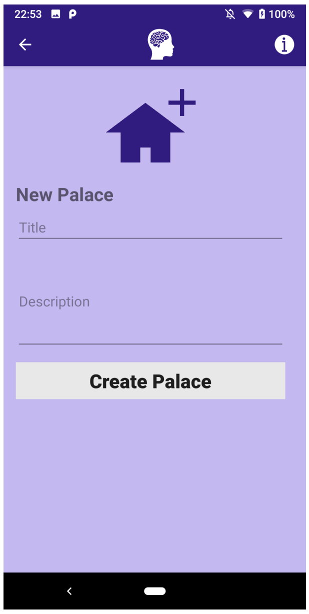


Figure E.9: New palace.

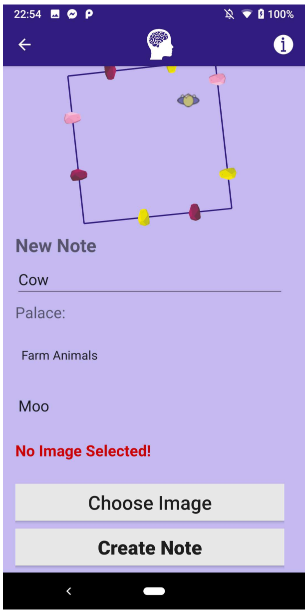


Figure E.10: New note.

Figure E.11: New note.

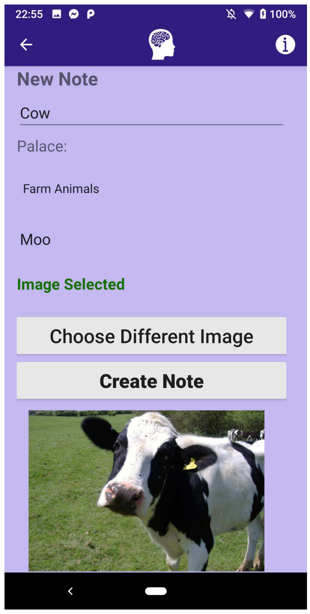


Figure E.12: New note.

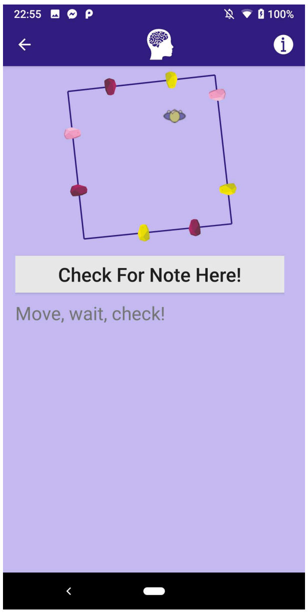


Figure E.13: Retrieve note.

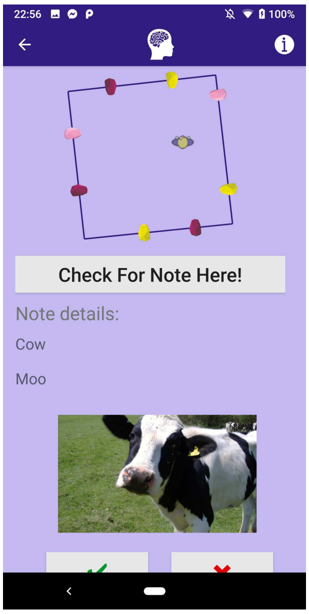


Figure E.14: Retrieve note.

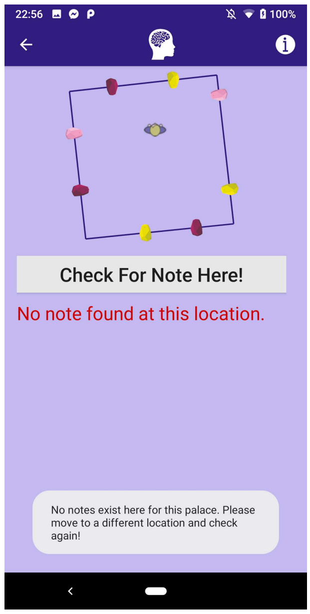


Figure E.15: Retrieve note.

Figure E.16: Progress.

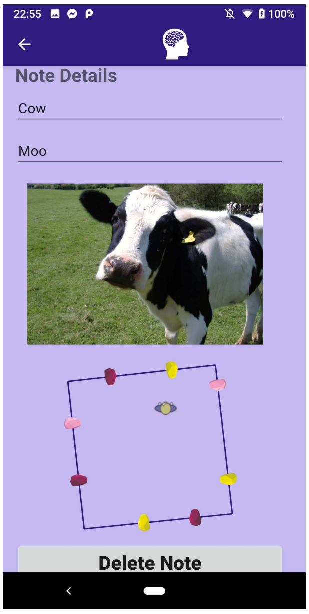


Figure E.17: Note details.

Figure E.18: Progress.

E.2 RESTful Web Service

RESTful service for Create, Read, Update, Delete (C.R.U.D.) operations on Mind Palace project data. Service root URL: `https://mindpalaceservice.herokuapp.com/`

The following endpoints have been implemented:

- `GET /users`
- `GET /palaces`
- `GET /notes`
- `GET /user/<user_id>`
- `GET /userbyusername/<user_username>`
- `GET /palace/<palace_id>`
- `GET /palacesbyuser`
- `GET /note/<note_id>`
- `GET /notesbypalace/<palace_id:integer>`
- `GET /nearestnote/<palace_id>`
- `GET /unremememberednotes`
- `GET /progress`
- `POST /newuser`
- `POST /newpalace`
- `POST /newnote`
- `POST /updatenotestatus/<note_id>`
- `DELETE /user/<user_id>`
- `DELETE /userbyusername/<user_username>`
- `DELETE /notesbypalace/<palace_id:integer>`

- DELETE /palace/<palace_id>
- DELETE /note/<note_id>

More details: https://gitpitch.com/cd223/MindPalaceService

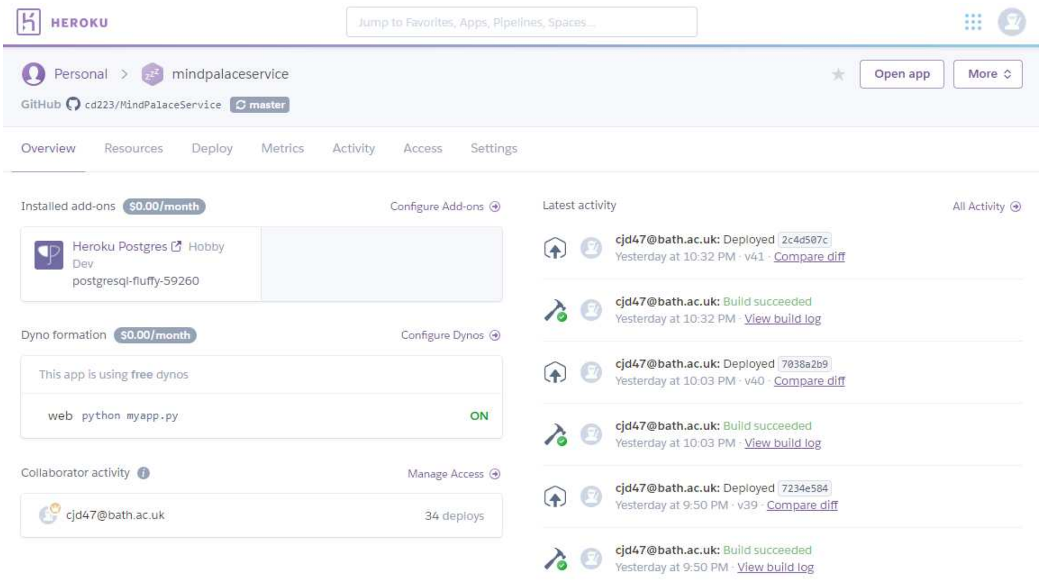


Figure E.19: Heroku dashboard displaying details of the Web service.

E.3 PostgreSQL Database

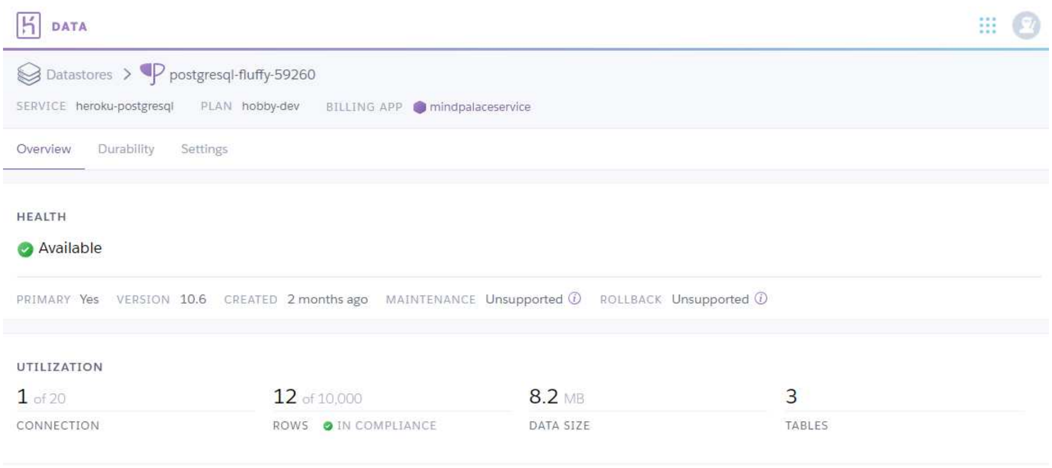


Figure E.20: Snapshot of the database when hosted on Heroku.

Appendix F

Testing Evidence

F.1 Unit Testing

HTT Mobile Application

Sign In Screen

UT1.1 **Sign In Button - Valid Credentials (Mocked REST Call)**
On entry of a valid username and password and tapping the Sign In button (mocking a successful REST call), a user must be taken to the Main Menu screen with a 'Login successful' toast displayed.

- **Priority:** High — **Pass/Fail:** Pass

UT1.2 **Sign In Button - Invalid Credentials (Mocked REST Call)**
On entry of an invalid username or password and tapping the Sign In button (mocking an unsuccessful REST call), a user must be denied access to the Main Menu screen with a 'Login failed' toast displayed.

- **Priority:** High — **Pass/Fail:** Pass

UT1.3 **Sign Up Button**
On tapping the Sign Up button, a user must be taken to the Sign-Up screen.

- **Priority:** High — **Pass/Fail:** Pass

Sign Up Screen

UT2.1 **Sign Up Button (Mocked REST Call)**
On entry of a valid name, username and password and tapping the Sign Up button (mocking a successful REST call), a user must be taken to the Main Menu screen.

- **Priority:** High — **Pass/Fail:** Pass

Main Menu Screen

UT3.1 **Sign Out Button**
On tapping the Sign Out button, a user must be logged out of the application and taken to the Sign In screen.

- **Priority:** High — **Pass/Fail:** Pass

UT3.2 **Personalisation**
The name of the user must be displayed on the Main Menu at all times.

- **Priority:** Medium — **Pass/Fail:** Pass

UT3.3 **"Create Mode" Button**
On tapping the Create Mode icon, a user must be taken to the Create Menu screen.

- **Priority:** High — **Pass/Fail:** Pass

UT3.4 **"Train Mode" Button**
On tapping the Train Mode icon, a user must be taken to the Train Menu screen.

- **Priority:** High — **Pass/Fail:** Pass

UT3.5 **"Track Mode" Button**
On tapping the Track Mode icon, a user must be taken to the Track Menu screen.

- **Priority:** High — **Pass/Fail:** Pass

UT3.6 **Settings Button**
On tapping the Settings icon, a user must be taken to the Settings screen.

- **Priority:** High — **Pass/Fail:** Pass

Create Menu Screen

UT4.1 **New Palace Button**
On tapping the New Palace button, a user must be taken to the Create Palace screen.

- **Priority:** High — **Pass/Fail:** Pass

UT4.2 **New Note Button**
On tapping the New Note button, a user must be taken to the Create Note screen.

- **Priority:** High — **Pass/Fail:** Pass

Create Palace Screen

UT5.1 **Create Palace Button (Mocked REST Call)**
On entry of a title and description and tapping the Create Palace button (mocking a successful REST call), the user must be taken to the Main Menu screen with a 'Palace '[title]' created.' toast displayed.

- **Priority:** High — **Pass/Fail:** Pass

Image Loader

UT6.1 **Image Loading from URL**
Images must be able to be loaded from a HTTP or HTTPS URL.

- **Priority:** High — **Pass/Fail:** Pass

Create Note Screen

UT7.1 **Create Note Button (Mocked REST Call)**
On entry of a title, description and image URL, and tapping the Create Note button (mocking a successful REST call), the user must be taken to the Main Menu screen with a 'Note '[title]' created.' toast displayed.

- **Priority:** High — **Pass/Fail:** Pass

UT7.2 **Check Image Button**
On tapping the Check Image button after entering a valid URL of an image, a user must see the image displayed at the bottom of the screen.

- **Priority:** High — **Pass/Fail:** Pass

Train Menu Screen

UT8.1 **Palace Selection (Mocked REST Call)**
On loading the activity, a list of palaces the user has created must be fetched and loaded into the Spinner selection on the current screen.

- **Priority:** High — **Pass/Fail:** Pass

UT8.2 **"Go!" Button**
On tapping the "Go!" button, a user must be taken to the View Note screen.

- **Priority:** High — **Pass/Fail:** Pass

Track Menu Screen

UT9.1 **"Go!" Button**
On tapping the "Go!" button, a user must be taken to the View Palace screen.

- **Priority:** High — **Pass/Fail:** Pass

F.2 Integration and API Testing

HTT Mobile Application

Sign In Screen

IT1.1 **Sign In Button - Valid Credentials**
On entry of a valid username and password and tapping the Sign In button, a user must be taken to the Main Menu screen with a 'Login successful' toast displayed.

- **Priority:** High — **Pass/Fail:** Pass

IT1.2 **Sign In Button - Invalid Credentials**
On entry of an invalid username or password and tapping the Sign In button, a user must be denied access to the Main Menu screen with a 'Login failed' toast displayed.

- **Priority:** High — **Pass/Fail:** Pass

Sign Up Screen

IT2.1 **Sign Up Button**
On entry of a valid name, username and password and tapping the Sign Up button, a user must be registered with the system and taken to the Main Menu screen.

- **Priority:** High — **Pass/Fail:** Pass

Create Palace Screen

IT3.1 **Create Palace Button**
On entry of a title and description and tapping the Create Palace button, a new palace must be stored and the user must be taken to the Main Menu screen with a 'Palace '[title]' created.' toast displayed.

- **Priority:** High — **Pass/Fail:** Pass

Create Note Screen

IT4.1 **Location tracking**
On loading the activity, the location must be fetched from the Estimote Cloud and a Bluetooth listener must scan for position updates.

- **Priority:** High — **Pass/Fail:** Pass

IT4.2 **Create Note Button**
On entry of a title, description and image URL, and tapping the Create Note button, a new note must be stored and the user must be taken to the Main Menu screen with a 'Note '[title]' created.' toast displayed.

- **Priority:** High — **Pass/Fail:** Pass

Train Menu Screen

IT5.1 **Palace Selection**
On loading the activity, a list of palaces the user has created must be fetched and loaded into the Spinner selection on the current screen.

- **Priority:** High — **Pass/Fail:** Pass

View Note Screen

IT6.1 **Location Tracking**
On loading the activity, the location must be fetched from the Estimote Cloud and a Bluetooth listener must scan for position updates.

- **Priority:** High — **Pass/Fail:** Pass

IT6.2 **Check Button**
On tapping the Check button, a user must see the nearest note's title, description and image displayed on the screen.

- **Priority:** High — **Pass/Fail:** Pass

IT6.3 **Mark as Remembered Button**
On tapping the ✔button, the status of the currently-displayed note must be updated to "true" (remembered) and the user should see a 'Note '[title]' marked as remembered' toast displayed.

- **Priority:** High — **Pass/Fail:** Pass

IT6.4 **Mark as Unremembered Button**
On tapping the ✖button, the status of the currently-displayed note must be updated to "false" (unremembered) and the user should see a 'Note '[title]' marked as NOT remembered' toast displayed.

- **Priority:** High — **Pass/Fail:** Pass

Track Menu Screen

IT7.1 **Palace Selection**
On loading the activity, a list of palaces the user has created must be fetched and loaded into the Spinner selection on the current screen.

- **Priority:** High — **Pass/Fail:** Pass

View Palace Screen

IT8.1 **Progress Tracking**
On loading the View Palace screen, a user must see the selected palace's title,

description, progress (% of notes marked as remembered) and list of notes still to be marked as remembered.

- **Priority:** High — **Pass/Fail:** Pass

IT8.2 **Note Details**
On tapping any of the displayed notes that are still to be marked as remembered, the user should be able to view the note title, description, image and location.

- **Priority:** High — **Pass/Fail:** Pass

RESTful Web Server

Users

IT9.1 `GET /users`
List all users as a JSON.

- **Priority:** High — **Pass/Fail:** Pass

IT9.2 `GET /user/<user_id>`
List user with this ID as a JSON.

- **Priority:** High — **Pass/Fail:** Pass

IT9.3 `GET /userbyusername/<user_username>`
List user with this username as a JSON.

- **Priority:** High — **Pass/Fail:** Pass

IT9.4 `POST /newuser`
Create new user with details contained a JSON.

- **Priority:** High — **Pass/Fail:** Pass

IT9.5 `DELETE /user/<user_id>`
Delete user with this ID.

- **Priority:** High — **Pass/Fail:** Pass

IT9.6 `DELETE /userbyusername/<user_username>`
Delete user with this username.

- **Priority:** High — **Pass/Fail:** Pass

Palaces

IT10.1 `GET /palaces`
List all palaces as a JSON.

- **Priority:** High — **Pass/Fail:** Pass

IT10.2 `GET /palace/<palace_id>`
List palace with this ID as a JSON.

- **Priority:** High — **Pass/Fail:** Pass

IT10.3 `GET /palacesbyuser`
List all palaces created by this username.

- **Priority:** High — **Pass/Fail:** Pass

IT10.4 `POST /newpalace`
Create palace with details contained in the JSON.

- **Priority:** High — **Pass/Fail:** Pass

IT10.5 `DELETE /palace/<palace_id>`
Delete palace with this ID.

- **Priority:** High — **Pass/Fail:** Pass

Notes

IT11.1 `GET /notes`
List all notes as a JSON.

- **Priority:** High — **Pass/Fail:** Pass

IT11.2 `GET /note/<note_id>`
List note with this ID as a JSON.

- **Priority:** High — **Pass/Fail:** Pass

IT11.3 `GET /notesbypalace/<palace_id:integer>`
List notes under this palace ID as a JSON.

- **Priority:** High — **Pass/Fail:** Pass

IT11.4 `GET /nearestnote/<palace_id>`
List details of note closest to current location with this palace ID as a JSON.

- **Priority:** High — **Pass/Fail:** Pass

IT11.5 `GET /unrememberednotes`
List notes marked as not remembered under this palace ID as a JSON.

- **Priority:** High — **Pass/Fail:** Pass

IT11.6 `GET /progress`
List the total of notes marked as remembered under this palace as a JSON.

- **Priority:** High — **Pass/Fail:** Pass

IT11.7 `POST /newnote`
Create a new note with these details contained in a JSON.

- **Priority:** High — **Pass/Fail:** Pass

IT11.8 `POST /updatenotestatus/<note_id>`
Update the status of the note with this ID.

- **Priority:** High — **Pass/Fail:** Pass

IT11.9 `DELETE /notesbypalace/<palace_id:integer>`
Delete all the notes under this palace ID.

- **Priority:** High — **Pass/Fail:** Pass

IT11.10 `DELETE /note/<note_id>`
Delete note with this ID.

- **Priority:** High — **Pass/Fail:** Pass

Appendix G
Usability Study

G.1 Demonstration Feedback Survey

"Hold That Thought": User Feedback

Responses: 24

Source: `https://goo.gl/forms/AkNOW4WJknQLockx1`

Techniques (mnemonics) such as the Method of Loci / "Mind Palace" have been shown to enhance information recall over simple rote learning techniques.

For my dissertation, I have created an Android mobile application for memorising information using the Mind Palace technique.

Research question: "Can technology effectively assist users with practising the Method of Loci technique to memorise information?"

SUMMARY:

- The application uses Bluetooth technology to track users' locations in a room.
- Users can:
  - create many different palaces in the same room.
  - add notes (text and an accompanying online image) to their palace by walking around the room.
  - "retrieve" notes by revisiting the locations they were added.
  - record whether they have remembered the information correctly.
  - track how many notes in a palace they have remembered.

SURVEY STEPS:

1. SLIDES - View the short slides to understand the app: `https://bit.ly/2WMvSLa`
2. VIDEO - View the short (90 sec) demo of the app: `https://youtu.be/4U--HYut0m8`

3. QUESTIONS - Fill out below questions.

The data from responses gathered will be used to help inform the evaluation sections of my final year dissertation for the accreditation of BSc Computer Science at the University of Bath.

All responses are anonymous.

Q.1 **What do you like about the application and why?**

- Great use of technology to assist with the practical task of memorisation.
- It's unique and brings to life something that was previously only a concept.
- Novel idea, encourages a different type of working (getting away from your desk).
- Cool idea and potentially useful
- Has a nice simple UI. Sounds like a good way to train memory skills. I like the progress bar to be able to track progress.
- Clean, simple and professional design.
- Great user interface, easy to use.
- I like the fact it tracks your movement and allows you to add pictures.
- The concept is sound, and the introductory menu was clearly formatted. The auto capitalization of words for the title and subtitle were a nice touch.
- Interesting abstraction of a technique usually completely internalised. I imagine it would help users to understand how the Mind Palace technique works, where they otherwise may not have.
- It's a clever use of technology to better peoples' lives.
- Simplicity of design, ability to track progress.
- It looks like a novel way of revising/learning. As well as encouraging the use of the mind palace technique, the interactivity of the app may help the game be more engaging.
- It aims to solve a problem I have - bad memory.
- Great concept because it is a more interactive way of memorisation.
- I like how it proposes a different approach to memorising information, which is a task everyone faces.
- I like that it's something new - I've never seen an application like this.
- It has a good cause - memorising things.
- It's quite unique, I've never seen anything like this.
- It's a unique idea, haven't seen anything like it in the market. Can be applied to a lot of fields.
- It gives more variety to methods of revising and therefore makes me not procrastinate as much.
- Memorisation is a difficult task, particularly in the context of mundane topics. This idea provides a physically engaging and visual way to approach memorisation.
- I like that the app is interactive and requires you to move around your environment. It aids the traditional mind palace recall method rather than replaces it. The app looks user-friendly and tracks individual progress.

- Might not be as beneficial for more in-depth recall such as complex theoretical understanding etc, rather more appropriate for lists or fixed answers.
- It requires you to walk around the room, this is both a really good thing but also might be a weakness as not all situations would allow for someone to wander around the room.

Q.2 **What do you dislike about the application and why?**

- N/A (x4)
- Could perhaps do with sleeker UI.
- Looks like you need to have fixed Bluetooth points around the room. Don't think I would buy these just to use the app, nor do I have enough other Bluetooth devices to use instead.
- No indication of how the app handles different size and shape rooms. Does the room need to be a certain width for it to work? Looks cumbersome to have to keep switching between Chrome and the app to paste the images. Is there a way to be able to search for images within the app? Adding each item manually seems cumbersome. Is there a way to batch add each item first, and then maybe set the locations? Is there a limit on the number of items I can add to a palace? It's not hard to remember 5 things, and there are certainly more than 5 countries in Europe.
- Being limited by the number of Bluetooth devices.
- I don't like that you must use URL links instead of uploading from the camera roll.
- The submenus and item cards look a bit too busy (possibly due to the barebones layout, strange as it sounds, since different sections don't feel like they have proper separation yet). Adding an image seems awkward given the way you'd navigate out of the app and it seemed like a lot of button presses were involved.
- Seems quite specific to categories. Support for arbitrary knowledge might be lacking.
- I think it would end up needing a lot of narrative throughout the use, in order to assist users who are not familiar with this type of technology.
- Certain aspects unclear - were the loci specific Bluetooth communicators that you would have to purchase separately? If so, this could be problematic.
- It could be possible for the app to distract you from your physical surroundings, thus limiting the impact of the mind palace technique, but I'd have to try it out to understand if it is an issue or not.
- The exercise(!)
- Nothing that I dislike!
- I don't think it's hugely practical as it requires access to a room and access to Bluetooth beacons which could be costly. Also, I feel like my methods of memorisation currently work well enough and I don't need to change my methods.
- The moving around is dependent on the size of the space etc. - nice to visualise in a lecture theatre but average homes might not have space to fully create and explore palaces.
- There doesn't seem to be any history of performance. It would be nice to

be able to see how my performance changes over different training sessions.
- The design is simple and effective, I like the ability to add a picture, this would be beneficial to those who are visual learners.

Q.3 **What is your opinion of the application's design? Do you have any suggestions to improve the user experience?**

- Simple and intuitive design.
- Looks good – no improvements I can think of. (x4)
- Appears simple. I would use Google's Material design to make it feel familiar to many existing Android applications.
- Add text to each icon. Add a help page that explains what each button does.
- I like that it is clean and minimal. If not yet available, maybe include a demo that would play following installation to show the user which buttons do what.
- Having the option to modify the background colour based on user account / see above for picture upload.
- Include a gallery of most recent pictures as an option to add an image so that they don't navigate away from the screen they're adding it to.
- Maybe to help users visualise their room, allow objects to be placed only for visual representation, e.g. table, computer etc.
- Clean and simple, which I like. Perhaps a way to see all available palaces' progress without having to click each one - almost like a leader board.
- Generally nice and simple, which is good, as it should minimise the distractions, and focus on the content at hand.
- Icons on the home screen might not be that intuitive; perhaps adding labels could make it clearer that, e.g. the house means "go to your mind palace".
- I think it would be good if the previous 'note' could slowly fade out when you move away from its location, to make it clearer that that note was associated with a different location. Again, this may impact the usability in practice, so it would be worth evaluating if this is helpful in practice.
- Minor, but some people might find it easier to take photos with the camera than to copy an image URL. Depends on who this app is aimed for, of course.
- Very minor, but it takes a surprising amount of time for the 'map' to load on some screens.
- Easy to use interface, good colours!
- You could remove the need to scroll the screen slightly each time you want to check an answer (step 2) by trying to fit everything on the screen. Otherwise, I like the design, good use of icons etc. and layout.
- I think it's good. Things seem to be easy to access and it looks functional enough. It'd probably look better and motivate me to use the application if you used Material Design rather than basic Android components though.
- I like the design - I think it's clean and neat and nice colours.
- The UI looks really clear and intuitive. The colour theme is easy on the eyes.
- Simple interface, might be nice to have labels on the landing page as the icons are not immediately obvious.

- Being able to use photos from my phone's internal gallery would be nice.
- The purpose is very clear. The design is simple and effective and its ability to be personalised is a nice touch.

Q.4 **Is the purpose of the application clear from its design? Please explain your answer, suggesting improvements if applicable.**

- Yes, the application is split up nicely into appropriate sections (create a palace, train palace, track progress) making it simple to understand and use.
- Yes, it's clear that it is a memory testing/enhancing app.
- Yes, there is no unnecessary information overpowering the screen.
- Yes you can easily see the beacons on the app and it tracks your movement so it's easy to see where you can make and view notes.
- The position in the room is clear, though it could be styled differently (e.g. with Sims-style walls) to make it look like a room rather than pipe-cleaner edges.
- Yes, to help people use the Mind Palace memory technique.
- It is clear but this is as someone with a background in memory; maybe layperson would need more information.
- Perhaps a subtitle/tagline could make it clear exactly what the app is about, from the home screen alone.
- It's not clear from the video what the 'on-boarding' process is like, but when you first use the app, it could use some prompts such as 'move around the room', to make it clear how to use the app.
- Yes, if you are familiar with Palace of Loci. (x3)
- Could have an explanation/background section for people who haven't used the mind palace technique before.
- It is clear if the user knows what a "palace" and "note" is in the context of the application. Could possibly add a brief explanation as to what you mean by a palace.
- From the home screen, the menu uses images only and it's not clear what these buttons do until you click on them. It's also not clear that these are buttons and not just images either. It might be better to give them a border.
- Yes, I think the three-point mantra works well in the app.

Q.5 **What is your favourite feature of the application? Please provide reason(s).**

- The input of images/image URLs is a nice touch, to ease the action of associating a location with something to remember/have memorised.
- The location tracking.
- The tracking/recall test. Helps you see if you're getting a benefit from the technique.
- The scoring/training functionality.
- I like that you can see live tracking of the user as you walk around the room.
- Clean design looks very professional!
- The option to include images for the nodes.
- The ability to see your movement on the screen.

- I really like Method of Loci and the idea of augmented reality to support it, so the room display is genuinely great.
- Tracking of users' location is a very intuitive way to record locations.
- The novelty! It looks fun to use.
- Its minimalism, actually – the reviewing part works as intended, and the analysis features, while basic, are enough to help track your progress.
- Adding notes.
- Can track your position in the app's map and also colour coordinating the stops is good.
- I like the live tracking of your position as it provides instant feedback regarding your movement and location in the space.
- The movement tracking is novel and sets this application apart.
- The training mode, it's unique.
- Top down map to show relative location of memory items. Makes it easy to visualise the mind palace and remember it.
- Linking each locus to an image is nice, it acts as a good memory aid.
- I like that it can be used with a varying number of palaces because this makes it more flexible.
- The Bluetooth feature to enable you to walk to specific places in the room, interacts with the real world to improve recall.

Q.6 **Are there any more features you would like to be included? Do you think there are any unnecessary features which could be removed?**

- Nothing comes to mind. (x7)
- Speech to text for notes might be useful.
- Perhaps some kind of reward system to incentivise users to use the app.
- I want to be able to make voice notes too.
- Images might not be necessary (or could be reconsidered in terms of the process to add them).
- Formatting of text would be nice, but that would probably suit a tablet more since I noticed there was very little space for anything (such as formatting buttons) on the phone.
- Object placement for visualisation and perhaps a general category for arbitrary information.
- Perhaps a way to see all available palaces and progress without having to click each one? Almost like a leader board?
- I don't know how well the app would work for directing your learning on things you don't know – if you're consistently remembering something, could it disappear from the palace for a while, and reappear later to check that you still remember it? Or would this just be confusing? It might also be nice if the app was able to (optionally) give you an overview of your mind palace, to help you get back 'into the zone' if you haven't used the app in a while.
- Some way to include handwritten notes or inputting photos from the camera.
- You should add the option of uploading images directly, uploading other media like recorded audio, maybe video. I don't think any of the features are unnecessary.

- Not really - might be good if you could share mind palaces with other people for popular places? And again, other methods for different types of learning/remembering.
- I think it's a great system in theory. I don't think anything needs to be changed.
- Does the app support irregular sized rooms (non-square)? Maybe make the map orientate to the room. Have a greater variety of markers for locations (different shapes or colours), they all look a bit similar.
- This is incredibly difficult... but the same app in a VR-like setting would be much better. It minimises movement and removes the space constraint on users.
- As I said above being able to track progress over multiple training sessions. Also as above allowing images from a phones internal gallery.
- This might already be part of the application but the ability to recall through the memory of the positions in the room i.e. tap the position on the screen whilst remembering that position in your head. That will be beneficial if an individual was revising in an environment where moving around is not possible or they aren't near the original place.

Q.7 **If experiments showed that the application effectively supports memorising information using this technique, would you consider using it?**

- Yes (50.0%)
- No (40.9%)
- Maybe (9.1%)

Q.8 **Please provide a reason for your previous answer.**

- Memorisation is useful throughout a variety of tasks we face in life, so a way to improve this process would certainly interest me.
- A greater ability to remember stuff is always good!
- Would depend on if the technique was useful for me. (x2).
- Walking around sounds like it would get tiring fast. May not always have space or room to manoeuvre either.
- Aiding in memory retention would certainly be helpful when studying and an app is easy to get hold of and use as my phone is something, I have on my person all the time.
- I think other methods of learning are personally more useful for me but would try it out to see if it worked any better than what I use now. If it's effective, then it's a useful tool to vary my revision
- As a student, effective studying is my jam.
- Improved memory would help with many day-to-day tasks in addition to recalling academic knowledge.
- Would be useful in exam revision.
- If this were to be completed before my final exams/while I was still in education, I think it would be useful in recalling studies etc., but unsure of its application to non-academic life as don't really need to memorise that much outside of university.
- I'm already entrenched in using flashcards for revision, but if this technique turns out to be effective, it could be worthwhile. However, a significant barrier could be the set-up involved of the BLE beacons.

- Well I'd need a beacon and a big room, can't see it realistically happening. Provided I have a big enough room for many notes and beacons, yes, I would. I want to use it for studying my degree, which has a lot of content, than just memorising flags or musical instruments.
- I generally write out notes to memorise content, but I would be interested to try out a new technique.
- I'd be interested to see how it could possibly be better than my current memorisation methods but wouldn't want to buy the kit and walk around a room all the time.
- Would be great for exams etc.
- I am always looking for ways to improve the efficiency of my revision.
- If the app helps with recall I would use this for exam revision.

Q.9 **Please provide any more comments you might have on the application that have not been addressed above. If you do not have any further comments, please put "N/A".**

- N/A (x22)
- Perhaps using AR techniques to map out the room could be an interesting (if less accurate) direction to take.
- I like it! Cool project.

G.2 Think Aloud Protocol Participant Consent Form

"Hold That Thought": Usability Study Participation Consent Form

Responses: 5

Source: `https://goo.gl/forms/t6bovHa9YaO8Bcqy2`

Techniques (mnemonics) such as the Method of Loci / "Mind Palace" have been shown to enhance information recall over simple rote learning techniques.

For my dissertation, I have created an Android mobile application for memorising information using the Mind Palace technique.

Please fill out the below survey to consent to participation in the usability study.

The data from responses gathered will be used to help inform the evaluation sections of my final year dissertation for the accreditation of BSc Computer Science at the University of Bath.

Student: Christopher J. Davies (`cjd47@bath.ac.uk`)
Project Supervisor: Dr Fabio Nemetz (`F.Nemetz@bath.ac.uk`)

Email address: ....

Project Details
Title: "Hold That Thought": Location-based Mind Palace generation for memorisation assistance

Research question: "Can technology effectively assist users with practising the Method of Loci technique to memorise information?"

SUMMARY:

- The application uses Bluetooth technology to track users' locations in a room.
- Users can:
  - create many different palaces in the same room.
  - add notes (text and an accompanying online image) to their palace by walking around the room.
  - "retrieve" notes by revisiting the locations they were added.
  - record whether they have remembered the information correctly.
  - track how many notes in a palace they have remembered.

Usability Study Consent
I am undertaking a usability study to investigate problems with the design of the application before an experimental study is carried out. This will involve watching a demonstration and explanation of the application in action, before carrying out tasks yourself without assistance whilst "thinking aloud", explaining your thought processes.

C.1 **I understand the purpose of this study and I am willing to participate.**

- Yes, I understand and consent to participating. (100%)

C.2 **I understand I am entitled to withdraw from, take a break from or ask questions of this study at any time.**

- Yes, I understand. (100%)

C.3 **I am available between 11:15 - 13:05 on Monday 25th February 2019 to participate in the study taking place in 1W 2.101, University of Bath.**

- Yes, I am available. (100%)

C.4 **I consent to photos, videos and voice recordings being captured where appropriate to assist in creating accurate transcripts and provide evidence of the study. I am aware that this will be anonymised and stored securely.**

- Yes, I consent. (100%)

C.5 **I understand that all raw data captured will be anonymised and stored securely.**

- Yes, I understand. (100%)

C.6 **I am aware of my right to contact the student or project supervisor in the event that I have further questions or any complaints.**

- Yes, I am aware. (100%)

Submitting this form
Please confirm that you have read the above and agree to the terms of the study. By submitting this form with an email, you are consenting to participating. Names and email addresses will not be associated with any of the data produced in the study.

Thank you for your time.

G.3 Think Aloud Protocol Participant Briefing Script

"Hello and thank you for volunteering to take part in the Hold That Thought usability study. As you are aware of from the consent form you have filled out, this project investigates if technology can effectively assist with the Method of Loci, or Mind Palace technique. The application uses Bluetooth technology to track users' locations in a room. Users can:

- create many different palaces in the same room.
- add notes (text and an accompanying online image) to their palace by walking around the room.
- "retrieve" notes by revisiting the locations they were added.
- record whether they have remembered the information correctly.
- track how many notes in a palace they have remembered.

To begin, I will be giving a quick demonstration of the HTT application and the features you are going to be testing today. So, let us begin.

Here you can see the application's Sign In screen. I am now going to create a new account. I have just clicked on the "Sign Up" button in order to take me to the Sign-Up screen and enter my details. After typing my name, chosen user name and password (which will always be a dummy value 'pass' for demonstration purposes), I can click the Sign-Up button which registers my new account and logs me into the application. If I log back out from the main menu by clicking Sign Out, I can see the Sign In screen. This is where I can enter my credentials each time I use the application in order to log in. On the main menu I am presented with 4 main options:

1. **Create Menu:** Allows me to create a new palace or add notes to an existing palace.
2. **Train Menu:** Allows me to select a palace and retrieve the notes in it (this selection list is currently empty as we have not made any palaces).

3. **Track Menu:** Allows me to select a palace and view my progress in remembering the notes in it (this selection list is currently empty as we have not made any palaces).
4. **Settings:** Allows me to delete a palace or delete my account.

In today's study, we are going to be making a new palace using the physical space, adding notes to it and then retrieving these notes and tracking our progress.

For this demonstration's purposes, if we want to remember a list of football teams, we first create a palace with a title and description. We navigate from the Main Menu to the Create Menu to the Create Palace screen. We can call our new palace "Football Teams" with the description "List of Teams" and click "Create Palace" for our new palace to be created. Once the palace is created we can view it in our application, but it is currently empty.

Now we are back on the Main Menu screen, we want to add a note to this palace. We navigate from the Main Menu to the Create Menu to the Create Palace screen. Let us move around the room and choose a suitable location to store the note "Chelsea". If I wish to store this note where I am currently, then I stop here, entering the title "Chelsea" and description "Blue Lion" to help me remember this. You can see that the avatar on the map is moving to reflect my current detected location. I also have space to add a URL of a suitable image to represent the item. If I navigate to a popular search engine such as DuckDuckGo or Bing Images, I can search for an image to represent "Chelsea". I have just chosen their club crest. When I click on the image, I click View File and then copy the URL of the resulting web page. Once this is copied, I can go back to the HTT application and paste this into the URL box. To be sure, I can click Check Image to confirm my choice of image. Otherwise, I can now click Create Note, to register my new note with the palace "Football Teams". From the main menu, we can navigate to the Track Menu to the View Palace screen to see our progress, the unremembered note and where it is located.

The next part is to train using the palace. For every note created in the palace, we can retrieve it by navigating from the Main Menu to the Train Menu to the View Note screen. Similar to the way we made the note, we return to the same location we created the note and wait for the map to update to show our current location. Once this has happened, we can retrieve the note by clicking the Check button at the bottom. This leaves us with the option to hit the tick box when we have remembered the item correctly, as well as the cross box which means we can mark the note as unremembered. If we go to a location where no note exists, the application will tell us with a message on the screen. Let me mark the Chelsea note as remembered for now.

We can see our progress in remembering items by navigating from the Main Menu to the Track Menu to the View Palace screen. Now our progress is shown as 100% because we marked all the notes as remembered. Finally, we can delete our palace by navigating from the Main Menu to Settings and clicking Delete Palace. The process is similar for deleting our account. We have now been logged out and our account has been deleted.

That now concludes our demonstration of the HTT application. The next part of the study will involve you performing 9 short tasks to assess the application's usability. Do you have any questions?"

G.4 Think Aloud Protocol Tasks

Task TA1: Sign Up

Goal	To create a new account and be signed into it by the end of the task.
Inputs	Name, Username, Password
Entry	Sign In Screen
Pre-requisites	• The device is connected to a network (cellular or Wi-Fi).
Steps	• Tap the “Sign Up” button. • Enter a name, username and password. • Tap the “Sign Up” button. • User should see a “Login successful” toast message and be taken to the main menu.
Instructions for User	“Begin by creating a new account and logging into the application. You can use any credentials you like, but make sure not to use a meaningful password for security reasons, as this data is not encrypted.”
Expert completion time	Around 20 seconds.
Notes	The user will already have the application open at the beginning of the study, with the Sign In screen active.

Task TA2: Sign In

Goal	To sign into the application using an existing account.
Inputs	Existing username and password.
Entry	Sign In Screen
Pre-requisites	• The device is connected to a network (cellular or Wi-Fi). • The user has an existing account registered with the system.
Steps	• Enter existing valid username and password. • Tap the “Sign In” button. • User should see a “Login successful” toast message and be taken to the main menu.
Instructions for User	“Please, sign into the application using the account you recently created.”
Expert completion time	Around 15 seconds.
Notes	The user will already have the application open at the beginning of the study, with the Sign In screen active.

Task TA3: Create Palace

Goal	To create a new palace using the application (initially empty).
Inputs	Palace title and description.
Entry	Main Menu
Pre-requisites	• The device is connected to a network (cellular or Wi-Fi). • The user has an existing account registered with the system and is logged in.
Steps	• Tap the "Create Mode" icon (house with plus sign). • Tap the "New Palace" button. • Enter palace title ("American Football") and description ("NFL teams"). • Tap "Create Palace". • User should see a "Palace 'American Football' created." toast message and be taken to the main menu.
Instructions for User	"Now, please create a new palace, entitled 'American Football' with the description 'NFL teams"'.
Expert completion time	Around 20 seconds.
Notes	The creation of a palace is separate from the creation of notes. This task will determine whether users have been able to understand this.

Task TA4: Add Notes to Palace

Goal	To add notes to the previously-created palace "American Football".
Inputs	Note title, description and image URL (for each note).
Entry	Main Menu
Pre-requisites	• The device is connected to a network (cellular or Wi-Fi). • The device has Bluetooth enabled. • The user has an existing account registered with the system and is logged in. • The user has created a palace where notes are to be stored.
Steps	For each note: • Tap the "Create Mode" icon (house with plus sign). • Tap the "New Note" button. • Move to location. • Enter note title (e.g. "Miami Dolphins"). • Choose palace note belongs to (tap list then tap "American Football"). • Enter note description (e.g. "Turquoise Dolphin"). • Switch to duckduckgo application and search for image. • Click "View File" and copy image URL. • Switch to HTT and paste image URL into note field (e.g. `https://scoreboredsports.com/wp-content/uploads/2016/03/Miami_Dolphins-1024x768.jpg`). • Tap "Check Image". • Tap "Create Note". • User should see a "Note 'Miami Dolphins' created." toast message and be taken to the main menu.
Instructions for User	"Please add 3 notes to your new palace: Miami Dolphins, New York Jets, Chicago Bears. Ensure these are at distinct locations in the room."
Expert completion time	Around 30-45 seconds per note.
Notes	This is the task with the greatest number of steps to complete. It is hoped that navigating out of the application is not too distracting for the user.

Task TA5: Track Progress (Before Session)

Goal	View the palace just created and its notes on the tracking screen, noting which are still to be remembered.
Inputs	N/A
Entry	Main Menu
Pre-requisites	• The device is connected to a network (cellular or Wi-Fi). • The user has an existing account registered with the system and is logged in. • The user has created a palace where notes are stored. • The user has not marked any notes as remembered.
Steps	• Tap the "Track Mode" icon (graph). • Choose palace to view (tap list then tap "American Football"). • User should see progress tracking screen with progress at 0% and 3 notes listed as "Still to go: Miami Dolphins, New York Jets, Chicago Bears".
Instructions for User	"Let us now look at the palace and its notes in the progress-tracking screen. Please navigate to that and look at where each note is located on the map."
Expert completion time	Around 15 seconds.
Notes	This task will show the user the complete list of notes which are to be remembered.

Task TA6: Train using Palace (Retrieve Notes)

Goal	Explore the palace and retrieve the notes that have been created, marking them as remembered or not remembered.
Inputs	• "✔" if note remembered. • "✖" if note not remembered.
Entry	Main Menu
Pre-requisites	• The device is connected to a network (cellular or Wi-Fi). • The device has Bluetooth enabled. • The user has an existing account registered with the system and is logged in. • The user has created a palace where notes are stored.
Steps	• Tap the "Train Mode" icon (house). • Choose palace to view (tap list then tap "American Football"). • Tap "Go!" button. For each note: • Move to location. • Tap "Check" button. • Tap "✔" button if note remembered. • Tap "✖" button if note remembered.
Instructions for User	"Now please train using the palace you have created. Return to the places you made notes and check if they are there. Please mark the first note: "Miami Dolphins" as not remembered and the others as remembered."
Expert completion time	Around 15 seconds per note.
Notes	This task is very similar to note creation, without the same data entry as now we are recalling the data. Conditions for both tasks are matched as closely as possible to ensure Encoding Specificity [Tulving and Thomson, 1973].

Task TA7: Track Progress (After Session)

Goal	View the palace just created and its notes on the tracking screen, noting which are still to be remembered.
Inputs	N/A
Entry	Main Menu
Pre-requisites	• The device is connected to a network (cellular or Wi-Fi). • The user has an existing account registered with the system and is logged in. • The user has created a palace where notes are stored. • The user has marked some notes as remembered.
Steps	• Tap the "Track Mode" icon (graph). • Choose palace to view (tap list then tap "American Football"). • Tap "Go!" button. • User should see progress tracking screen with progress at 66% and 1 note listed as "Still to go: Miami Dolphins".
Instructions for User	"Let us now look at the palace and its notes in the progress-tracking screen. Please navigate to that and see which note is still to be remembered."
Expert completion time	Around 15 seconds.
Notes	If the user coped with task TA5, then this should be an easy task to complete as it is identical in terms of execution steps - one simply shows different data to the other.

Task TA8: Delete Palace

Goal	Delete the palace that has been created.
Inputs	N/A
Entry	Main Menu
Pre-requisites	• The device is connected to a network (cellular or Wi-Fi). • The user has an existing account registered with the system and is logged in. • The user has created a palace.
Steps	• Tap the “Settings” icon (cogs). • Choose palace to delete (tap list then tap “American Football”). • Tap “Delete Palace” button. • Tap “Yes” on confirmation dialog message box. • User should see a “Palace ‘American Football’ deleted.” toast message and the palace should disappear from the list.
Instructions for User	“Now we have finished with that palace, please delete it.”
Expert completion time	Around 8-10 seconds.
Notes	The user will hopefully be familiar with the action of selecting a palace from a list by now, as they will have done this before in tasks TA4, TA5, TA6, TA7.

Task TA9: Delete Account

Goal	Delete the user account that has been created.
Inputs	N/A
Entry	Main Menu
Pre-requisites	• The device is connected to a network (cellular or Wi-Fi). • The user has an existing account registered with the system and is logged in.
Steps	• Tap the “Settings” icon (cogs). • Tap “Delete Account” button. • Tap “Yes” on confirmation dialog message box. • User should see a “User ‘XXX’ deleted.” toast message where ‘XXX’ represents their username and they should be redirected to the Sign In screen.
Instructions for User	“Finally, please delete your account.”
Expert completion time	Around 8-10 seconds.
Notes	The user can now delete their account from the system.

G.5 Think Aloud Protocol Results

Results are summarised below, numbered from P1 to P5 to represent the 5 different participants of the study. Full verbatim responses are omitted for brevity.

Task TA1: Sign Up

P1 Clicked on Sign Up, chose a suitable name, username and password. The participant was successfully registered with and logged into the application.

P2 Clicked on Sign Up, chose a suitable name, username and password. The participant was successfully registered with and logged into the application.

P3 Clicked on Sign Up, chose a suitable name, username and password. The participant was successfully registered with and logged into the application. The participant commented on the 'clean UI'. On seeing the main menu screen, the participant commented on making the 4 icons to reach each submenu more obvious and separated-out, perhaps with a label beneath.

P4 Clicked on Sign Up, chose a suitable name, username and password. The participant was successfully registered with and logged into the application. During data entry, the participant commented on wishing data entry to be done in a 'scrollable' way, instead of requiring the user to press 'enter' to go to the next field.

P5 Clicked on Sign Up, chose a suitable name, username and password. The participant was successfully registered with and logged into the application.

Task TA2: Sign In

P1 Successfully remembered their credentials from task TA1 and entered these, clicking Sign In. The participant was successfully logged into the application.

P2 Successfully remembered their credentials from task TA1 and entered these, clicking Sign In. The participant was successfully logged into the application.

P3 Successfully remembered their credentials from task TA1 and entered these, clicking Sign In. The participant was successfully logged into the application. The participant commented on the experience being 'smooth' with it being clear what is expected of the user.

P4 Successfully remembered their credentials from task TA1 and entered these, clicking Sign In. The participant was successfully logged into the application.

P5 Successfully remembered their credentials from task TA1 and entered these, clicking Sign In. The participant was successfully logged into the application.

Task TA3: Create Palace

P1 Navigated to the Create Palace screen successfully. Entered the title 'American Football' and description 'NFL teams'. Clicked the Create Palace button with no issue. Participant successfully created a palace.

P2 Navigated to the Create Palace screen successfully. Entered the title 'American Football' and description 'NFL teams'. Clicked the Create Palace button with no issue. Participant successfully created a palace.

P3 Navigated to the Create Palace screen successfully. Entered the title 'American Football' and description 'NFL teams'. Clicked the Create Palace button with no issue. Participant successfully created a palace. Without any prompting, the participant knew that the palace was now viewable in the train and track menus, seeming confident in what was happening.

P4 Navigated to the Create Palace screen successfully. Entered the title 'American Football' and description 'NFL teams'. Clicked the Create Palace button with no issue. Participant successfully created a palace.

P5 Navigated to the Create Palace screen successfully. Entered the title 'American Football' and description 'NFL teams'. Clicked the Create Palace button with no issue. Participant successfully created a palace.

Task TA4: Add Notes To Palace

P1 Navigated to the Create Note screen successfully. Participant chose to create notes using the beacons as distinct locations. For example, created note 'Miami Dolphins' successfully by giving it a title, description and suitable image URL. Other notes were chosen to be placed at other locations far away from the original.

P2 Navigated to the Create Note screen successfully. Participant chose to create notes using the beacons as distinct locations. For example, created note 'Miami Dolphins' successfully by giving it a title, description and suitable image URL. Other notes were chosen to be placed at other locations far away from the original.

P3 Navigated to the Create Note screen successfully. Participant chose to create notes using the beacons as distinct locations. For example, created note 'Miami Dolphins' successfully by giving it a title, description and suitable image URL. Other notes were chosen to be placed at other locations far away from the original. On completing the task, the participant commented that an information screen would have been helpful here, explaining each sub-step of the process of adding a new note. The process was 'very intuitive once you know how to do it at first'. Participant also commented on moving the Check Image button below the Create Note button. The participant used the description function for its intended purpose - not a verbatim copy of the title.

P4 Participant initially chose the train menu instead of the create menu, before realising their mistake and returning to the main menu and then the create menu. They suggested that the main menu should indicate the function - 'create', 'train', 'track', 'settings' to make their meanings clear and avoid that mistake. After this error, they were able to perform the task effectively as normal. The participant also suggested not auto-capitalising the words in the description.

P5 Navigated to the Create Note screen successfully. Participant chose to create notes using the beacons as distinct locations. For example, created note 'Miami Dolphins' successfully by giving it a title, description and suitable image URL. Other notes were chosen to be placed at other locations far away from the original. The participant remarked on waiting for the avatar to move to their current location before entering the data. 'Do I need to check the image each time?' was asked.

Task TA5: Track Progress (Before Session)

- P1 Participant initially chose the train menu instead, before realising their mistake and returning to the main menu. The participant then selected the track menu and viewed the 3 notes under their palace.
- P2 Navigated to the View Palace screen successfully. Participant viewed the 3 notes under their palace. They tried clicking on each one to see where the note was stored in the palace.
- P3 Navigated to the View Palace screen successfully. Participant viewed the 3 notes under their palace. They tried clicking on each one to see where the note was stored in the palace.
- P4 Navigated to the View Palace screen successfully. Participant viewed the 3 notes under their palace. They tried clicking on each one to see where the note was stored in the palace.
- P5 Navigated to the View Palace screen successfully. Participant viewed the 3 notes under their palace. They tried clicking on each one to see where the note was stored in the palace.

Task TA6: Train using Palace (Retrieve Notes)

- P1 Navigated to the View Note screen successfully. Participant chose to retrieve the notes in the order they were created. No issues were found in checking for a note at each location. The participant successfully marked each note as remembered or unremembered accordingly.
- P2 Navigated to the View Note screen successfully. After loading the screen, the participant attempted to enter text into the fields, mistaken by their appearance as editable fields and with the Check button out-of-sight. After some prompting, they were able to see the Check button and understand how it worked but remarked that they wanted the process to be clearer, by changing the fields' appearance and making the Check button more visible. The purpose of the tick and cross buttons was obvious from their appearance.
- P3 Navigated to the View Note screen successfully. After loading the screen, the participant wasn't sure whether they were expected to enter text into the Title and Description boxes, much like the previous participant. After a few seconds and some scrolling, they realised the existence of the Check button. After the note popped up, they were back on track, ticking the tick and cross buttons accordingly. The participant commented on having these buttons higher up the screen. They wanted the Check button above the tick and cross buttons. Otherwise, they liked the map feature: 'brilliant - easy to use'. Another suggestion was to use an information screen like when adding a note to explain the procedure.
- P4 Navigated to the View Note screen successfully. Participant chose to retrieve the notes in the order they were created. After loading the screen, the participant wasn't sure whether they were expected to enter text into the Title and Description boxes, much like the previous participant. They also commented that it

might be worth not showing the tick and cross buttons until clicking the check button, to avoid ‘button-overload’ of the user. After retrieving the first note, there was no issue completing the task.

P5 Navigated to the View Note screen successfully. Participant chose to retrieve the notes in the order they were created. No issues were found in checking for a note at each location. The participant successfully marked each note as remembered or unremembered accordingly.

Task TA7: Track Progress (After Session)

P1 Participant remembered their mistake from task TA5 and selected the track menu successfully. Participant successfully viewed the note still to be marked as remembered under their palace.

P2 Participant remembered the process from task TA5 and selected the track menu successfully. Participant successfully viewed the note still to be marked as remembered under their palace.

P3 Participant immediately recognised the tracking was to do with viewing their progress. Participant remembered the process from task TA5 and selected the track menu successfully. Participant successfully viewed the note still to be marked as remembered under their palace.

P4 ‘I like the track icon, to signify progress’. Participant remembered the process from task TA5 and selected the track menu successfully. Participant successfully viewed the note still to be marked as remembered under their palace. They also mentioned that they would like a number of items - ‘2 out of 3’ or something similar. When all items are remembered, the participant suggested having an appropriate message, instead of the ‘still to go...’ list.

P5 Participant remembered the process from task TA5 and selected the track menu successfully. Participant successfully viewed the note still to be marked as remembered under their palace.

Task TA8: Delete Palace

P1 Navigated to the Settings screen successfully. Clicked Delete Palace after selecting the correct palace and confirmed their choice.

P2 Navigated to the Settings screen successfully. Clicked Delete Palace after selecting the correct palace and confirmed their choice.

P3 Navigated to the Settings screen successfully. Clicked Delete Palace after selecting the correct palace and confirmed their choice. ‘Very easy!’.

P4 Navigated to the Settings screen successfully. Clicked Delete Palace after selecting the correct palace and confirmed their choice.

P5 Navigated to the Settings screen successfully. Clicked Delete Palace after selecting the correct palace and confirmed their choice.

Task TA9: Delete Account

P1 Navigated to the Settings screen successfully. Clicked Delete Account and confirmed their choice.
P2 Navigated to the Settings screen successfully. Clicked Delete Account and confirmed their choice.
P3 Navigated to the Settings screen successfully. Clicked Delete Account and confirmed their choice. 'I like that takes you back to the home screen'.
P4 Navigated to the Settings screen successfully. Clicked Delete Account and confirmed their choice.
P5 Navigated to the Settings screen successfully. Clicked Delete Account and confirmed their choice.

Additional Questions and Comments

P1 Walking around the environment was really helpful to test the application out - I like the project!
P2 The fields for title and description on the View Note screen were a little ambiguous as to whether they were editable or not as the Check button was out of sight. Also, the error message when a note is out of range is a little confusing - not many people will understand the use of the word 'loci'. Finally, perhaps as an extension, it would be cool to overlay the objects to be remembered over the map as a Gods-eye view or add obstacles to it to remember the room in more detail.
P3 The application is very good and very clean - especially the simple navigation flow. The menu looks great, but I would love to make icons larger and add labels to make their function clearer - just to emphasise the point that these are the main functions of the application. Also, the info screens on adding and retrieving notes would be fantastic.
P4 Main comments would include the use of labels on the main menu and the tick and cross button only displaying when a note is checked. Also, currently you add and delete a palace from two different places. It would be good to make these functions exist in one place. I would also like a back button in the application itself instead of the built-in Android back button.
P5 A dedicated back button would be great instead of relying on the inbuilt Android one would be perfect. Also, if possible, it would be great to have an in-app browser to view and select the image.

G.6 Think Aloud Protocol Participant De-Briefing Script

"Thank you for taking part in the usability study for the HTT application. Your responses and any recordings or pictures taken will be anonymous and only viewable by myself, my project supervisor and the second marker. Do you have any questions from or additional comments on what you have seen today or the project in general?"

Appendix H
Code

H.1 Source Code Structure

The source code submitted in a .zip folder on Moodle along with this submission is presented in the following structure:

```
src/
├── MindPalaceApp/
└── MindPalaceService/
```

H.2 MindPalaceApp

This directory contains all of the code required to create the HTT Android mobile application.

GitHub repository URL: `https://github.com/cd223/MindPalaceApp`.

H.3 MindPalaceService

This directory contains all of the code required to create the web service and database and host them both remotely on Heroku.

GitHub repository URL: `https://github.com/cd223/MindPalaceService`.

Appendix I

Ethics Check List

Ethics need to be considered in line with the 13-point Computer Science Ethics checklist[1]. During any study involving participants, the following ethics checklist needed to be considered:

E.1 **Have you prepared a briefing script for volunteers?**
Users will be briefed on what they will be required to do, the kind of data to be collecting from them and how it will be used. Experimental and Usability briefing scripts can be seen in Appendix G.3 and Appendix J.2. Both give detail on what the study involves and the data to be captured. It also invites participants to ask questions or make any comments.

E.2 **Will the participants be using any non-standard hardware?**
It is unlikely that participants will have interacted with mobile applications using BLE sensor technology before. Anything other than pen and paper or typical interaction with PCs on desks is classed as non-standard hardware. Participants will be using a mobile phone to navigate around a 3D space and create notes along a path. They will be given a trial run before the experiment to ensure they are familiar with how to interact with the system. Using the mobile application correctly will require some prior instructions and so a trial run will be offered for users to become familiar with the system and mobile interface before use.

E.3 **Is there any intentional deception of the participants?**
There is an element of deception in the experiment procedure whereby users will complete a Victoria Stroop task in order to provide a cognitive distraction between the memorisation task and being tested for recall. In order to make the distraction effective, participants will be under the impression the task is assessed as well as the memorisation task. Participants will be told about the deception as soon as they have completed it. No details about the 7-day recall test will be given to participants on the day, but they will be consenting to fill in a "survey" 1 week after completing the initial study. In this sense, no major deceptions will be given to participants - all minor deceptions or withholding of information is necessary.

E.4 **How will participants voluntarily give consent?**
The volunteers will be required to give consent before any experiments. Consent is needed from participants via separate signed consent forms if the results are to

[1] `http://www.cs.bath.ac.uk/Leon/files/EthicsChecklist.pdf`

be published. Experimental and Usability consent forms can be seen in Appendix G.2 and Appendix J.1.

E.5 **Will the participants be exposed to any risks greater than those encountered in their normal work life?**
Participants will not be subject to any risks during the investigation. Participants using the HTT application in the 1 West 2.101 room will have a pre-defined route to follow which not expose them to any great deal of risk.

E.6 **Are you offering any incentive to the participants?**
No incentives will be offered to the participants (e.g. payment) to induce them to take part.

E.7 **Are any of your participants under the age of 16?**
Participants will not be under the age of 16 - all participants will be 18 years old or above. As such, no parental consent is required for participants to take part in experiments.

E.8 **Do any of your participants have an impairment that will limit their understanding or communication?**
Additional consent will be obtained for participants with impairments that will limit their understanding or communication. There is no restriction on their participation in the study, so long as they provide consent and indicate whether they are able to walk around a room in the case they are allocated to the HTT group.

E.9 **Are you in a position of authority or influence over any of your participants?**
I will not have any position of authority or influence over any of the participants in the experiments.

E.10 **Will the participants be informed that they could withdraw at any time?**
Participants will be informed that they can withdraw from experiments at any time. They will be told this in the introductory script.

E.11 **Will the participants be informed of your contact details?**
Participants will be given contact details in case they wish to contact me or my supervisor after the investigation.

E.12 **Will participants be de-briefed?**
Participants will be de-briefed to enable them to understand the nature of the investigation. Experimental and Usability briefing scripts can be seen in Appendix G.6 and Appendix J.7.

E.13 **Will the data collected from the participants be stored in an anonymous form?**
Data collected from participants will be stored securely and in an anonymous form. Any email addresses collected will be necessary to send a follow-up survey to participants to assess their recall accuracy after 7 days. These details will not be published in the raw data displayed in the write-up.

Appendix J
Experimental Evaluation

J.1 Participant Consent Form

Before the experiment, the participants were asked to read and sign a consent form in the style below.

PARTICIPANT CONSENT FORM

'Hold That Thought": Location-based Mind Palace generation for memorisation assistance

Student: Christopher J. Davies (`cjd47@bath.ac.uk`)
Project Supervisor: Dr Fabio Nemetz (`F.Nemetz@bath.ac.uk`)

1) I have been informed of the purpose of this study and what my role in the study is.

2) I have been told about the overall project aim and how I will be contributing to this by participating in the study.

3) I have been told I am entitled to withdraw from, take a break from or ask questions of this study at any time.

4) I have been informed that the data produced from my participation in this study will not contain personally-identifying information that can be traced back to my involvement.

5) I have been made aware of the potential for the data I produce to be published providing that it remains anonymous.

6) In the event of an interview or audio recording of a study, I have been told that my voice may be recorded in order for an accurate transcript to be produced, which I consent to.

7) I have been informed that raw data produced from the study will be visible only to the above-named student and project supervisor as well as a second marker.

8) I have been made aware of my right to contact the student or project supervisor in the event that I have further questions or any complaints.

Please confirm that you have read the above and agree to this, and consent to participating in the user study by signing below. Names and signatures will not be associated with any of the data produced.

Name of Participant: ....

Signature: .... Date: ....

J.2 Briefing Script

The briefing script below was used to brief participants of the experiment.

PARTICIPANT BRIEFING SCRIPT

'Hold That Thought": Location-based Mind Palace generation for memorisation assistance

Student: Christopher J. Davies (`cjd47@bath.ac.uk`)
Project Supervisor: Dr Fabio Nemetz (`F.Nemetz@bath.ac.uk`)

I am a final year Computer Science student investigating how technology can assist with an ancient mnemonic technique called the Mind Palace. As part of my dissertation, I am conducting an experiment to investigate the ways technology can assist users with the Mind Palace technique. I am carrying out an experimental study which investigates how different methods of memorisation (assisted and unassisted) compare in their efficacy.

The study should take no longer than 40-45 minutes to complete. It involves:

- Completing a couple of short memory and cognitive tasks (more detail will follow)
- A post-study survey
- A short survey 1 week after the study.

Please first sign and date the consent form provided. Whilst the study is carried out, recordings of your voice will be made to ensure accuracy in reporting results. This will be stored anonymously and securely along with any data produced in the study. During the study, we will be following this script to ensure all tasks are performed correctly.

Many thanks for agreeing to participate. At this stage, are there any questions you may have?

J.3 NASA-Task Load Index Sheet (NASA-TLX)

- **MENTAL DEMAND**: How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex?

- **PHYSICAL DEMAND**: How much physical activity was required? Was the task easy or demanding, slack or strenuous?
- **TEMPORAL DEMAND**: How much time pressure did you feel due to the pace at which the tasks or task elements occurred? Was the pace slow or rapid?
- **OVERALL PERFORMANCE**: How successful were you in performing the task? How satisfied were you with your performance?
- **EFFORT**: How hard did you have to work (mentally and physically) to accomplish your level of performance?
- **FRUSTRATION LEVEL**: How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?

Name: .... Date: ....

Please rate how you feel right now, at the current moment **BY CIRCLING THE APPROPRIATE VERTICAL LINE**.

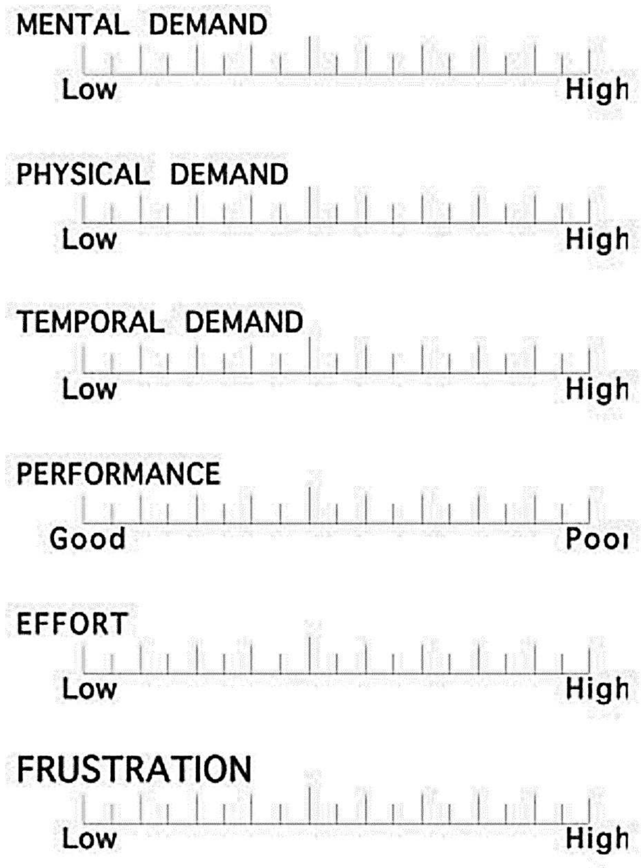


Figure J.1: NASA TLX: a Task Load Index proposed by Hart [2006].

J.4 HTT Experiment Script

In this experiment you will be using the following set of instructions to carry out a series of memory and cognitive tasks to evaluate an application called “Hold That Thought” designed to assist users in practising an ancient mnemonic called the Mind Palace.

- **Student:** Christopher J. Davies (`cjd47@bath.ac.uk`)
- **Project Supervisor:** Dr Fabio Nemetz (`F.Nemetz@bath.ac.uk`)

Please complete the below tasks in order, asking questions at any stage.

TASK-LOAD MEASURE (PRE-MEMORISATION TASK) – 3 MINUTES Please fill in the sheet provided to indicate how you feel at this current stage. The sheet should look like the below:

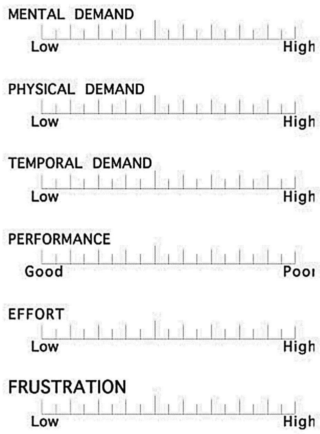


Figure J.2: NASA TLX: a Task Load Index proposed by Hart [2006].

MEMORISATION TASK (HTT) – 10 MINUTES There will now follow a short demonstration of how to retrieve notes using the HTT application. When you move around the room, an avatar will show your current detected location. When you stop at a certain location, allow a few seconds for the avatar to catch up with you! Once the avatar has caught-up, click "Check for notes here!"

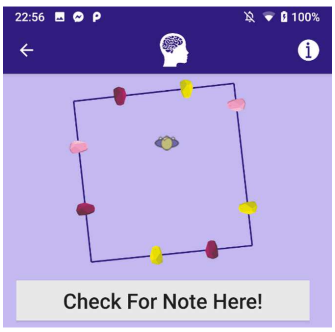


Figure J.3: Memorisation task: Checking for notes.

Please navigate around the room using the HTT application, checking for notes corresponding with the following words:

1. flame
2. museum
3. tongue
4. rumour
5. trust
6. muck
7. pause
8. cave
9. thirst
10. bike

These items are placed at the below locations on the map. Please follow the route from stop 1 to stop 12 and click "Check for notes here!" at each stop to retrieve the item.

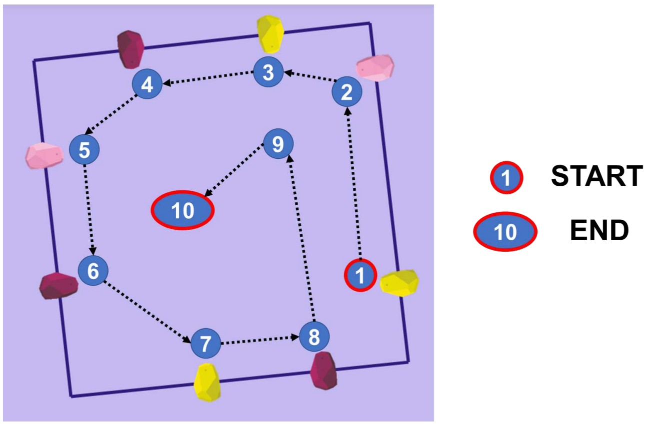


Figure J.4: Memorisation task: Route to follow.

When you have checked and viewed each of the items in the list, you can retrace your steps as many times as you like to recall the items.

TASK-LOAD MEASURE (POST-MEMORISATION TASK) – 3 MINUTES
Please fill in the sheet provided to indicate how you feel at this current stage. The sheet should look like the below:

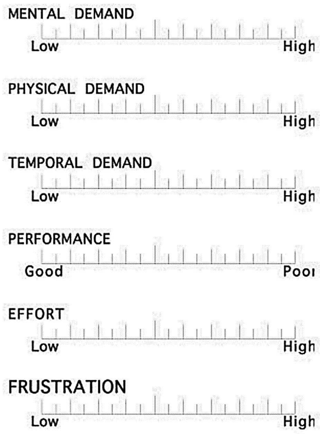


Figure J.5: NASA TLX: a Task Load Index proposed by Hart [2006].

VICTORIA STROOP TASK – 3-5 MINUTES Please complete the Victoria Stroop task using the laptop provided. This task requires you to identify the colour of the item (shape or word) using the keyboard keys [1,2,3,4] appropriately. Feel free to ask questions at any stage.

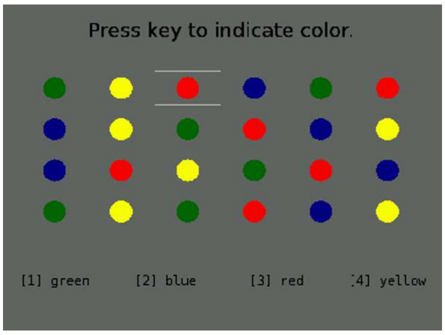


Figure J.6: Victoria Stroop: a task to encourage cognitive effort.

RECALL TASK – 3-5 MINUTES Please fill out the below form. Feel free to ask questions at any stage. `https://goo.gl/forms/SgOc2FSC4Ng6SfJA2`

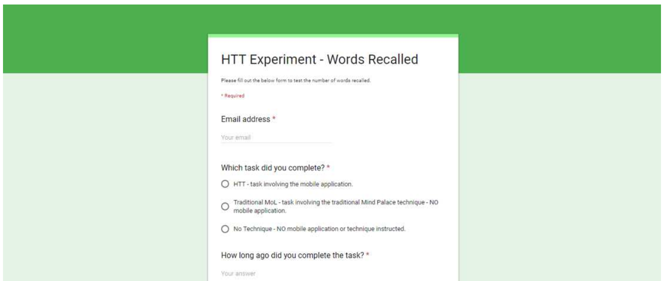


Figure J.7: Recall Test: a form to collect recalled words.

EXPERIENCE SURVEY – 3-5 MINUTES Please fill out the below form using the laptop provided. Feel free to ask questions at any stage. `https://goo.gl/forms/WAQUql042xPxkoQr1`

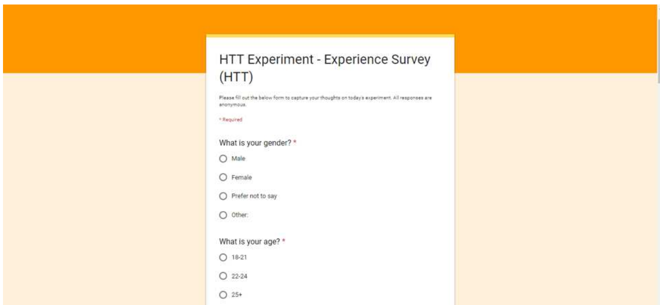


Figure J.8: Experience survey: a form to collect feedback on the experiment.

Thank you for completing all tasks and participating in this study. You now have time to ask any questions or make any further comments.

In 1 weeks' time, you will be emailed with a follow-up survey which will take a maximum of 3-5 minutes to complete – please do take the time to fill this out – it is necessary for your participation to be counted in the project!

J.5 MoL Experiment Script

In this experiment you will be using the following set of instructions to carry out a series of memory and cognitive tasks to evaluate an application called "Hold That Thought" designed to assist users in practising an ancient mnemonic called the Mind Palace.

- **Student:** Christopher J. Davies (`cjd47@bath.ac.uk`)
- **Project Supervisor:** Dr Fabio Nemetz (`F.Nemetz@bath.ac.uk`)

Please complete the below tasks in order, asking questions at any stage.

TASK-LOAD MEASURE (PRE-MEMORISATION TASK) – 3 MINUTES
Please fill in the sheet provided to indicate how you feel at this current stage. The sheet should look like the below:

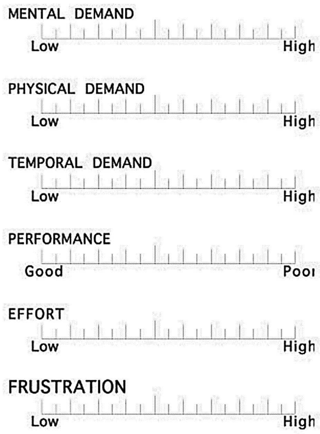


Figure J.9: NASA TLX: a Task Load Index proposed by Hart [2006].

MEMORISATION TASK (MoL) – 10 MINUTES The Mind Palace (MoL) is an ancient mnemonic technique that is used by world memory champions and has been adopted since the times of Ancient Greece. It works as follows:

1. Choose an environment (palace) that you are comfortable navigating in your imagination (i.e. a well-known setting such as a family home).
2. Navigate through the palace in your mind until you reach a distinctive place to store the item.
3. Visualise the item and fix it at this place.
4. Repeat steps 2-3 until all items have been placed at distinct places.
5. To recall, retrace this mental journey through the palace and view each item.

Using the Mind Palace technique, please attempt to place the following words as items in your imaginary palace:

1. flame
2. museum
3. tongue
4. rumour
5. trust
6. muck
7. pause
8. cave
9. thirst
10. bike

When you have placed the items in your imaginary palace, you can retrace your mental steps as many times as you like to recall the items.

TASK-LOAD MEASURE (POST-MEMORISATION TASK) – 3 MINUTES Please fill in the sheet provided to indicate how you feel at this current stage. The sheet should look like the below:

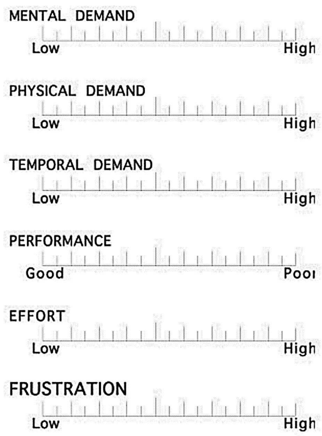


Figure J.10: NASA TLX: a Task Load Index proposed by Hart [2006].

VICTORIA STROOP TASK – 3-5 MINUTES Please complete the Victoria Stroop task using the laptop provided. This task requires you to identify the colour of the item (shape or word) using the keyboard keys [1,2,3,4] appropriately. Feel free to ask questions at any stage.

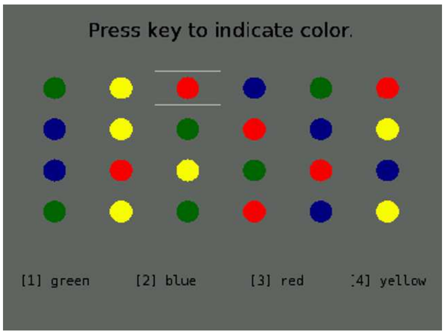


Figure J.11: Victoria Stroop: a task to encourage cognitive effort.

RECALL TASK – 3-5 MINUTES Please fill out the below form. Feel free to ask questions at any stage. `https://goo.gl/forms/Sg0c2FSC4Ng6SfJA2`

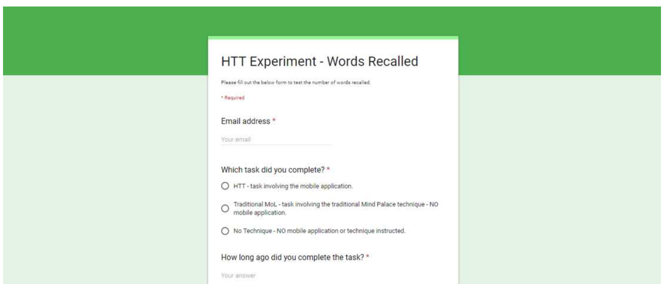
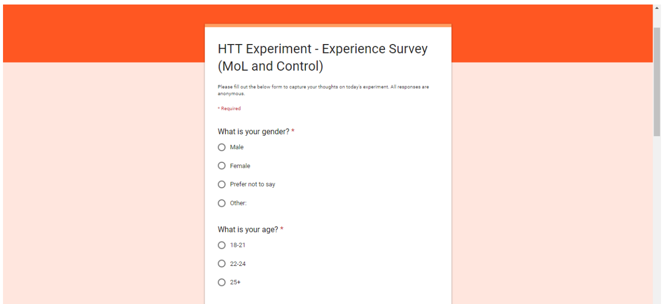


Figure J.12: Recall Test: a form to collect recalled words.

EXPERIENCE SURVEY – 3-5 MINUTES Please fill out the below form using the laptop provided. Feel free to ask questions at any stage. `https://goo.gl/forms/FSlRt8HJtr5kTLgl1`



HTT Experiment - Experience Survey (MoL and Control)

Please fill out the below form to capture your thoughts on today's experiment. All responses are anonymous.

* Required

What is your gender? *

- Male
- Female
- Prefer not to say
- Other:

What is your age? *

- 18-21
- 22-24
- 25+

Figure J.13: Experience survey: a form to collect feedback on the experiment.

Thank you for completing all tasks and participating in this study. You now have time to ask any questions or make any further comments.

In 1 weeks' time, you will be emailed with a follow-up survey which will take a maximum of 3-5 minutes to complete – please do take the time to fill this out – it is necessary for your participation to be counted in the project!

J.6 Control Experiment Script

In this experiment you will be using the following set of instructions to carry out a series of memory and cognitive tasks to evaluate an application called "Hold That Thought" designed to assist users in practising an ancient mnemonic called the Mind Palace.

- **Student:** Christopher J. Davies (`cjd47@bath.ac.uk`)
- **Project Supervisor:** Dr Fabio Nemetz (`F.Nemetz@bath.ac.uk`)

Please complete the below tasks in order, asking questions at any stage.

TASK-LOAD MEASURE (PRE-MEMORISATION TASK) – 3 MINUTES
Please fill in the sheet provided to indicate how you feel at this current stage. The sheet should look like the below:

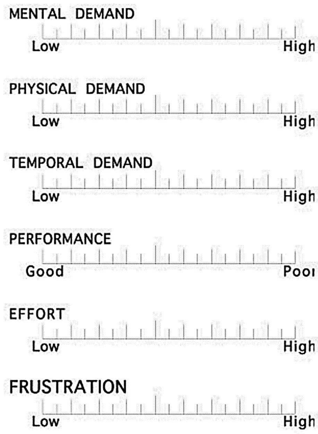


Figure J.14: NASA TLX: a Task Load Index proposed by Hart [2006].

MEMORISATION TASK (Control) – 10 MINUTES Using any technique that you feel is appropriate, please attempt to memorise the following words:

1. flame
2. museum
3. tongue
4. rumour
5. trust
6. muck
7. pause
8. cave
9. thirst
10. bike

TASK-LOAD MEASURE (POST-MEMORISATION TASK) – 3 MINUTES Please fill in the sheet provided to indicate how you feel at this current stage. The sheet should look like the below:

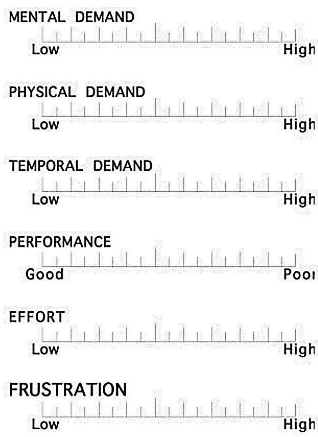


Figure J.15: NASA TLX: a Task Load Index proposed by Hart [2006].

VICTORIA STROOP TASK – 3-5 MINUTES Please complete the Victoria Stroop task using the laptop provided. This task requires you to identify the colour of the item (shape or word) using the keyboard keys [1,2,3,4] appropriately. Feel free to ask questions at any stage.

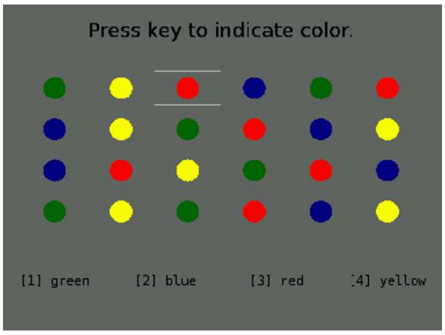


Figure J.16: Victoria Stroop: a task to encourage cognitive effort.

RECALL TASK – 3-5 MINUTES Please fill out the below form. Feel free to ask questions at any stage. `https://goo.gl/forms/Sg0c2FSC4Ng6SfJA2`

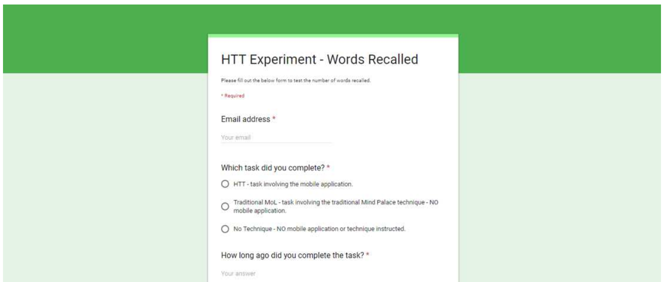


Figure J.17: Recall Test: a form to collect recalled words.

EXPERIENCE SURVEY – 3-5 MINUTES Please fill out the below form using the laptop provided. Feel free to ask questions at any stage. `https://goo.gl/forms/FS1Rt8HJtr5kTLgl1`

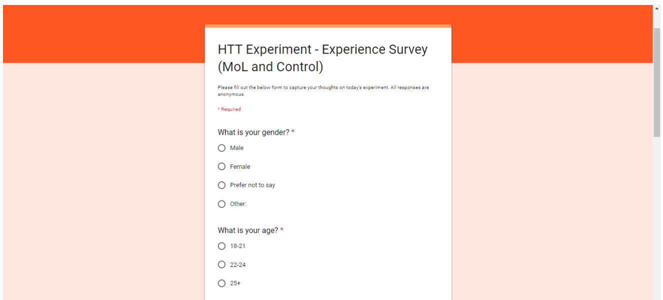


Figure J.18: Experience survey: a form to collect feedback on the experiment.

Thank you for completing all tasks and participating in this study. You now have time to ask any questions or make any further comments.

In 1 weeks' time, you will be emailed with a follow-up survey which will take a maximum of 3-5 minutes to complete – please do take the time to fill this out – it is necessary for your participation to be counted in the project!

J.7 De-Briefing Script

The de-briefing script below was used to de=brief participants of the experiment.

PARTICIPANT DE-BRIEFING SCRIPT

'Hold That Thought": Location-based Mind Palace generation for memorisation assistance

Student: Christopher J. Davies (cjd47@bath.ac.uk)
Project Supervisor: Dr Fabio Nemetz (F.Nemetz@bath.ac.uk)

The study you have participated in is being carried out in order to research whether technology can effectively assist with the Mind Palace (Method of Loci) technique. The study compares the use of the application I have developed entitled "Hold That Thought" against the traditional Mind Palace technique. I am testing the hypothesis that the performance of users of HTT will be better on average (measured in terms of the number of words recalled) than the control group. It is predicted that participants will also find the task more enjoyable and less difficult when using HTT compared to the traditional Mind Palace technique. Your performance is not what is being tested explicitly here - it is the method used to memorise information that is under scrutiny.

Please ensure to fill out the survey that is sent out after 1 week from today to ensure your contribution is counted towards this study!

If you have any further questions or comments on the project or study, please raise them now. Otherwise, you may contact me via email at cjd47@bath.ac.uk. Many thanks once again for your participation!

J.8 Word Recall Form

"Hold That Thought": Words Recalled

Responses: 60

Source: https://forms.gle/4BtK31Wx9bVDrKMZ8

Please fill out the below form to test the number of words recalled.

Email address: ....

Q.1 **Which task did you complete?**

- HTT (33.3%)
- MoL (33.3%)
- Control (33.3%)

Q.2 **How long ago did you complete the task?**

- 5 mins (50.0%)
- 7 days (50.0%)

Q.3 **Please, list as many words as you can remember from the experiment task as possible below. Once you have finished recalling all words, click submit.**

- Answers omitted for brevity - see section J.12 for recall accuracies.

J.9 Experience Survey - HTT

"Hold That Thought": Experience Survey (HTT)

Responses: 10

Source: `https://forms.gle/2iW94ZHkZeVtVHoS7`

Please fill out the below form to capture your thoughts on today's experiment. All responses are anonymous.

Q.1 **What is your gender?**

- Male (90.0%)
- Female (10.0%)
- Prefer not to say (0.0%)
- Other (0.0%)

Q.2 **What is your age?**

- 18-21 (30.0%)
- 22-24 (70.0%)
- 25+ (0.0%)

Q.3 **Have you ever practised the Mind Palace technique before?**

- Yes (10.0%)
- No (90.0%)

Q.4 **To what extent do you find memory techniques useful when trying to memorise information? (1 = Not at all, 5 = Very)**

- 1 (0.0%)
- 2 (0.0%)
- 3 (20.0%)
- 4 (50.0%)
- 5 (30.0%)

Q.5 **To what extent did you find the instruction sheet clear and useful? (1 = Not at all, 5 = Very)**

- 1 (0.0%)
- 2 (0.0%)
- 3 (0.0%)
- 4 (30.0%)
- 5 (70.0%)

Q.6 **To what extent did you find the memorisation task enjoyable? (1 = Not at all, 5 = Very)**

- 1 (0.0%)
- 2 (10.0%)
- 3 (0.0%)
- 4 (50.0%)
- 5 (40.0%)

Q.7 **To what extent did you find the memorisation task difficult? (1 = Not at all, 5 = Very)**

- 1 (20.0%)
- 2 (30.0%)
- 3 (40.0%)
- 4 (0.0%)
- 5 (10.0%)

Q.8 **I think that I would like to use this system frequently. (1 = Strongly Disagree, 5 = Strongly Agree)**

- 1 (0.0%)
- 2 (30.0%)
- 3 (20.0%)
- 4 (40.0%)
- 5 (10.0%)

Q.9 **I found the system unnecessarily complex. (1 = Strongly Disagree, 5 = Strongly Agree)**

- 1 (40.0%)
- 2 (50.0%)
- 3 (10.0%)
- 4 (0.0%)
- 5 (0.0%)

Q.10 **I thought the system was easy to use. (1 = Strongly Disagree, 5 = Strongly Agree)**

- 1 (0.0%)
- 2 (0.0%)
- 3 (0.0%)
- 4 (60.0%)
- 5 (40.0%)

Q.11 **I think that I would need the support of a technical person to be able to use this system. (1 = Strongly Disagree, 5 = Strongly Agree)**

- 1 (50.0%)
- 2 (50.0%)
- 3 (0.0%)
- 4 (0.0%)
- 5 (0.0%)

Q.12 **I found the various functions in this system were well integrated. (1 = Strongly Disagree, 5 = Strongly Agree)**

- 1 (0.0%)
- 2 (0.0%)
- 3 (30.0%)
- 4 (50.0%)
- 5 (20.0%)

Q.13 **I thought there was too much inconsistency in this system. (1 = Strongly Disagree, 5 = Strongly Agree)**

- 1 (20.0%)
- 2 (50.0%)
- 3 (20.0%)
- 4 (10.0%)
- 5 (0.0%)

Q.14 **I would imagine that most people would learn to use this system very quickly. (1 = Strongly Disagree, 5 = Strongly Agree)**

- 1 (0.0%)
- 2 (0.0%)
- 3 (10.0%)
- 4 (60.0%)
- 5 (30.0%)

Q.15 **I found the system very cumbersome to use. (1 = Strongly Disagree, 5 = Strongly Agree)**

- 1 (40.0%)
- 2 (50.0%)
- 3 (10.0%)
- 4 (0.0%)
- 5 (0.0%)

Q.16 **I felt very confident using the system. (1 = Strongly Disagree, 5 = Strongly Agree)**

- 1 (0.0%)
- 2 (0.0%)
- 3 (40.0%)
- 4 (40.0%)
- 5 (20.0%)

Q.17 **I needed to learn a lot of things before I could get going with this system. (1 = Strongly Disagree, 5 = Strongly Agree)**

- 1 (70.0%)
- 2 (20.0%)
- 3 (10.0%)
- 4 (0.0%)
- 5 (0.0%)

Q.18 **What did you like about the experiment?**

- I enjoyed the challenge of remembering the keywords, improving my ability to recall the words. It was interesting to see that when I tried to remember the words that I visualised myself walking around the room in the order I had learnt them. I found this beneficial for remembering the words.
- Interesting memorising task, using techniques I haven't really used before
- Easy to perform and not too challenging, mind techniques are interesting in general so was insightful
- It was a fun challenge, I am excited to see the results.
- It was different and quite interesting.
- The setup and the enjoyment of a memory task.
- It was interesting to see a different way of memorising things, through the use of technology
- It was fun to walk around the room and make a story about the items
- It was physical and very different to other studies I've taken part in. I can actually see this research being useful in my life.
- Interesting concept, nice to experience this relatively unused location tracking hardware. Experiment tasks laid out sensibly. Didn't take too long.

Q.19 **What did you dislike about the experiment?**

- The accuracy of the tracking device, although technological limited an improvement in this would allow for a great learning tool.
- Application lagged a little when updating location
- The time between memorising items. Size of the room the object were spread far apart which meant more walking.
- Slightly dodgy location, but otherwise fine
- The problems with the app in the centre of the room and the delay.
- The poor connection (most likely due to Bluetooth issues)
- Being tricked into doing a decoy task! (the task itself was fine, and I understand the need to be tricked)
- Strangely worded questions on the initial NASA sheet due to me not actually having done any task yet.
- Inaccuracy of memory locations 9 and 10 is a shame but not much you can do to overcome that.

Q.20 **Any further comments? If not, type "N/A".**

- N/A
- Would be interesting to see if this technique can be used in more scenarios rather than just lists.

J.10 Experience Survey - MoL and Control

"Hold That Thought": Experience Survey (MoL and Control)

Responses: 20

Source: `https://forms.gle/mqgjzsWVQhe21Ead9`

Please fill out the below form to capture your thoughts on today's experiment. All responses are anonymous.

Q.1 **What is your gender?**
MoL:

- Male (100.0%)
- Female (0.0%)
- Prefer not to say (0.0%)
- Other (0.0%)

Control:

- Male (70.0%)
- Female (30.0%)
- Prefer not to say (0.0%)
- Other (0.0%)

Q.2 **What is your age?**
MoL:

- 18-21 (40.0%)
- 22-24 (60.0%)
- 25+ (0.0%)

Control:

- 18-21 (20.0%)
- 22-24 (80.0%)
- 25+ (0.0%)

Q.3 **Have you ever practised the Mind Palace technique before?**
MoL:

- Yes (40.0%)
- No (60.0%)

Control:

- Yes (10.0%)
- No (90.0%)

Q.4 **To what extent do you find memory techniques useful when trying to memorise information? (1 = Not at all, 5 = Very)**
MoL:

- 1 (0.0%)
- 2 (10.0%)
- 3 (10.0%)
- 4 (60.0%)
- 5 (20.0%)

Control:

- 1 (0.0%)
- 2 (0.0%)
- 3 (20.0%)
- 4 (40.0%)
- 5 (40.0%)

Q.5 **To what extent did you find the instruction sheet clear and useful? (1 = Not at all, 5 = Very)**
MoL:

- 1 (0.0%)
- 2 (0.0%)
- 3 (10.0%)
- 4 (30.0%)
- 5 (60.0%)

Control:

- 1 (0.0%)
- 2 (0.0%)
- 3 (0.0%)
- 4 (50.0%)
- 5 (50.0%)

Q.6 **To what extent did you find the memorisation task enjoyable? (1 = Not at all, 5 = Very)**
MoL:

- 1 (0.0%)
- 2 (0.0%)
- 3 (0.0%)
- 4 (60.0%)
- 5 (40.0%)

Control:

- 1 (0.0%)
- 2 (0.0%)
- 3 (10.0%)
- 4 (60.0%)
- 5 (30.0%)

Q.7 **To what extent did you find the memorisation task difficult? (1 = Not at all, 5 = Very)**
MoL:

- 1 (10.0%)
- 2 (50.0%)
- 3 (40.0%)
- 4 (0.0%)
- 5 (0.0%)

Control:

- 1 (20.0%)
- 2 (40.0%)
- 3 (30.0%)
- 4 (0.0%)
- 5 (10.0%)

Q.8 **What did you like about the experiment?**
MoL:

- Fun imagining the mind palace
- It was an interesting visualisation task and the decoy task was engaging.
- Tasks were quite fun/entertaining, not too challenging or stressful either
- Actually just using the technique itself I found interesting, and also the use of a decoy in the middle.
- Interesting to use the mind palace method for remembering items
- Interesting technique!
- It was fun.
- I enjoyed visualising the items in a memory palace format, it felt easier to remember them by doing it this way in a familiar environment
- Well organised, the idea was novel (to me), exposed me to a new memorisation technique.
- Fun problem-solving puzzle. Really interesting learning a new technique, I think it worked pretty well and might adopt it in the future.

Control:

- Interesting use of the NASA indexes of performance.
- Very easy to participate in, instructions clear
- It was structured well and had a nice variety.
- Relaxed environment, short and little paperwork.
- Clear, concise and intelligent to give time after memorisation task
- Selecting the right colour game was fun.
- The random list of words to memorise - couldn't really group them by category to learn
- It was interesting and I like brainteasers
- Tried to distract me with the colour game
- Testing my ability to memorise the words under a time limit. Clear instructions!

Q.9 **What did you dislike about the experiment?**
MoL:

- Guessing the coloured words.
- It was slightly difficult to rate myself accurately on the baseline scale at the start
- Too long intro to tasks, can be faster.
- In the colours questions, I would have liked to be able to choose my own keys for the words. It was uncomfortable.
- The colour task was more frustrating than anticipated!
- For the colours game, it would have been nice to be able to bind the colours to your own choice of keys.
- I found that I was being slowed down not by my ability to know what colour to press but rather mapping that colour to a number.

Control:

- Mentally taxing doing the memorisation & colour picking tasks.
- Little cognitive exercises relative to paperwork, but it was a short experiment so I can't really complain...
- 6 minutes is a long time for 10 words.
- The decoy! wanted to write out the memorised words straight away
- It was stressful, I know it's not me being tested, but it feels like a challenge to win...
- Colour game was hard.
- NASA sheet was a little bit hard to fill out as the scale is quite big.

Q.10 **Any further comments? If not, type "N/A".**
MoL:

- I visualised entering my current accommodation from the back door, put down a ball of fire, went through the kitchen past a miniature building until I got to the tongue, turned and saw an Umbrella Academy character, went up the stairs past some bank notes, saw mud people had tracked at the top, saw an invisible wall, turned into my room with the entrance of a cave instead of a door, saw an empty glass and the bike resting in the corner.
- I visualised my university house and placed each item in the list in reverse order. First I placed the 'bike' in the doorway, went downstairs to the kitchen (thirst) in the basement (cave) and imagined a 'pause' to look at the walls as they are slightly dirty (muck). I then went back upstairs where I usually speak to my housemate ('trust' that he will be there) and he tells me about a 'rumour'. I then go upstairs to the kitchen (tongue) and then to my room (museum) where there is a fireplace (flame).
- I used my current home not in Bath, for some of the items I tried to attach them to a memory of some sort in my home, or a similar item. For example, I used the cabinet with trophies in for 'museum' and playing in the garden for 'muck'. I tried to attach them so they all occurred in one path as best I can so each one almost occurs in one room after another.
- I used my home as my palace. I had a designated walk through the house visiting the rooms in a certain order, then assigning a word to each room. I then iterated through the list repeatedly trying to name as many of the words as possible without looking. Trying to go further into the list/ virtual walk, with each loop.
- Chose my natal home because I know it best, went around the rooms in circles and associated something about that room with the word to be remembered, for example, if the word thirst came up and I had to place it in the kitchen I located it next to the sink so there was a logical connection.
- I used campus as my palace. I mapped my Palace route based on my typical routine after playing frisbee. At the AstroTurf I had "muck" and put a lot of "trust" in my team-mates. As I walk out from the Astros, I usually water, so there was "thirst". Then I see the canteen so there was "tongue". As I walk out of the STV, I see the "bike" rack. The team usually go to the SU, where we spread "rumour"s which is a "pause". As I come out of the SU, I see the Mech Eng building which is so ancient, it should be in a "museum". I walk towards the Parade Bar, which has "flame" grilled food. Finally, I

walk to my "cave": 1 West 4.12.

- I visualised the items in my Bath house, room by room as this was a familiar place I could go through with ease. I chose one room per item, going in order from the given list. Bedroom 1 - Flame (Campfire), Toilet 1 (Museum-like structure), Bedroom 2 - Tongue (Visualisation of a tongue), Toilet 2 - Rumour (person whispering into another person's ear), Bedroom 2 - Trust (visualisation of pinky promise), Bedroom 3 - Muck (Puke), Bedroom 4 - Pause (Pause music sign), Living Room - Cave (3D Cave), Kitchen - Thirst (Someone drinking water), Back Room of House - Biking (Bike)
- I chose my student house, and placed items in it roughly in the order they appeared in the list, even if it meant going to a previously visited room. I moved around the house associating different items with not only different locations but also activities performed in and people associated with those locations. E.g. I placed the flame in the living room fireplace (obviously), and tongue and rumour in the kitchen because that's where I most often talk to people. Trust was placed in the bedroom of a housemate who I trusted greatly, and the bike was stored in the garage where we keep our bikes. Item placement was influenced by both spatial, and experience-based factors.
- My palace: A hotel lobby - chose because it has a lot of separate sections. I placed a drink at the bar to remember thirst. I walked through the lobby several times in different orders to cement my knowledge. The harder ones to place were qualities of objects or people rather than a specific object. In order to remember trust, I had to place people in the palace and infer it from their presence and what I perceived of them. Altogether a fun study, I definitely feel like I can walk away and I have learnt a skill that I can bring into the future when doing memorisation.

Control:

- As all words were short with no common theme, I constructed nonsensical sentences, e.g. 'RUMOUR has it that a FLAME in the MUSEUM was caused by TONGUES'.
- I used the song memorisation technique to remember the words, mapping the words to a tune in my head. For the colour picking, I found I had better learnt the colour to keyboard mappings by the end of the study.
- Split the list into smaller lists, and remember each of them at a time. Repeat through elements of the list. Look away from the sheet, continue repeating. Occasionally word association - e.g. tongue and rumour.
- Created a story linking words together. Colour association was very well streamlined and easy to use. Happy with the simplicity of the questionnaires I completed before and after the cognitive exercises. Overall very pleased that I chose to partake in this experiment.
- Used simple repetition of words in my head as a technique.
- Technique used: Storytelling
- Learnt in order, uncovered 1 by 1 on the page, counted on fingers to see how many I recalled.
- I made up 2 stories of 5 words each. I went to the museum, due to a tongue and cheek rumour from someone I trusted. I rode my bike to the cave

because I was thirsty, but the water was mucky so I paused.

- Used chunking - broke up list into chunks of 3 then repeatedly said 3 words until I remembered each, then said the whole list a few times to remember the order of chunks. After the sheet of words was taken away, I kept saying the list to make sure I remembered it in case I was asked to recall it.
- Made a story up using the words, where each new word was something significant happening in the story.

J.11 HTT Experiment Data

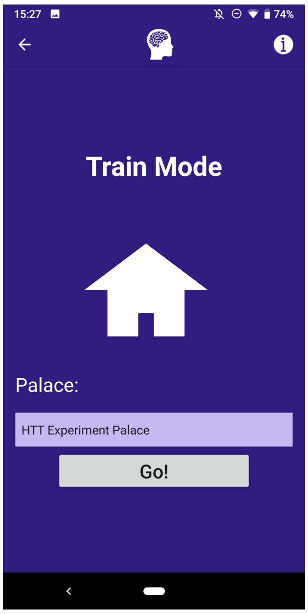


Figure J.19: Train menu.

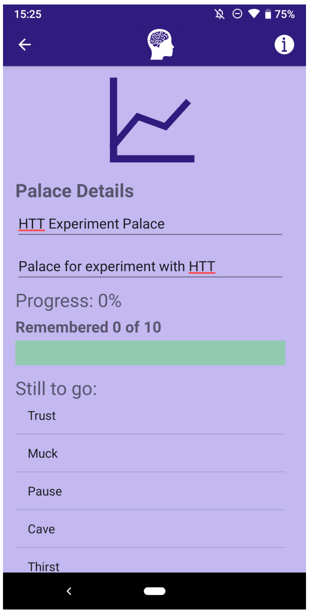


Figure J.20: Track screen.

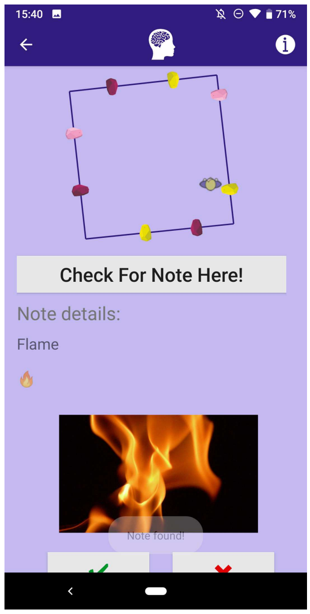


Figure J.21: Flame.

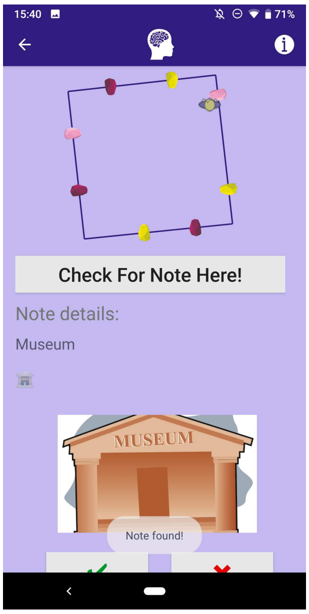


Figure J.22: Museum.

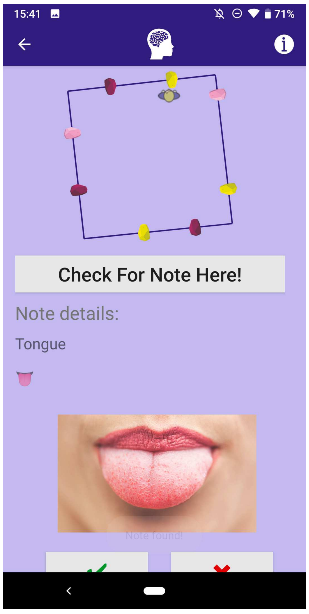


Figure J.23: Tongue.

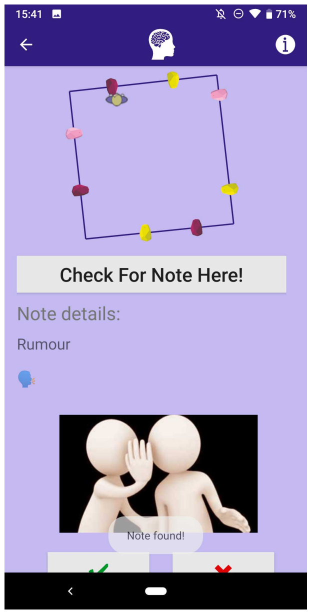


Figure J.24: Rumour.

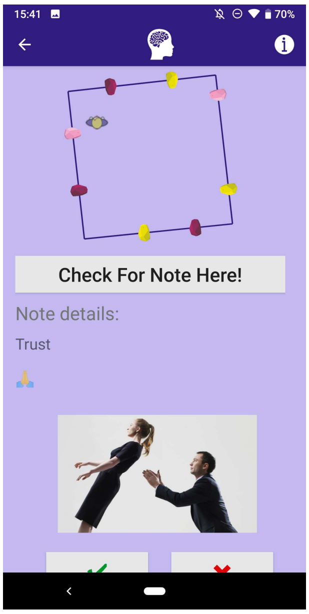


Figure J.25: Trust.

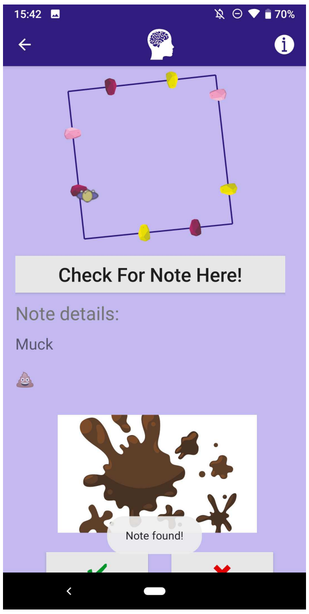


Figure J.26: Muck.

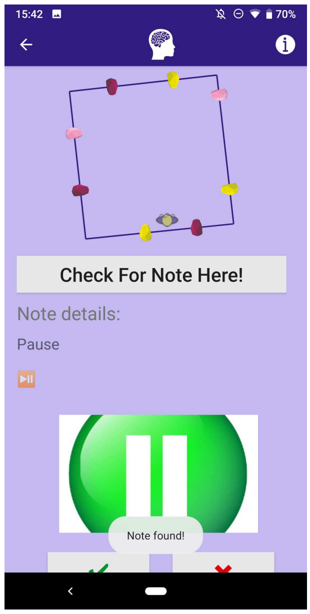


Figure J.27: Pause.

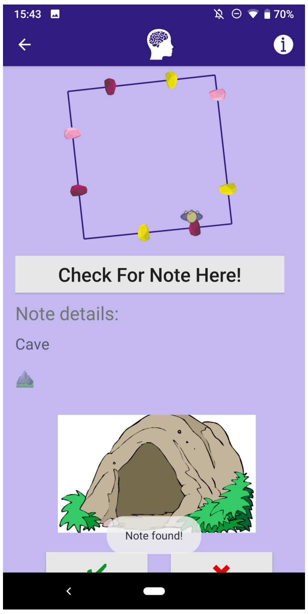


Figure J.28: Cave.

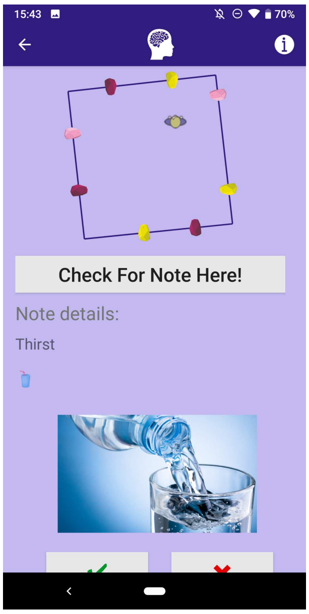


Figure J.29: Thirst.

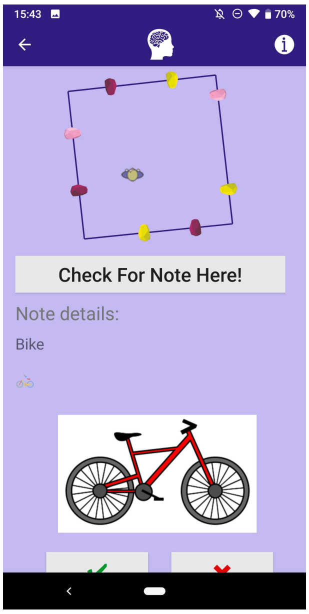


Figure J.30: Bike.

J.12 Raw Data

#	Task	TLX 1	TLX 2	TLX DELTA	SUS	RECALL (5 MINS)	RECALL (1 WEEK)	TECHNIQUES USEFUL	INSTRUCTIONS CLEAR	ENJOYABLE	DIFFICULT	PRACTISED MoL
1	HTT	10.000	34.167	24.167	90.0	10	8	4	4	5	2	No
2	HTT	12.500	35.000	22.500	77.5	10	10	5	5	4	2	No
3	MoL	5.833	42.500	36.667	N/A	10	10	5	5	5	3	No
4	HTT	9.167	40.833	31.667	70.0	10	7	4	4	4	2	Yes
5	HTT	32.500	41.667	9.167	72.5	10	4	3	4	4	3	No
6	MoL	11.667	16.667	5.000	N/A	10	9	4	3	4	3	Yes
7	MoL	26.667	32.500	5.833	N/A	10	10	4	5	5	1	Yes
8	MoL	18.333	43.333	25.000	N/A	10	9	4	5	4	2	Yes
9	HTT	31.667	40.833	9.167	75.0	10	9	4	5	4	3	No
10	MoL	16.667	28.333	11.667	N/A	10	8	2	5	4	2	No
11	MoL	36.667	70.833	34.167	N/A	10	2	5	4	5	3	No
12	MoL	11.667	45.000	33.333	N/A	10	10	4	4	5	3	Yes
13	MoL	34.167	55.000	20.833	N/A	10	7	4	5	4	2	No
14	HTT	37.500	38.333	0.833	60.0	9	4	5	5	5	5	No
15	HTT	49.167	52.500	3.333	85.0	8	6	3	5	4	3	No
16	HTT	25.000	28.333	3.333	100.0	10	9	5	5	5	1	No
17	HTT	18.333	27.500	9.167	85.0	10	10	4	5	5	1	No
18	HTT	47.500	49.167	1.667	62.5	8	7	4	5	2	3	No
19	MoL	32.500	49.167	16.667	N/A	10	10	3	4	4	2	No
20	MoL	24.167	43.333	19.167	N/A	10	9	4	5	4	2	No
21	Ctrl	30.833	43.333	12.500	N/A	10	7	5	5	4	2	No
22	Ctrl	10.833	74.167	63.333	N/A	1	0	4	5	3	5	No
23	Ctrl	25.000	55.000	30.000	N/A	10	9	4	5	4	3	No
24	Ctrl	20.000	36.667	16.667	N/A	10	10	5	4	5	1	No
25	Ctrl	35.000	61.667	26.667	N/A	10	0	3	4	4	2	No
26	Ctrl	16.667	29.167	12.500	N/A	10	3	3	4	4	2	No
27	Ctrl	37.500	58.333	20.833	N/A	9	8	4	5	4	3	No
28	Ctrl	46.667	60.833	14.167	N/A	10	10	5	4	4	3	No
29	Ctrl	32.500	58.333	25.833	N/A	10	0	4	5	5	1	No
30	Ctrl	26.667	50.000	23.333	N/A	9	8	5	4	5	2	Yes

J.13 Statistical Analysis

Descriptive Analysis

AVERAGE	HTT	MoL	Ctrl
TLX 1	27.333	21.833	28.167
TLX 2	38.833	42.667	52.750
TLX DELTA	11.500	20.833	24.583
SUS	77.8	N/A	N/A
RECALL (5 MINS)	9.50	10.00	8.90
RECALL (1 WEEK)	7.40	8.40	5.50
TECHNIQUES USEFUL	4.10	3.90	4.20
INSTRUCTIONS CLEAR	4.70	4.50	4.50
ENJOYABLE	4.20	4.40	4.20
DIFFICULT	2.50	2.30	2.40

STANDARD ERROR	HTT	MoL	Ctrl
TLX 1	4.678	3.361	3.356
TLX 2	2.550	4.689	4.193
TLX DELTA	3.413	3.624	4.732
SUS	3.9	N/A	N/A
RECALL (5 MINS)	0.27	0.00	0.89
RECALL (1 WEEK)	0.70	0.78	1.35
TECHNIQUES USEFUL	0.23	0.28	0.25
INSTRUCTIONS CLEAR	0.15	0.22	0.17
ENJOYABLE	0.29	0.16	0.20
DIFFICULT	0.37	0.21	0.37

STANDARD DEV	HTT	MoL	Ctrl
TLX 1	14.792	10.627	10.612
TLX 2	8.062	14.828	13.258
TLX DELTA	10.793	11.460	14.965
SUS	12.4	N/A	N/A
RECALL (5 MINS)	0.85	0.00	2.81
RECALL (1 WEEK)	2.22	2.46	4.28
TECHNIQUES USEFUL	0.74	0.88	0.79
INSTRUCTIONS CLEAR	0.48	0.71	0.53
ENJOYABLE	0.92	0.52	0.63
DIFFICULT	1.18	0.67	1.17

Kruskal-Wallis Non-Parametric 1-Way ANOVA

IV	k (Samples)	DV	N	Alpha	df	Test Stat. (H)	Sig. (p) (2-tailed)	Null Hypothesis	Decision
Method (HTT, MoL, Control)	3	Recall (5 mins)	30	0.05	2	**3.577**	**0.167**	The distribution of RECALL (5 MINS) is the same across categories of METHOD.	**Retain the null hypothesis.**
Method (HTT, MoL, Control)	3	Recall (7 days)	30	0.05	2	**3.397**	**0.183**	The distribution of RECALL (7 DAYS) is the same across categories of METHOD.	**Retain the null hypothesis.**
Method (HTT, MoL, Control)	3	Enjoyment	30	0.05	2	**0.110**	**0.800**	The distribution of ENJOYABILITY is the same across categories of METHOD.	**Retain the null hypothesis.**
Method (HTT, MoL, Control)	3	Difficulty	30	0.05	2	**0.446**	**0.946**	The distribution of DIFFICULTY is the same across categories of METHOD.	**Retain the null hypothesis.**
Method (HTT, MoL, Control)	3	TLX 1	30	0.05	2	**1.333**	**0.514**	The distribution of TLX 1 is the same across categories of METHOD.	**Retain the null hypothesis.**
Method (HTT, MoL, Control)	3	TLX 2	30	0.05	2	**6.932**	**0.031**	The distribution of TLX 2 is the same across categories of METHOD.	**Reject the null hypothesis.**
Method (HTT, MoL, Control)	3	TLX DELTA	30	0.05	2	**6.007**	**0.050**	The distribution of TLX DELTA is the same across categories of METHOD.	**Reject the null hypothesis.**

Wilcoxon Signed-Rank Test

IV	k (Samples)	DV	N	Alpha	z Score	Sig. (p) (2-tailed)	Null Hypothesis	Decision
Method (HTT)	2	TLX 1, TLX 2	10	0.05	**-2.807**	**0.005**	There is no significant difference between TLX 1 and TLX 2 (equal medians).	**Reject the null hypothesis.**
Method (MoL)	2	TLX 1, TLX 2	10	0.05	**-2.803**	**0.005**	There is no significant difference between TLX 1 and TLX 2 (equal medians).	**Reject the null hypothesis.**
Method (Control)	2	TLX 1, TLX 2	10	0.05	**-2.805**	**0.005**	There is no significant difference between TLX 1 and TLX 2 (equal medians).	**Reject the null hypothesis.**
Method (HTT)	2	Recall (5 mins), Recall (7 days)	10	0.05	**-2.536**	**0.011**	There is no significant difference between RECALL (5 MINS) and RECALL (7 DAYS) (equal medians)..	**Reject the null hypothesis.**
Method (MoL)	2	Recall (5 mins), Recall (7 days)	10	0.05	**-2.226**	**0.026**	There is no significant difference between RECALL (5 MINS) and RECALL (7 DAYS) (equal medians)..	**Reject the null hypothesis.**
Method (Control)	2	Recall (5 mins), Recall (7 days)	10	0.05	**-2.555**	**0.011**	There is no significant difference between RECALL (5 MINS) and RECALL (7 DAYS) (equal medians)..	**Reject the null hypothesis.**